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About the Agronomy Journal of Nepal (Agron JN)

Agronomy Society of Nepal (ASoN) was established in 2050 BS (1994 AD) by a group of eminent agronomists of Nepal. The ASoN is a forum of academicians, researchers, and professionals for sharing research and development works carried out in the field of agronomy and crop science. The ASoN publishes professional journal the Agronomy Journal of Nepal (Agron JN), a peer reviewed ISSN journal that embraces relevant works in associated disciplines of agricultural science. The journal seeks articles from the field of agronomy, crop science and allied fields that helps boost agriculture production and productivity, address the issue of climate change and conserve environment in general and Nepal in particular. This 5th volume of the Agron JN has been published in 2021 in a joint effort of the Agronomy Society of Nepal (ASoN) and Center for Crop Development and Agro-Biodiversity Conservation (CCDABC), Lalitpur, Nepal. The financial support for the publication of this volume has been provided from Center for Crop Development and Agro-Biodiversity Conservation, Lalitpur (FY 2077/78).

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Patenting need of unique geographical indicator commodities and products to enhance livelihoods and resources conservation in Nepal

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Abstract
This is high time for Nepal to patent endemic genetic resources, commodities and products available in Nepal by studying them scientifically. Nepal is one of the 10th richest countries of Agrobiodiversity availability in Asia and 31st globally. Nonetheless, Nepal being one of the nine oldest countries in Asia, has not been able to harness her potentiality in these areas which could help enhance livelihoods of rural people and gain profit by patenting these resources efficiently. After Prithvi Narayan Shah unified Nepal in 1768 BS, eight countries; Afghanistan, India, China, Korea, Japan, Magnolia, Oman, and Turkey were existed in Asia. The evidences documented in many Vedic and other Sanskrit literatures support Nepal's existence since time immemorial. This article will help maintain Nepal's intact for being historically a glorious country since ancient times. Geographical indications (GIs) of crops, commodity and products have special identification of ancientness in Nepal. *Bala Chaturdahsi*, a unique festival thrived only in Nepal, is an earliest form of genetic resources conservation under Pashupati Nath areas and Shiva temples across Nepal sowing seeds of hundreds of crops since Vedic times. In this article, efforts have been made to document some of the important Nepali cuisine, agricultural commodity, crops, animals, vegetables, fruits, both indigenous and ethnic foods, and products which are very important and endemic to Nepal as GIs with respect to claim their patent rights by Nepal. This article puts efforts to make clear understanding about Nepal with respect to such endemic indigenous genetic resources and their produce locally and globally. It is imperative that Nepal should be in food self-sufficiency and conserve vast pool of unique biodiversity resources and products by patenting them without any delay in days to come.

Keywords: Nepal, geographical indications (GIs), *Bala Chatirdashi*, agrobiodiversity conservation, genetic resources

Introduction
We know that Nepal is one of the ancient countries even in the Vedic period and conservation of genetic resources covering plants, animals and many flora and fauna had been done in those ancient times in Nepal. This indicates that there are many flora and fauna geographically important in Nepal where it demands an urgent need to conserve and patent these genetic resources.

Geographically, present day Nepal was founded by the National Hero and the Great King Prithibi Narayan Shah in 1768 BS, is roughly trapezoidal shape, with an area of 1,47,516 sq km (56,956.25 sq miles). It is in between China in the North and India in other three directions that lies in coordinates of 28.3949° N and 84.1240° E. Nepal is some of the few ancient countries in Asia. As listed in the name of sovereign countries of Asia, even after 1768 BS, Nepal is 9th ancient sovereign countries after Afghanistan, India, China, South Korea, Japan, Mongolia, Oman, and Turkey (https://en.wikipedia.org/wiki/List_of_sovereign_states_by_date_of_formation#Asia). If we consider Vedic era of independent countries, Nepal is one of few most ancient sovereign countries in the world, probably among few hand counting countries in the world. Ancientness of Nepal is nicely documented in many of the Vedic literatures in the Vedic times 1500 to 500 BC (http://www.culturalindia.net/indian-history/ancient-india/vedic-civilization.html) which is 3500 to 4000 years before present (BP) (Shrestha, 2001). It was recorded that Hari-Hara Kshetra of present day Gandaki Basins, including Mukti Nath, Deughat and Triveni of Western Nepal, was one of the most important centers of Vedic Aryans, who had already expanded Swarswat Vedic Civilization (Ibid).

Under *Skanda Puran* of Nepal Mahatmya, among the prime pilgrimage in Nepal, Muktinath (now in Mustang, 3710 masl) was one of the ancient pilgrimage site of Vedic Aryans including Pashupati Nath

(Kathmandu, 1370 masl) where there was dense forest of *Sleshmantak Forest* i.e. Lapsi (*Choerospondias axillaris)*, khajur, i.e. date palm (*Phoenix dactylophoria*), nibu (C*itrus* spp.) and many flowers and trees. Nepal is clearly mentioned even in Shiva Puran, an ancient Hindu epic as "तद्रूपेण स्थितस्तत्र भक्तबत्सलनामभाक् / नयपाले शिरोभागो गतस्तद्रुपत: स्थितः // १५- शिबपुराण कोटी रुद्र संहिता १९ अध्याय (२०७५ बि.सं.)". Meaning that in deep affection of followers and being placed in uppermost part of the region, Nepal is situated in its firmed position. This all suggests that even during Shiva period, Nepal had been in existence. During that Vedic period, Shiva, the lord of Omkar group which includes Hinduism, Buddhism, Jainism, Shamanism, and Shintos have deep faith on Shiva and his favorite places such as the Mount Kailash (Tibet), Banaras (India) and Pashupat (Nepal) were of prime importance. Lord Shiva used to roam in these areas since Vedic period and Pashupati region is one of his most loveable places. To support this saying some Sanskrit stanzas from episode one of Nepal Mahatmya of Skanda Puran which has been exerted from one of the pamphlets of Shipadol Temple, Bhaktapur, Nepal cited here as "नेपालक्षेत्रमहत्यां शृणु सावहितो मुदा / पीठानां परम् पीठं क्षेत्राणां क्षेत्र मुत्तमम //६// खजुरैनार्गन्श्चै बीजुपुरैश्च मण्डितं/ नाना निर्झरणोपेतं नानापक्षिनिनादितं //८//" Ancient name of Nepal pilgrimage is *Sleshmantak* forest where there are many trees including lakes and other vegetation. Trees and forest in *Sleshmantak* forest includes date palm, citruses, waterfalls and many types of birds. This is the place named *Pashupat Kshetra* where Shiva used to roam in the incarnation of the single horned deer.

Ancientness of Nepal has been mentioned Before Christ in many Vedic epic as cited by Swami Prapancharya (2050 BS) in one of Sanskrit verse like this*:* "ने नाम्ना मुनिना पूर्व पालनात्तपुण्यकर्मणा / इदं हि हिमवात्कुक्षौ नेपाल इति चोच्यते //". The literal meaning of this verse is that some sage named *Ne* has named this pious and beautiful country in the lap of the Himalaya as Nepal. Accordingly, again, Swami says that in 69 episode of the *Skanda Puran* Nepal is mentioned in such way "ने नामा यो मुनि: श्रेष्ठ आसित्पुरा महातपा:/ सप्तर्षिभिस्संमं भक्त्या शैलकोष्ठे तुने: मुनि: // आनर्च योगिनी देबीं त्वार्ष्टा सुनिमिर्तै: स्तवैः / वरम् दातुं ततस्तस्मै आविर्भूत्वा (ता) च योगिनी //" Meaning that sage *Ne* was great devotee and he did his devotion in Pashupati area, the most sacred region in the lap of the Himalaya along with seven sages where there is full implementation of religion of law. As a result, *Ne* got blessing in his name as Nepal. The verse has many other lines in this regard. In similar way, it had been reported that before founding modern Nepal by the Great King Prithivi Narayan Shah in 1768 BS, there were Neolithic tools found in the Kathmandu valley indicating inhabitation of people in the Himalayan region for at least eleven thousand years ago (Bhattrai, 2008; Paudel, 2016). Baral (1996) also came in conclusion that the first mentioned of Nepal in late Vedic *Atharvaveda Parisista Upanishad* was as a place exporting blankets to other countries and similarly in Samudragupta's Allahabad Pillar, Nepal is mentioned as a bordering country. The *Skanda Purana* has a separate chapter known as *Nepal Mahatmya* that explains in more details about the beauty and power of Nepal (http://www.gktoday.in/current-article-indias-bilateral-relationships-nepal)/. Likewise, Nepal is also mentioned in Hindu texts such as the *Narayan Puja* (Baral, 1996). It explains that existence of Nepal was known even in the Vedic and still older time of different periods.

Methodology

Collection of Nepali indigenous knowledge and commodities were done by the visual observation, formal and informal interaction with different stakeholders, secondary sources and indigenous knowledge of the Nepali as well. Most of the information collected herein were received by the author with numerous interaction and discussion with concerned stakeholders in general and particular to farmers under different agro-ecological niches of Nepal where there is vast pool of diverse ethnic group who have conserved, maintained and utilized these genetic resources, commodities and products since time immemorial. Listing of such pool of resources and information was possible mainly during long course of association and exposure with genetic resources conservation coupled with visits and observations in different parts of Nepal encompassing high mountain, hills, and Terai by the author.

Objectives

The general objective of this article is to provide insight knowledge on creating awareness on conservation of unique Nepali genetic resources, products and commodities before it is getting too late to take initiatives to patent, conserve and utilize them by Nepal so that other countries could not place claim patenting them which are already endemic to Nepal only. The specific objective is to document such critical commodities and endemic genetic resources which have inherent traits and verge of extension maintained by many ethnic groups as a source of their socio-cultural settings and maintenance of livelihood since time immemorial in Nepal.

Discussions

Discussion about ancientness of Nepal with respect to genetic resource conservation as envisioned in available literatures both in eastern and in western medias giving special references to Vedic literatures were sought as far as possible. In this section, discussions are made on biodiversity status of Nepal globally and nationally. Similarly, there has been inclusion of uniqueness of Nepali genetic resources and products which are only home to this country. And at the end detail tables consisting of different commodities and products of Nepal which have unique geographical indicators having specific agroecological domains and geographical locations for the products and commodities in questions are presented by the author. The end sum of these geographical identities is to provide niches for them as specific to Nepali geographical indications (GIs) that reserve only patenting authority for Nepal which is the sole objective of this article. These have been explained in depth.

Genetic conservation in Nepal in Vedic period

In this connection to solidify some evidence that genetic conservation was given due priority in Vedic period, some Vedic reference of crop conservation is cited like this in *Yajurved:* “बृहस्चमे यवास्च मे माषस्च मे तिलाश्च मे मुदगाश्च मे खल्वाश्च मे/ प्रियङ्गवश्च मेणवश्च मे श्यामाकाश्च मे नीवाराश्च मे गोधूमास्च मे मसूरास्च मे यज्ञेन कल्पन्तामद्रू// १८/ १२/ शुक्ल यजुर्बेद”. In the 18th Episode stanza 12th of the *Sukla Yajur Ved* it is stated that there are long lists of different crops grown in Vedic period. Above stanza states that Brihi (rice), Yaba (oat), Ubayak (fox tail millet), Mudga (mung), Maas (black gram), Til (sesame), Anu (rapeseed mustard, broad leaf mustard, millets), Khalba (barley), Gomudh (wheat), Siwara (long grain rice, wild rice), Priyangu (Fox tail millet, Piplali), Masur (lentil), Shyamak (finger millet or Black Marshi rice) and many more including red *Bayar* (jujube, Rani jujube and Sati *Bayar* including dozens of crops have been explained). Therefore, these above listed crops in Vedic period are geographical indications of Vedic Region entailing Nepal as well. In Jumla valley there are two rivers namely *Tila* and *Jawa* giving the name of til (*Sesamum indicum*) and barley (*Hordium vulgare*), respectively which indicate cultivation and conservation of these crops in Jumla is as old as these two rivers flowing from the Himalayas in the Jumla valley. Now the question arises where the Vedic Region is. Accordingly, Vedic Region is: “आ समुद्रात्तु वै पूर्वदासमुद्रात्तु पश्चिमात् / तयोरेवान्तरम् ग्रियोरार्यवर्तबिदुर्बधा:”// (मनुस्मृति, २/२२). Vedic Region is situated in between the Himalaya and the Bindhyachal region encompassing China Sea in the East and Red Sea in the West which is *Aryabart*, the Vedic Region or the place where Veda was originated in more than 4000 years ago. Nepal is one of the prime locations of the Vedic Region where Vedic literatures were written in the bark of Bhoj Patra tree (*Bitula utilis*) which grows up to 4500 masl in the Himalayan range and there is handmade paper prepared from Lokta (*Daphne bholua/ D. papyracea*) for writing official records up to now in Nepal. As in other Vedic literatures, *Manusmriti*, the Hindu code of conduct, mentions of seed and agriculture field which support conservation of plant genetic resources (PGRs) in ancient times in Nepal because she remained a Hindu country since her inception. The importance of seeds in *Manusmriti* is mentioned in this way “सुबीजं चैब सुक्षेत्रे जातं संपधते यथा”/ (मनुस्मृति १०/६९). That good seeds planted in good field yield abundantly. These all support PGRs conservation in Nepal since early Vedic civilization.

***Bala Chaturdashi*, the earliest unique form of agriculture plants genetic resource (APGRs) conservation**

Logically, these above listed crops are the GI of Vedic Region where Nepal automatically deserves GI of these crops steadfastly. *Sleshmantak* forest is one of the holiest places of Vedic period and was most liked by Shiva more than Banaras and the Mount Kailas (Nepal Mahatmya Episode one). In *Bala Chaturdashi*, the 14th day of blackmoon, in the month of Mansir every year, people in Nepal throng in Shiva temples and broadcast *Satbij* (hundreds of crop seeds). Among these Shiva shrines *Sleshmantak* forest, the forest of Lapsi (*Choerospondias axillaris)* in Pashupati Nath Area in Kathmandu, is the main place of *Satbij* broadcasting. *Satabij* is misnamed as broadcasting of seven seeds only during *Bala Chaturdashi*. Personal communication with Dr Madhab Prasad Bhattrai, Chair Person, Nepal Rastriya Dharma Sabha, mentioned that *Satbij* is sowing of hundreds of crops' seed in the Pashupati Nath area and Shiva Temples across Nepal are the Vedic period rituals followed mainly to conserve seeds of different crops in Nepal as a religious ritual every year by Omkar groups of religion.

It is a unique practice followed to conserve crops seed only in Nepal even in the Vedic Regions and such practices were not followed in other parts of *Aryabart* region even in the Indian subcontinent. He also added that *Satabij* meaning seven seeds is only misnomer given to it while in real sense it is hundreds of crops' seeds sown during *Bala Chaturdashi* in the month of Mansir only in Nepal. This shows how important agriculture was in Nepal since the Vedic period. The literal meaning of *Bala Chaturdashi* festival in Nepal is briefly explained like this "seeds are dropped in remembrance of dead beloved ones mainly by their siblings and family members in *Sleshmantak* forest of Pashupati Nath area mainly in all Shiva temples areas across Nepal. It is believed by performing *Bala Chaturdashi* rituals one can secure a better place in heaven for the dead relatives. It is also believed that this helps settle the restless souls of departed ones who were not properly cremated/burnt. This is the belief that when thousands of people pray for the same consideration, that will be fulfilled in this ritual. *Slesmantak* forest of the Kailas in the Pashupati area where the *Satbij* is dropped which is mentioned in Shiva Puran Mirgasthali as the place where Lord Shiva dwelled as in incarnation of one horned deer. This place is hence considered very sacred place, and hence a drop of seed in this place is equal to a *Ratti* of gold which is about 0.121 grams" (http://www.weallnepali.com/nepali-festivals/bala-chaturdashi).

These above mentioned evidences signify the importance of Shiva temple in Nepal as a GI of conservation of hundreds of crops by sowing annually which is again an age old practice of crop conservation even in the Vedic period. Interested ones can dig out many literatures concerning *Bala Chaturdashi* festival in Nepal. This is just an insight about conservation of crops followed by some of the unique Vedic rituals in Nepal. Literally *Stabij* is hundreds of seeds or pure seeds in Sanskrit. In *Bala Chatirdashi* seed broadcast around premises of Shiva temples many crops such as rice (if possible wild rice (*Oryza nivara, O riffipogan, O perennis, O officinalis, O sativa f. spontanea*, and *Leersia hexandra*) along with many cultivated aromatic rice seeds are broadcasted. Aside from rice, other crops of maize, wheat, millets (finger millet, panicum millet, poroso millet, fox tail millet, sorghum millet, jowar and many others), legumes (black gram, lentil, red gram, horse gram) peas and beans (cow pea, rice bean, sword bean, mung bean, grass pea, faba bean, soybeans), radish, turnip, mustard, sesame, sugarcane, citrus (citron, mandarin orange, sweet orange, lime (both sweet and acid limes), oat, barley, buckwheat and many other food, fiber, and forages crops of both wild and cultivated species making hundreds of seeds are sown as a religious rituals in Nepal every year up to now. This practice of *Satbij* broadcasting is very unique to Nepal in terms of APGRs conservation since Vedic times. This justifies Nepal as one of the homes of crops origin in the world. As a result, there is a vast diversity of rice and many more unique crops in the country. Now because of modernization of agriculture and introduction of improved varieties of different crops, most of such crops' diversity has been threatened and many of the indigenous crops have been eroded from Nepal as well.

Nepal and biodiversity

According to Nepal Biodiversity Report (2007), Nepal comprises only 0.1% of land area on a global scale and has rich diversity of flora and fauna at genetic, species and ecosystem levels. The report further explains that there are about 2,000 lichen species in Nepal of which 48 species are reported to be endemic to Nepal. Similarly, there are 1,822 species of fungi, 687 species of algae, 853 species of bryophytes, and 534 species of ferns and fern allies in Nepal. Similarly, there are 6,391 angiosperm floras of which 25 species of gymnosperms have been listed in Nepal. Same report has documented a checklist of 168 species of helminth parasites, 33 species of trematodes, 67 species of nematodes, 36 species of cestodes, and 32 species of plant nematodes have been recorded. There are 144 species of spiders, and approximately 5,052 species of insects. Furthermore, 2,253 species of moths (excluding Microlepidoptera) have been recorded in Nepal (Ibid). Up to 2007 the list of 651 species of butterflies and 785 species of moths, 187 species of fish and 195 species of Herpeto fauna (117 amphibians and 78 reptiles) have been reported in Nepal. Likewise, the number of bird species was 874, and mammals 185. Similarly, there are four new additions in the mammal checklist which are Binturong (*Arctictis binturong*), Indian Mongoose (*Herpestes nyula*), Himalayan marmot (*Marmota himalayana*) and Tibetan gazelle (*Procapra picticaudata*). Biodiversity Report (2007) further highlights species in different ecological regions of Terai, hills and mountains in much elaborated scales. Of the total number of mammal species, the Terai-Siwaliks region harbors the highest number of confined species (35 mammal species, 111 bird species, 46 Herpeto species, and 106 fish species). The central phyto-geographical region harbors the highest number of confined species (28 mammal species, 24 bird species, 40 Herpeto species, and 31 fish species). Similarly, the mid hills centre block harbors the highest number of mammals (55%) and bird species (77%), whereas Terai-Siwaliks centre harbors the highest number of Herpeto (45%) and fish species (74%).

Overall, the mid hills centre has the highest species richness followed by the Terai Siwaliks centre. The report further emphasizes about 399 endemic flowering plants in Nepal of which about 63% are from the High mountains, 38% from the mid hills, and only 5% from the Terai and Siwaliks. In the same way, the central region contains 66% of the total endemic species followed by western (32%) and eastern regions (29%). The Himalayan field mouse (*Apodemus gurkha*) which is found in central Nepal between 2200-3600 masl, is the endemic mammal species of Nepal. There are very endemic species such as Spiny Babbler (*Turdoides nipalensis*) and the Nepal Kalij (*Lophura leucomelanos*) are endemic to Nepal. There are 14 species of herpeto fauna and six species of fish that are endemic to Nepal. Correspondingly, one hundred and eight species of spiders are reported to be endemic to Nepal.

Status of Nepal in global genetic resources (GRs)

Geographically Nepal is a small country, however, genetically due to its location and position it is rich in biodiversity. Joshi *et al*., (2017) reported that for rice only there is a vast contribution of genetic resource maintained and available in Nepal in global perspective. They found that a total of 8389 rice accessions collected from Nepal are conserved in nine different gene banks across the world including Nepal, IRRI, Japan, India, Korea, Bhutan, USA, Vavilob institute Russia, and Benin (British Museum). In the same way, APGRs collected for other crops such as wheat, barley, oat, maize, potato, legumes, forage and fodder, and other cultivated and wild relative crops have been collected and conserved in different gene banks including CGIARs, Millennium Seed Bank (Kew, Garden), World Seed Vault Korea, Global Seed Vault, Svalbard Norway and many other institutions across the world. Paudel *et al.,* (2016) reported that there is a high diversity of vegetable crops in Nepal which include wild relatives of *Colocasia* (three spp.), *Amaranthus* (four spp.), *Chenopodium* (two spp.), *Rumex* (three spp.), *Pisum* (three spp.), *Alium* (three spp.), *Ipomoea* (five spp.), *Dioscorea* (four spp.), *Mentha* (three spp.), *Trigonella* (two spp.), *Solanum* (two spp.), and *Curcuma* (five spp.). Nine species of *Prunus*, three species each of *Castanopsis, Malus, Morus* and *Rubus* and two species each of *Barberies, Ficus, Hippophae, Olea, Pyrus* and *Vitis* are documented as temperate wild fruit relatives. Also there is abundance of subtropical and tropical wild fruit relatives of *Annona, Citrus, Mangifera, Musa, Foenix (*Chhoda*)* and *Rhus (*Bhakimlo*).*

Paudel *et al.*, (2017) have done some citation with respect to status of Nepal in global status of APGRs. They have explicitly mentioned about what Nepal deserve with respect to conservation of genetic resources broadly. There are recorded 181 mammal species, 844 bird species, 100 reptile species, 43 amphibian species, 185 freshwater fish species, and 635 butterfly species while the flora recorded are 5,160 species of flowering plants and 1,120 non-flowering plants in Nepal (BPN, 1996). Nepal possess only about 0.1% of global land masses, however it is rich in the availability of biodiversity and harbors 2.2% of flowering plants, 1.4% of reptiles, 2.2% of fishes, 8.5% of birds, 4.2% of butterflies and 4% of mammals of the world (Paudel, 2016). Nepal has 7000 flowering plant species and out of that them 370 species are endemic and about 600 food plants species have been estimated to be grown within the altitude range of 60 to 4200 masl (MoFSC, 2002; Upadhyay and Joshi 2003, Gauchan and Shrestha, 2017). Paudel *et al.*, (2016) have reported that of 60 reported species of *Ameranthus* in the world at least 11 species (cultivated, for grain and green vegetables, wild and weedy types) have been reported in Nepal. Also, they have mentioned a large diversity among barley (*Hordium* spp.), buckwheat (*Fagopyrum sp.*), naked barley (*Hordeum vulgare* var. *nudum* L.), and finger millet (*Eleusine* sp.) in wild and cultivated form have been found abundantly indicating their center of origin in Nepal. Nepal has one of the highest levels of biodiversity encompassing 399 endemic flowering plants of which about 63% are from the high mountains, 38% from the mid hills, and only 5% from the Terai and Siwaliks covering different development regions of the country (BPN, 1996).

Geographical indications (GIs) and Nepal

According to European Commission, "GI (geographical indication) means a geographical indication, is a specific name of a product that can apply if it has characteristics or reputation due to its origin (EC, 2007). Generic names and names of non-specific products cannot be considered as geographical indications – nor can names of products whose characteristics or reputation are not linked to, or due to, their origin. GIs are equally applicable to the fisheries sector". EC also emphasizes that GIs may therefore enable producers, especially small holders, in developing countries to exercise more control over the marketing of their products, combat counterfeiting, and secure a higher share of the value added by distinguishing their product in the marketplace. GI, therefore, gives special rights to small and developing countries where patenting and marketing of produce are masked by developed nations. Likewise, World Intellectual Property Organization (WIPO) has defined GI as "GI as a sign used on products that have a specific geographical origin and possess qualities or a reputation that are due to that origin. In order to function as a GI, a sign must identify a product as originating in a given place. In addition, the qualities, characteristics or reputation of the product should be essentially due to the place of origin. Since, the qualities depend on the geographical place of production; there is a clear link between the product and its original place of production" (http://www.wipo.int/geo_indications/en/).

Nepal could be a very prominent place for GIs of unique commodity and products. To elucidate some of the GIs brands for instances are *Juju Dhau*, *Pharphing pear*, *Pokhereli Jetho Budho rice*, Basmati rice, handmade Nepali paper, medicinal herbs and so on. These are not built or maintained by an individual or an industry rather these are maintained by the communities of special geographical region since historical periods. As time passed by, these and other GI related commodities and products are becoming main source of livelihoods enhancement of the communities of that specific geographical region including country, agro-ecological domains, zone, district, village, or any particular geography where special products and commodities are famous since long time of human settlement history. The main raw material of such special products and commodity come from specific region, hence it is the inheriting right of that geography and communities owing in the region or locality. Therefore, unlike other intellectual property rights, the application for GIs must be made through an association of persons or producers or any organization or authority concerned in a particular region or geography under a provision which represents the interests of the producers of the goods concerned. GI could be of plants, plants and their products, foods, animal or animal products or any value added products directly or indirectly associated with certain community or locality indicating uniqueness of such commodity/

products in question. Therefore, GI is so associated with farmers and common people of country like in Mysore of India where there were reports of more than 3000 traditional foods of which now there exists only 100 of these (Kumari and Rehal, 2015). The status of today's market scenario can further push traditional food industry to brink of vanishing livelihoods of rural people and their sustainability. GIs is equally important for managing indigenous knowledge tailored with livelihoodss enhancement by preserving community knowledge, reduces rural migration to urban areas by creating self-employment in rural areas, and enhances rural tourism as a means of income generation and sustainability in agro-based niches of developing country like Nepal. Hence, GI is beneficial to developing countries where there is still a lot to do for its valuables. Nepal should put high thrust on all her unique agriculture commodity, products of cottage industry, handicrafts, and such other rural livelihoods supporting products and stuffs with a geographical indication tag on the register as included for commodities/ product listed in the tables (Table 1 and 2) and many more in coming days ahead. There should be firm commitment of all concerns to make efforts to provide benefit from GIs for crucially important grassroots level producers and beneficiaries.

For that reason, Nepal, a unique Himalayan country which is divided in parallel bands stretching from east to west mainly in the four agro-ecological zones from lowest elevation of 60 m (Terai) to 8848.86 m, Sagarmatha (the highest Himalaya peak) in the world, has been harboring many important genetic resources globally and endemically. Terai, river basin, mid hills and high hills are the major agro-ecological regions in Nepal. Both of above definition of GIs support unique commodity and their products having GIs in Nepal. Such GIs related products could be the full proof to have the uniqueness for claiming patent of such products which could largely benefit to uplift livelihoods of rural masses in the country. There are endemics GIs of agriculture genetic resources in these regions. To support GIs of agriculture and natural resources endemically available in Nepal, genuine efforts have been made to include some of the very promising GIs of products and commodity. Proposed list of GIs should be amended by adding many potential candidates in coming days as well. Few of important GIs products and commodities have been listed under different agro-ecological domains of Nepal to create awareness among concerned in Nepal (Table 1 and 2) so that their patent can be claimed before these are patented by other competing and developed countries in this arena.

Table 1. Some of the potential Geographical indications (GIs) of agriculture commodity, products, indigenous foods, and ethnic based endemic itinerary of Nepal

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
1.	Achhame cattle (*Bos primigenius indicus*)	Endangered smallest dwarf cattle recorded in the world	Achham district	Achham district	लोपुन्मुख नौमुठे अछामे गाई, संसारको सबभन्दा होचो गाई
2.	Apple (*Malus domestica*)	Trans-Himalayan apple of Marpha/Jumla	Mustang/ Jumla	Apple	मार्फा/जुम्लाको स्याउ
3.	Arna buffalo (*Bubalus arnee*)	Endangered wild buffalo	Koshi Tappu	Wild buffalo	लोपोन्मुख जंगली अर्ना भैंसी
4.	Baadaa prepared from black gram (*Vigna mungo*)	Hills and mountain where Newar community holds majority	Kathmandu valley	Unique ethnic based cousin	काठमाडौँको मासको बाड़ा
5.	Bamboo and bamboo products	Locally made bamboo products	Hills and mountain	Different product from bamboo	बाँसको डोको, चित्रो, नांग्लो, भकारी, स्याखु
6.	Bamboo shoot/Nigalo Tusa	Unique and organic bamboo shoots as fresh delicacy	High hills	Gandaki, Dhaulagiri, Mechi, Koshi zones	स्वादिलो निगालो बाँसको टुसा
7.	Banana (*Musa* spp.)	Banana of Terai	Terai	Jhapa, Sunsari, Chitwan, Nawalpur, kailali	झापा/चितवनको केरा
8.	Bhote Lasun/Garlic (*Allium sativum*)	Local organic garlic of high hills	High hills	Across Nepal	भोटे लसुन मसला
9.	Bitten rice (*Oryza sativa var japonica*)	Bitten rice from Glutinous Taichun variety	Mid hills	Bitten rice from Taichung variety of rice Chiura	काठमाण्डौको टिकनबडी चिउरा
10.	Black gram (*Vigna mungo*)	Tasty black gram	River basin maize/black gram or maize-millet/black gram cropping system	Gandaki ra salyan ko Kaalo maas	तनहुँगे कालो मासको दाल
11.	Black lentil (*Lens culinaris*)	Black lentil of mid hills	Mid hills	Rasuwa, Nuwakot, Kabhre	रसुवा, नुवाकोटको स्वादिलो कालो मुसुरो दाल
12.	Black pig (*Sus scrofa domesticus*)	Black pig of Dharan	Terai and mid hills	Black pig	धराने कालो बंगुर

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
13.	Black pig (*Sus scrofa*)	Black pig of mid hills	Eastern hills	Eastern hills	कालो सुँगुर
14.	Broad leaf mustard (*Brassica juncea*)	Broad leaf mustard of Marpha/ Tankhuwaa	Mid hills	Marphaa/ Tankhuwaa	मार्फा/तान्खुवाको रायो
15.	Broom grass /Tiger grass (*Thysanolaena latifolia*)	Nepali Kucho	Mid hills	Nepali broom (Nepali Kucho)	अम्रिसो/ नेपाली कुचो
16.	Brown Black-gram (*Vigna mungo*)	Brown black-gram of mid hills	Mid hills	Gandaki, Lumbini and Rapti zone	स्वादिलो फुस्रो मास दाल
17.	Buddha Chitta (*Ziziphus buddensis*)	Buddha chitta of mid hills	Mid hills	Kabhre and Ramechhap districts	नेपाली बुद्धचित्तको माला
18.	Buffalo (local buffaloes available in Nepal), Lime, Parkote and Gaddi buffaloes	Across Nepal	Hills and Terai	Easter, Central, western and farwestern hills and Terai	नेपाली स्थानीय रैथाने भैंसी; लिमे, पार्कोटे र गड्डी
19.	Butter tree /Chiuri (*Diploknema butyracea*)	Butter tree of Chepang community in the Chure region	Chure region	In dry and harsh environment of Bhawar and Churiya region	मकवानपुर/धार्डिंगको चिउरी
20.	Castrated rooster (*Gallaus gallus domesticus*)	Veri/Rapti zone regions		Dang/ Deukhuri valley castrated chicken	दांग/देउखुरीको वधिया भाले (खसी पारेको) कुखुरा
21.	Cheese/Chhurpi prepared from yak (*Bos grunniens*) milk	Cheese prepared from yak of trans-Himalayan	Himalaya/ trans-Himalaya region	Yak cheese/Chhurpi	लेकाली याक चिज/छुर्पी
22.	Chilly/ Jyanmara Khursani (*Capsicum frutescence*)	Most pungent Chilly of hills	Eastern mid hills	Mechi, Koshi Zone and similar domains	ज्यानमारा/ अति पिरो डल्ले खुर्सानी
23.	Chiraito (*Swartia chirata*)	Chiraito of high hills	Eastern high hills	Across Nepal (1200-3000 m)	चिराइतो औषधि
24.	Chukauni, a food made up of mass potato, whey and native spices	Chukauni prepared in Syangja and Palpa districts	Mid hills	Lumbini zone	चुकौनी-दहि र आलुको झानेको अचार
25.	Cinnamon/Alainchi (*Cinamon verum*)	Cinnamon of mid to high hills	Hills and mountain	Across Nepal	दालचिनी मसला

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
26.	Cold water fish (*Neotropius atherinoides*)	Jal kapur of Koshi river	Cold water fish in the rivers flowing from the Himalaya	Koshiko Jalkapoor	कोशीको जल कपुर स्वादिलो माछा
27.	Dal Bhat, a unique Nepali cousin	Nepali Dal Bhat	Across Nepal	Special system of cooking rice and pulses as a main course of Nepali	नेपाली खाना, दालभात
28.	Different pickles for different ethnic community i.e. Tomato**+** coriander leaves**+** chilly/ Timur**+** black pepper**+** garlic**+** turmeric	Unique Nepali pickle	Across Nepal	Across Nepal	गोलभेंडा+ खुर्सानी, गोलभेंडा+धनिया, गोलभेंडा+लसुन+टिमुर/नुन+बेसार मिश्रित चट्नी
29.	Dwarf Lulu cattle (*Bos taurus indicus*)	Lulu cattle	Mustang and Manang districts	Suited for harsh environment of high mountain	लोपोन्मुख मनांग/मुस्तांगको हिमाली लुलु गाई
30.	Ghee, local/organic ghee	Local ghee of Surkhet	Mid hills/Surkhet region	Pure ghee	मध्य पहाडी क्षेत्रको अर्गानिक घिऊ
31.	Gundruk Dhindo, a unique organic Nepali cousin	Special porridges prepared from flour of maize/millet porridge	Mid and high hills	Nepali radish silage and porridge as main course of hilly people	स्थानीय नेपाली खाना/ गुन्द्रुक ढिडो
32.	Handmade black Nepali cap	Special black handmade Nepali black cap	Bhaktapur	Special handmade black cap	भाद गाउँले कालो टोपी
33.	Handmade cotton clothes (Palpali/ Tehrathum Dhaka, Gharbuna, Hakupatasi)	Dhaka caps of Palpa and tehrathum districts/ Gharbuna clothes prepared by ethnic communities across Nepal, Haku Patasi (black saree and Choli prepared in Kathmandu valley by Newar community)	Hills and mountain	Handmade caps, saris, blouses, bags and many more	पाल्पाली/तेह्रथुमे ढाका कपडा, घरबुना कपडा, हाकुपटासी सारी चोली र घरेलु तयारि कपडा
34.	Him coffee, organic coffee (*Coffea arabica*)	Himalayan coffee of mid hills	Mid hills	Gulmi, Palpa, Syamgjaa , Lamjung	अर्गानिक हिम कफी, गुल्मी/पाल्पा

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
35.	Himalayan musk deer (*Moschus leucogaster*)	Himalayan region	Himalayan region	High Himalayan region	संकट ग्रस्त कस्तुरी मृग
36.	Hog plum/Lapsi (*Choerospondias axillaris*)	Hog plum of Kathmandu valley	Kathmandu valley	Only in Kathmandu and similar micro-climatic condition	काठमाडौँ लप्सी अचार
37.	Honey hunter- Bhir Mauri/ Singush/Rock bee/Giant Himalayan honey bee (*Apis dorsata/ A. laboriosa*)	Honey of rock bee	High Himalaya region	Lamjung, Manang and Gorkha districts	लम्जुंग, मनांग र गोर्खाको हिमाली भेगमा हुने भिर मौरीको मह-एक साहसिक कार्य
38.	Horse gram/Gahat (*Macrotyloma uniforum*)	Horse gram of hills	Mid hills across	Sindhuli/ Ramechhap	रामेछापको गहत
39.	Kidney beans/Simi (*Phaseolus vulgaris*)	Bean of Karnali	Karnali region	Karnaliko Simi	कर्णालीको सिमि
40.	Large cardamom/Alainchi (*Elettaria cardamomum*)	Nepali large Nepali cardamom	Mid hills of eastern and western region	Nepali cardamom (Alainchi) mainly Taplejung and Panchthar districts	नेपाली अलैंची/ कालो सुन/हिमालयन भायग्रा
41.	Local alcoholic drinks of different ethnic community prepared from rice and millets	Local drinks of Nepal	Nepal	Local drinks	तीन पाने स्थानीय रक्सि/हिलेको तोंग्वा आदि
42.	Local buffalo (*Bos* spp.)	Local buffalo of mid hill	Mid hills	Suited for draft and harsh environment	लिमे, पार्कोटे, र गर्दी स्थानीय भैंसी
43.	Local pigs (*Sus* spp.)	Local pig of Terai	Terai	Suited for harsh condition of Terai across Nepal	मुसहरको हुर्रा सुँगुर
44.	Lokta/Nepali paper (*Daphne bholua/papyracea)*	Handmade Nepali paper	High mountains	Handmade tradition Nepali paper used for ancient writings including religious Sanskrit books and epics	नेपाली कागज; सरकारी र धार्मिक र वैदिक अभिलेख राख्न प्रयोग भएको

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
45.	Mandarin orange (*Citrus reticuleta*)	Mandarin orange of Manakamana	Mid hills	Manakamanako/ Khokuko Suntala	मनकामना/खोकुको मिठो सुन्तला
46.	Mango (*Mangifera indica*)	Mulghat and Lahan (Dhankuta and Siraha)	River basin/Terai	Dhganhuta, Sirahaa	लहान /मुलघाटको स्वादिलो माल्दहा आप
47.	Medicinal herbs i.e. Satuwa (*Paris polyphylla*), Jethi madhu (*Glycyrrhiza glabra*), Thulo aushadhi (*Astilhe rivularis*), Ghottapre (*Centella asiatica*), Sikari Laharo (*Sciendapsus officinalis*), Paanch Aunle (*Dactylorhiza hatagiria*), Pakhan Bhed (*Bergenia lingulata/ciliate*), Sugandhawaal (*Valeriana officinalis*), Hing (*Ferula asafoetida*), Chillo Batulpate (*Cissampelos pareira*), Orchids, (*Orchis* spp.) Himalayan olives (*Olea cuspidate. O. ferruguinea, O. glandulifera*), and many other MAPS	Special Nepali medicinal herbs	Hills, mountain and terai	Nepali medicinal herbs (Nepali Jadibuti)	औधधिजन्य नेपाली जडी बुटी
48.	Medicinal mushroom (*Ganoderma, Merchella*, Sitake and many more)	Medicinal mushrooms	High mountain	Karnali zone	गानो डर्मा, मर्चेला र अन्य औषधि जन्य हिमाली च्याउहरु
49.	Mountain goat/Chyangra (*Capra falconeri*)	Mountain goat of trans-Himalayan	High mountain	Mountain goat good for Pashmina shawl and meat	मनांग, मुस्तांग, हुम्ला, जुम्ला आदि क्षेत्रका लेकाली च्यांग्रा
50.	Native foul (*Gallus gallus domesticus*)	Native foul of Nepal	Nepal	Across Nepal	स्थानीय साकिनी, घांटी खुइले, , र अन्य स्थानीय कुखुरा प्रजातीहरू

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
51.	Native goat (*Capra aegagrus hircus*, *Capra* sps.)	Native goat of mid and high hills	Mid and high hills	Harash environment	स्थानीय सिन्हाल, खरी बाख्रा
52.	Native hog (*Sus* sps.)	Native hog of mid hills and Terai	Mid hills and Tera	Across Nepal	स्थानीय बामपुड्के च्वांचे/सुँगुर
53.	Nepali handmade paper /Lokta (*Daphne bholua/D. papyracea*), Bhoj patra / Himalayan birch (*Betula utilis*),	Nepali handmade papers	Himalayan region up to 4500 m	Ancient time writing in Sanskrit for many religious books in Hinduism including the Vedas	नेपाली हाते कागज/भोज पत्रमा लिखित बैदिक संस्कृत लेखहरु जस्तै वेद र कयौ धार्मिक ग्रन्थहरु र अन्य आयुर वैदिक उपचारको लागि प्रयोग
54.	Nepali pepper /Timur (*Xanthoxylum armatum*)	Timur of high hills	Nepal	Rapti and Seti zone	नेपाली औषधिजन्य तरकारी मसला
55.	Nepali spices; coriander (*Coriandrum sativum*), ginger (*Zingiber officinalis*), pepper (*Piper nigrum*)	Nepali coriander	Nepal	Across Nepal	नेपाली मसला/अचार
56.	Nepali underutilized fruits such as Kaphal (*Myrica esculenta*), Katus (*Castonopsis indica*), Dale chuk (*Hippophae salicifolia*), Panhelo aiselu (*Rhubus foliolosus*), Kalo aiselu (*R. ellipticus*), Amla (*Embilica officinalis*), Bael (*Aegel marmelos*), Chutro (*Berberis* spp.), Jamun (*Eugenia jambolana/ Syzygium cumunill*), Dahi Kamlo (*Callicarpa macrophylla*), Pureni/wild grape (*Ampelocissus rugosa*), Angeri (*Melastoma melabathricum*) Bhakkamlo (*Rhus chinensis*) and many more	Nepali underutilized wild fruits	Terai (60m) to high mountain (4000m)	Medicinal value, fresh fruits, jam, jelly and wine preparation	काफल, कटुस, डाले चुक, ऐसेलु, अमला, बेल, चुत्रो, हर्रो, बर्रो, अंगेरी, जामुन,क्युं काफल, अमारो, पुरेनी इत्यादी सदुपयोग कम भएका औषधिजन्य वनस्पतिहरू, वाइन, ताजा फलफूल र विभिन्न घरेलु प्रयोग हुने विभिन्न नेपाली फलफूल तथा तरकारीजन्य बोट बिरुवाहरु

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
57.	Nepali underutilized vegetables i.e. Niuro (*Dryopteris cochleata*), Sipligan (*Cratera unilocularis*), Banko (*Arisaena tortuosum*), Jaringo (*Phytolacca acinosa*), Koiralo (*Bahunia variegate*), Kabro (*Ficus lacor*), Dumri (*Ficus racimos*), Sital Chini/Drum stick (*Moringa olifera*) Choto/ Lekali Mula (*Raphanus sativus* var. *oleifera*) and many more	Nepal	Terai , mid to high hills	Indigenous vegetables	नेपाली रैथाने तरकारी; निउरो, बांको, सिप्लिगान, जरिंगो, सितलचिनी, कोइरालो, काब्रो आदि
58.	Newari food, unique combinations of different non-vegan foods	Kathmandu valley	Mid hills	Newari khaana	काठमान्डूको खाँटी नेवारी खाजा
59.	One-horned rhinoceros (*Rhinoceros unicorn*)	Chitwan	Terai	Chitwan and Bardiya National park	एकसिंगे गैंडा-नेपालको राष्ट्रिय जनवार, संकट ग्रस्त जनावार
60.	Pear (*Pyrus* spp.)	Kathmandu	Mid hills	Pear of Pharphing	फर्पिंगको नासपाती
61.	Pop corn (*Zea mays everta*)	Trans-Himalaya	High hills	Mustang	मुस्तांगको काँडे-रातो मुरली मकै
62.	Potato (*Solanum* spp.)	High hills	High hills	Summer potato	मुडे/सिदुवाको आलु
63.	Radish (*Raphanus sativus*)	Pyuthan	Pyuthan/mid hills	Red radish	प्युठाने रातो मुला
64.	Radish (*Raphanus sativus*)	High hills	High hills	Kakani, Palung	ककनी र पालुंगको बेमौसमी मुला
65.	Radish silage (*Raphanus sativus*) and roasted soybean (*Glycine max*)	Hills and mountain	Across Nepal	Across Nepal	झानेको गुन्द्रुक र भटमासको अचार
66.	Rice (*Oryza sativa* var. *glutineous*)	Gandaki region	Gandaki Region	Glutinous rice	गण्डकी क्षेत्रको लट्टे खाने अनंदी धान
67.	Rice (*Oryza sativa* var. *indica*)	Mid hills (Tar/aerobic condition)	Mid hills of Gandaki and Dhaulagiri and Lumbini	Upland rice (Ghaiya)	टारको घैया धान

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
68.	Rice (*Oryza sativa* var. *japonica*)	High hills	Kaski/Mygdi	Chhumro Stahniya (local)	लेकाली छुम्रो धान
69.	Rice (*Oryza sativa* var. *Japonica)*	Karnali region	Chhum Chour Jumla, highest elevation of the world where Jumli Marsi rice is cultivated (3050m)	Cold tolerant rice (Jumli Marshi), place where rice cultivation is done in the highest elevation 3050 m	छुम चौरको जुम्लीमार्शी धान; विश्वको सबभन्दा अग्लो स्थानमा हुने
70.	Rice (*Oryza sativa*)	Jethobudho rice of Kaski	Mid hills	Pokhreli Jetho budho	वास्नादार पोखरेली जेठोबुढो धान
71.	Rice (*Oryza sativa*)	Tilki rice of Dang	Mid hills	Raptiko Tilki	दाङ्गको मसिनो र स्वादिलो तिल्की धान
72.	Rice (*Oryza sativa*)	Lalka Basmati/Kalanama rice of Mahottari and Bara	Terai	Barako Kalanimak, Dhanushako Lalka basmati	महोत्तरीको वास्नादार लल्का वासमती/बाराको वास्नादार कालानिमक धान
73.	Rice (*Oryza sativa*)	Manabhoig rice of Gandaki	Mid hills	Manabhog	पहाडी वास्नादार मसिनो मनभोग धान
74.	Roasted corn (*Zea mays*) and soybean (*Glycine max*)	Hills and mountain	Nepal	Across Nepal	स्थानीय खाजा; भुटेको मकै भटमास
75.	Rudraakshe (*Elaocarpus ganitrus*)	Rudraksha of Sanskusabha Dingla	Mid hills	Sankhuwasabha, bhojpur, khotang districts	दिन्नलाको शिव रुपी रुद्राक्ष
76.	Sahar Machha (*Tor putitora*)	Himalayan cold water fish	High mountain	Gandaki, Koshi and Karnali river system	नेपाली हिम नदीहरुमा पाइने शहर माछा
77.	Sel Roto-Achaar	Nepal	Nepal	Unique Nepali delicacy	नेपाली सेल रोटि, अचार
78.	Soybean (*Glycine* spp.)	Kaalo soybean of high hills	High hills	Across Nepal	कालो/खैरो औषधि युक्त भटमास
79.	Spinach/Palungo (*Tetragonia tetragonoides*) and cress/Methi (*Barbarea verna*) leaves/ Fenugreek (*Trigonella*	Kathmandu	Mid hills	Kathmandu valley	काठमांडूको लोकप्रिय चम्सुर, पालुंगो साग/ मेथी, पालुंगो साग

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
	foenumgraecum) and Spinach/Fenugreek and crees leaves				
80.	Sugarcane (*Saccharum officinalis*)	Panmara Morang/ Dhunibesi Dhading	River basin and mid hills	Kaalo Ukhu	धुनिबेसिको कालोउखु/पानमराको कालो उखु
81.	Summer vegetable (cauliflower, cabbage (*Brassica* spp.), radish (*Raphanus sativus*), carrot (*Daucus carrota*), turnip (*Brassica rapa*), pea (*Pisum sativum*), broadleaf mustard (*Brassica juncea*)	Off season vegetable of high hills	High hills	Summer vegetable/off season vegetable	धनकुटा, पालुंग/टिस्टुंग, पाल्पा, कपुरकोट, डढेल धुरा, बैतडीका बेमौसमी तरकारी
82.	Sweet orange/Junar (*Citrus sinensis*)	Sweet orange of Sindhuli/Ramechhap	Mid hills	Sindhuliko Junar	सिन्धुलीको जुनार
83.	Taro/Pindalu (*Colocasis esculentus*)	Taro of Gandaki and Rapti-Bheri zones	River basin	Gandaki ra Raptiko Pindaalu	गण्डकी/राप्तीको पिंडालु
84.	Tea (*Camellia sinensis*)	Orthodox tea Mechi/Koshi region	Mid high hills (Mechi, Koshi and Sagarmatha zones)	Orthodox tea of eastern hills (Illame Chiya)	इलामे चिया
85.	Tomato (*Solanum lycopersicum*)	Tomato of Sarlahi	Terai	Sarlahiko Golbhenda	लालबन्दीको गोलभेंडा
86.	Turmeric /Haledo (*Curcuma longa*)	Turmeric of mid hills and Terai	Nepal	Sunsari and sarlahi districts	नेपाली बेसार
87.	Under- utilized crops (buck wheat (*Fagopyrum esculentum, F. tartaricum*), naked barley (*Hordeum vulgare*), amaranthus (*Amaranthus* spp.) proso millet/Chino (*Panicum miliaceum*), foxtail millet (*Setaria italic*), high hill rice(*Oryza sativa* var. *japonica*))	Underutilized crops trans-Himalaya	Trans-Himalaya region	Lekalai khana	पहाडी खाद्यान्न; कोदो, फापर, जौ, उवा, कागुनो, लट्टे, सिमि, चिनो, जुनेलो आदि

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
88.	Unique cultural based food of different ethnic communities	Foods of different ethnic groups of Nepal	Nepal	Ethnic communities based attires	हिमाल, पहाड, तराईमा बसोबास गर्ने नेपालीहरुका संस्कृतिजन्य खानाहरु; दाल-भात, रोटि-अचार, खिर, जेरी-पूरी-हलुवा, ढिंडो-गुन्द्रूक, चपाती-दाल, मकै-भटमास, चना-चिउरा, लट्टे/चाम्रे, दहि-चिउरा, जेरी-पूरी-हलुवा, चुकौनी/कडी पूरी-तरकारी आदी
89.	Unique dress of different ethnic communities (Gurung, Magar, Tharu, Tamang, Jumli, Sherpa, Dhimal, Bhote, Khas, and all ethnic communities)	Different ecological regions of Nepal	Nepal	Ethnic communities based attires	नेपाली जनजातातिका आफ्ना पहिरन; टोपी-दौरा-सुरवाल -कोट, धोती-गम्छा, सारी-चोलो-पटुका, हाकु- पटासी, टोपी-भोटो-कछाड, घलेक-कछाड-भोटो आदि
90.	Unique Nepali attires for men (daura- surwaal-topi) and women (Guniu-choli-patuka)	Hills and mountain	Hills and mountain	Nepali attires	नेपाली पोशाक (मयल पोस, गुन्यु चोली)
91.	Wooden pots, special hand carved wooden pots	Wooden pots of mid hills, Churiya region	Nepal	Different pots from woods	काठका स्थानीय भाँडाहरु; ठेकी, सिमांग, पुंग, माना, पाथी, फाम, मदुस आदि
92.	Woollen blanket, special blanket locally made from wool of mountain goat (*Capra* spp.)	Woollen blanket Karnali	Karnali, Region	Blanket made from mountain goat (Sinhal)	कर्णालीको लिऊ
93.	Woollen blanket, special handmade blanket from local wool and mountain goat (*Capra* spp.) and mountain sheep (*Ovis ovis*)	Woollen blanket of high hills/mountain	Himalaya/ trans-Himalaya region	Made from the wool of sheep and goat	गण्डकी/रुम्जा टार्को राडी/ पाखी/बख्खु/काम्लो आदि उनीका उत्पादनहरु
94.	Yam (*Dioscorea* spp.)	Yam of Terai	Terai	Sarlahi/Rautahat	सर्लाहीको तरुल
95.	Yarsha Gumbu (*Cordyceps* spp.)	High Himalaya , Nepal	High hills of western Nepal	Yarsha Gumba of the Himalayan region	हिमाली यार्षा गुम्बु
96.	Yoghurt	Yoghurt of Bhaktapur	Mid hills	Juju Dhau	भक्तपुरे जुजु धौ

SN	Commodity/ product	Unique geographical indicators	Agroecological domain	Ggeographical location	Nepali GIs for patenting
97.	Zinger/Aduwa (*Zingiber officinalis*)	Illam	Mid hills	Fibreless zinger (bose Aaduwa)	इलामको / सल्यानको बोसे अदुवा
98.	Zuzube/Bel (*Ziziphus jujuba*)	Mid hills and Terai	Mid hills and Terai	Sindhuli, Ramechhap and bardiya	सिन्धुली/रामेछापको बेलको सर्वत

Joshi *et al.*, (2017) have come up with some geographically important local commodities (Table 2) in Nepal. These are some of the location specific unique land races of crops which are prime importance to be considered as special GIs crops in Nepal. This suggests that there are still more to documents such GI of locally important commodies in the the time to come in the country.

Table 2. Some of the location specific APGRs and land races of crops having unique properties indicating GIs of crops available in Nepal

SN	Crop commodity	Landrace	Geographical location	Unique traits	Nepali GIs indicator
1.	Banana	Mungre Kera	Lamjung and Tanahun	Yellow, long finger	उच्च शक्ति भएको केरा
2.	Black husked Rice	Mallaji	Lekhphant, Parbat	Aadilo	आडिलो हुने भात
3.	Buckwheat	Bhate Phaper	Dolpa	Loose husk	बोक्रा खुइलिने फापर
4.	Cauliflower	Sthaniya	Aaruchaur, Rupakot, Syangja	Perennial, sweet, large head, branch for Propagation	बाह्रमासे काउली
5.	Cucumber	Madale Kaakro	Pelakot, Rupakot, Syangja Aaruchaur,Rupakot	Good for pickle, disease and insect tolerant	मादले काक्रो
6.	Finger millet	Dalle Kodo, Barshe Kodo	Ghanapokhara-5, Lamjung	Dhindo sweet and tasty	मिठे कोदो
7.	Ginger	Syangja	Chilaune bas	High dry ginger recovery	धेरै सुठो पर्ने अदुवा
8.	Lapsi	Bhagara Sthaniya	Bhagara, Parbat	More pulp, tasty, long storability	स्वादिलो लप्सी
9.	Lentil	Sindur	Siraha	Small seeds, good taste, high quality	सानो दाना हुने स्वादिलो मुसुरो
10.	Maize	Murali	Chapakot, Syangja	Pop corn	फूल उठ्ने मुरली मकै
11.	Mandarin	Rumjataar Suntala	Rumjataar, Okhaldunga	Sweet	रुम्जाटारको स्वादिलो सुन्तला
12.	Mayal	Local Mayal	Marpha	Red bunchy small fruit, root stock for apple and pear	रुट स्टकमा प्रयोग हुने मयल

SN	Crop commodity	Landrace	Geographical location	Unique traits	Nepali GIs indicator
13.	Naked barley	Kalo Uwa	Jhong, Mustang	Black in color, tasty and colored flour	स्वादिलो कालो उवा
14.	Pigeon pea	Dhanusha Local	Dhanusa	SMD resistant, small seeds, tasty	रोग निरोधक रहर
15.	Potato	Tarkhole Seto, Dhorpatan Local	Tara VDC, Bobaang VDC, Baglung	Scented, fissa futne	वास्नादार आलु
16.	Potato	Sthaniya	Jantarkhani, Oklaldhunga	Boiled having very special quality taste	साठी दिने आलु
17.	Potato	Sthaniya	Gatlang, Rasuwa	Easy and fast cooking, special taste	छिटो पाक्ने आलु
18.	Rice	Junge Masino	Lamjung	Highly scented	वास्नादार जुंगे मसिनो धान
19.	Rice	Pokhareli Masino	Pokhara	Scented, fine grain, good taste, fine grain good quality	वास्नादार पोखरेली मसिनो धान
20.	Rice	Anadi	Gandaki zone	Glutinous and used as delicacy	पाहुनालाई स्वागत गर्ने र मीठो चोखोको रुपमा प्रयोग हुने चामल
21.	Rice	Ekle, Jhinuwa, Lekali, Basmati	Ghanapokhara-5, Lamjung	Scented, bhatbadne	वास्नादार हलुङ्गो मसिनो धान
22.	Rice	Anadi	Bhagwana, Parsa	More starch, good for popped rice	स्टार्च युक्त धान
23.	Rice	Jarneli	Chapakot, Syangja	Sweet, soft	स्वादिलो नरम भात हुने
24.	Rice	Jhinuwa	Syangja	Scented	वास्नादार भात हुने धान
25.	Rice	Gudura	Aruchaur, Syangja	Disease tolerant, high milling recovery	रोगप्रतिरोधी धानको जात
26.	Rice	Mansara	Aadhikhola, Syangja	Disease and lodging tolerant, high milling recovery	धेरै चामल पर्ने रोग प्रतिरोधी धान
27.	Rice	Atte marsi, Dudhe marsi,	Lokhim, Salyan, Tingala, Solukhumbu,	Tasty, soft	स्वादिलो र नरम भात हुने धान
28.	Rice	Anadi	Pokharathok, Palpa	Medicinal property for joint problem	
29.	Rice	Ate, Belguti, Chirakhe	Dhankuta, Ikhu, Terathum	More straw, lodging tolerant, tasty	पराल पर्ने, नढल्ने, स्वादिलो धान
30.	Sesame	Kalo and Seto	Kotdarbar, Ramjakot, Sundhara Tanahun	Tasty pickle	स्वादुलो चट्नी हुने तिल
31.	Seabuckthorn /Daale chuk	Muktinath	High mountain	Juicy yellow pulp, antioxidant property	डाले चूक
32.	Sesame	Khairo Til-1	Nawalpur, Chitwan	Less fiber, good for pickle	चट्नीको लागि मनपराउने तिल

SN	Crop commodity	Landrace	Geographical location	Unique traits	Nepali GIs indicator
33.	Sponge gourd	Basaune Ghiraula	Syangja	Scented, late maturity, fruiting only after	वास्नादार घिरौंलो
34.	Taro	Hattipau, Kharibot	Purkot, Aabu, Tanahun	Tasty vegetable, sweet for boiled	हात्तीपाईले पिंडालु
35.	Wheat	Kadu	Kimtang, Nuwakot and Rasuwaa	Tasty, nutritious	पोषिलो कडू गहुँ जुन नेपालमा मात्र पाईन्छ
36.	Wheat	Naaphal	Humla	Winter wheat, high protein content	शिशिर ऋतुमा हुने नेपालमा मात्र पाईने गहुँ
37.	Wild radish	Choto	Solu, Jumla, Humla, Kalikot, Karnali region	High off season vegetable, good storability, tasty, large and turnip-shaped	जंगली चोतो मूला

Conclusion

It indicates that there is the vast potentiality of increasing trade balance and listing GIs of agriculture commodity in Nepal. The government and concerned authority should take immediate initiative to register GIs of these crops/products in niches where these have been identified by locals for their specific traits that are quite enough to claim patent by local users in special and Government of Nepal in general. Taking ownership of GIs related commodity and products, it can be claimed patent right of these commodity thereby export potential of Nepali traders comes in favor of increased trade balance in Nepal where there is the skewed negative trade balance due to excessive imports of mostly consumable commodities. The above list of GIs including their products and commodity are just an initiation of registering some of the important itinerary in this regard. There is more to do sincere efforts in this filed to add all important, endemic and indigenous agricultural related commodities, cottage industry products and other community and ethnicity based endemic foods and products such as handicrafts, ethnic based foods, culturally based foods and attires, and other traditional products related to GIs in Nepal having enormous right to claim their patent rights. Bothe genotypic and phynotypic traits of genetic resurces should be studied scientifically and patented. By doing so important genetic resources and their and products are conserved, utilized and enhanced rural livelihoodss of Nepali in a way such GIs related commodity and products are used in a scientific manner to sustain demand of present generation without compromising the use for the future generation as well. Importance of genetic resources conservation and patenting of GIs is not only needed for the present generation but also equally important to the sustainability of the future generation without compromising their needs as well. Therefore, geographical indication of commodity and their products are very important gears for livelihoods enhancement and genetic resources conservation in Nepal.

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Does conservation agriculture work for rainfed farming in Nepal? A review

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Abstract

Intensive tillage-based agricultural practices severely affect the soil's physical, chemical and biological properties that eventually limit the crop yields in longer run. It is due to declining soil physical, chemical and biological properties. Several studies have been done to restore and improve the soil quality, however conservation agriculture (CA)-based practices of minimum tillage, crop residue retention and appropriate crop rotations has been observed to be promising across the globe. Studies on CA under Nepal's rainfed farming systems of Terai and hills of Nepal improved the soil quality, increased individual crop and system yields, reduced labor demand and was economically profitable. However, lack of adequate soil moisture during planting in initial seasons, inadequate tillage equipment and weed management options are the key constraints of rainfed farming to be transformed into CA in initial stages. In Nepal, the introduction of animal-drawn direct seeding equipment, management of residues or mulches, mechanical or herbicidal weed management options for small-scale rainfed hill farmers can be of paramount significance in scaling-out of the CA based practices in Nepal. For this, further on-station and on-farm verifications of CA based practices need to be carried out across the various cropping systems and agro-ecological regions of the country by Nepal Agricultural Research Council (NARC), Nepal in collaboration with international CG centers, universities, extension and development institutions.

Keywords: Conservation agriculture, economics, rainfed agriculture, soil water, yield

Introduction

Rain-fed agriculture, where crop production relies on seasonal precipitation, often shows a grim picture of a fragile environment due to water scarcity, drought, soil degradation, low rain (water) use efficiency, poor infrastructure and inappropriate policies. Rainfed agriculture covers 80% of the world's cultivated land, and contributes about 60% to the total crop production (UNESCO, 2009). Low productivity in many arid and semiarid rainfed agricultural systems is often due to degraded soil fertility and limited water and nutrients input. Though rain-fed agriculture is practiced in almost all hydro-climatic zones, it provides much of the food consumed by poor communities in developing countries. In Nepal, despite having ample fresh water resources, almost 67% of agriculture is based on rain-fed farming, the annual agricultural output in the dry season is highly dependent on weather conditions. In Nepal, more than 80% of total precipitation falls during the monsoon, from June to September (Malla, 2008). Therefore, the crop yields vary from year to year depending upon the weather conditions mainly precipitation. Studies on CA under rainfed agriculture in Nepal are meager. However, an attempt has been made to highlight the works done across the various cropping systems in Nepal.

Methodology

The methodology adopted to prepare this article is review of various works done on conservation agriculture (CA). As the CA in rain fed system is particularly less explored dimension in case of Nepal. Here we have tried to compare the empirical international studies on rain fed aspect of CA to the available research results done in the country to demonstrate the effectiveness of conservation agriculture in Nepalese context. The collected information are summarized and described in comprehensive way with the help of figures, pictures and tables wherever needed to give the clear picture of whether CA is useful or not in rain fed system of Nepal.

Results and Discussion

Water scarcity is the biggest threat to the food self-sufficiency, which seems to exert even stronger influence on rainfed agriculture in future (Hoff *et al.*, 2009). The scarcity of water for food production through agricultural droughts and dry spells will be a big challenge for water management (Rockstrom, 2003). Factors that influence the performance of rainfed farming systems include the ratio of precipitation to potential evapotranspiration, water availability, drought risk, temperature regimes, soil quality, external input use etc. There are many interrelationships among these factors (Harrington and Tow, 2011).

Broadly, agri-food systems under rainfed water scarcity is characterized by food and nutrition insecurity, unemployment and migration. Natural resources growth is hampered and more prone to losses of biodiversities and women are more vulnerable to these shocks. Therefore, the only option in these areas is to harvest, storage and utilize rainwater and the strategies for it has been shown in figure 1 below.

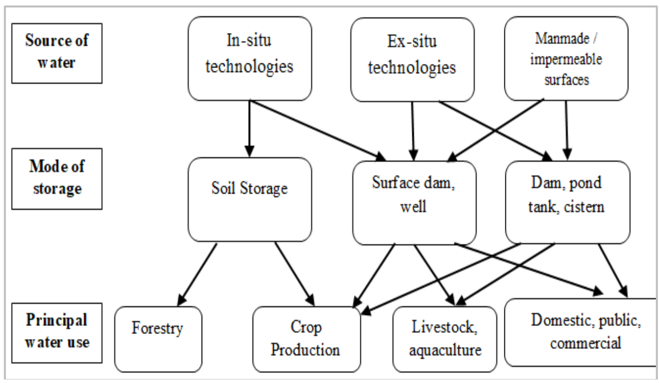

Fig.1: Rain water harvesting strategies

(Source: https://wocatpedia.net/wiki/File:Rainwater_harvesting_systems.jpg)

Categorically, it can be addressed by genetic resources, plant breeding and crop management. In this paper, an attempt has been made to highlight how crop management practices in particular conservation agriculture improve soil moisture regime under rainfed cropping systems. The emphasis will be primarily on *in-situ* water management under uplands.

In-situ water harvesting techniques

It is necessary to store the maximum amount of rainwater during the wet (monsoon) season for use at a later time. One of the methods frequently used in rainwater harvesting is the storage of rainwater *in-situ*. The *in-situ* technology consists of making storage available in areas where the water is going to be utilized. Rainwater harvesting for infiltration also known as in situ water harvesting is a practice in which rainwater uptake in soils is increased through the soil surface, rooting system and groundwater, hence influence the water availability and subsequent vegetative growth and crop yield (Manyatsi *et al.*, 2011). Soil effectively acts as the storage agent, which improves water holding capacity and fertility and reduces risks of soil loss and erosion. An attempt has been made in this paper on an alternative production system that could contribute to water harvesting, storage and efficient utilization *in-situ*.

Conservation agriculture

Conservation agriculture is a set of management practices including minimum tillage, crop residues (mulching) and crop rotation has demonstrated the potential to increase agricultural productivity and food security while preventing erosion and maximizing the ecological functions of the soil (Kassam *et al.*, 2009). It is often stated that the CA system can help agriculture adapt to increasing climate variability and the occurrence of extreme events (Williams *et al.*, 2018). The erosion protection, reduction in soil temperatures and improved infiltration rates can help deal with more intense rainstorms, and increased daily temperature ranges and frequency of drought (Kassam *et al.,* 2009). Summarizing available research, Dixon *et al.,* (2020) concluded that CA can improve food production, increase energy and water use efficiencies, while reducing greenhouse gas emissions.

Effects of CA practices on soil properties under rain-fed condition

Laborde and McDonald (2019) reported that after two years of conversion of conventional system to CA in maize-rapeseed and maize-wheat rotational systems, the mean weight diameter of dry aggregates (0-5 and 5-10 cm depths) was greater (by 45% and 24%, respectively), soil sorptivity slower, and bulk density (measured at the 0-15 cm depth) greater in CA than the conventional tillage (CT). These findings demonstrate that during the initial years of transition from conventional to a CA based crop management system, soil physical properties may improve but crop yield could either decrease or remain stable in the mid-hills of Nepal. As such, the benefits CA appear to be largely oriented towards improving environmental outcomes, and the efficiency and profitability of crop production. Additional management interventions are conversely likely to be needed to increase yield.

Conservation agriculture and soil moisture regime

One of the most notable distinctions of CA is that it requires spending little or no time on the physically demanding tasks of moving the soil (Haggblade *et al.,* 2011). In addition, reduced tillage can improve the physical, chemical and biological properties of the soil through increased soil organic matter. Mulching maintains moisture by covering the soil while rotation can help improve soil quality and reduce the incidence of crop diseases and pests. Summarizing available research, Dixon *et al.,* (2020) concluded that CA can improve food production, increase energy and water use efficiencies, while reducing greenhouse gas emissions. The major components of the conservation agriculture practice at the soil-atmosphere interface showing how tillage and mulch management affect infiltration, soil moisture availability, utilization and crop performance. Tillage alters soil structure and increase porosity of the upper layer and enhances the initial infiltration while mulch reduces raindrop impact on soil surface, increasing infiltration of rainwater and reducing evaporation.

CA and soil erosion control

A major benefit of CA is the control of soil erosion due to maintenance of soil cover, greater infiltration and reduced run-off (Erenstein *et al.,* 2015). Tiwari *et al.,* (2009c) suggested that reduced tillage (RT) with residue retention in maize-cowpea rotation was more effective in maintaining soil fertility and increasing farm income compared to a maize-millet rotation. Atreya *et al.,* (2005) reported no differences in maize yield between different tillage treatments but total annual soil and nutrient losses in RT (11.1, 126 kg/ha SOC, 11.8 kg/ha N, <1 kg/ha P and 2.4 kg/ha K, respectively) were lower compared to CT (16.6 t/ha, 188 kg/ha SOC, 18.8 kg/ha N, <1 kg/ha P and 3.8 kg/ha K, respectively) in a central mid-hill location in the Kathmandu valley. Atreya *et al.,* (2008) reported significantly lower annual and pre-monsoon soil and nutrient losses with RT and rice straw mulching compared to CT, but both conservation approaches neither significantly reduced runoff nor increased maize yield compared to CT. Both studies suggest that RT could be a viable option for minimizing soil and nutrient losses without sacrificing crop yields in the mid-hills of Nepal, although efforts are needed to overcome perceptual hurdles to adoption among farmers.

CA and soil moisture holding capacity

Moisture holding capacity (MHC) can be an important determinant in crop productivity. High crop water demand under rainfed farming promotes rapid soil drying by evapotranspiration, which can lead to plant moisture stress. Improvements in soil moisture holding capacity through aggregation and enhanced organic matter content are commonly observed in reduced tillage systems. After 13 years, tillage was found to have a significant ($P < 0.01$) effect on MHC at the three moisture tensions tested. Conventional tillage (CT) produced lower moisture holding capacity (MHC)s at all tensions. With increasing tension from (−10) to (−100) kPa, CT retained an average 67.49% of the (−10) kPa MHC, while no tillage (NT) retained 70.72%, and reduced tillage (RT) 65.73%. (Williams *et al.*,2018). Tiwari *et al.*, (2008b) reported that RT decreased runoff 7-11% and soil loss by 18-28% compared to CT in a mid-hill watershed in the central region of Nepal. The author finds out that the effect of prolonged drought on maize during winter season of 2015 at Rampur, Chitwan, Nepal was evident and no tilled with residues for three years had less effect of drought than the conventionally tilled without residue plot. Similarly, from another experiment on various tillage methods and hybrids of maize during winter season of 2014, at Rampur, Chitwan, Nepal, carried out by the author, revealed that at physiological maturity stage of maize significantly lower soil moisture content of 11.9% in conventional tillage as compared to 14.32%. in NT.

Infiltration rate

Improved aggregate stability, combined with the residue retention in CA systems, is often observed to have a significant positive impact on soil water storage. These increases typically due to a combination of greater rates of infiltration and decreased soil water evaporation (*Li et al.*, 2019b). Increases in infiltration are commonly attributed to the improved aggregate stability in the surface of the profile (where improvements in SOC are highest) and the greater number and continuity of macropores available to rapidly transmit water into the soil profile in the absence of tillage (Li *et al*., 2019b). It should also lead to increased water infiltration from the creation of a larger number of root channels (Baudron *et al.*, 2012). The presence of crop residues can also help protect the surface of the soil from raindrop impact and prevent the formation of surface seals, which can decrease infiltration rates (McGarry et al 2000). Knot (2014) observed that cover crops (surface residues) increased infiltration and soil water content and decreased run-off and associated soil loss (Mchunu *et al.,* 2011). They also shade the soil and decrease wind speeds at the soil surface, decreasing water loss from evaporation (Nielsen *et al.*, 2005; Lampurlanés and Cantero-Martínez, 2006). In a study carried out by the author at Rampur, Chitwan, Nepal during 2010 to 2015 under maize based cropping system, increased infiltration rate in CA than conventional agriculture was recorded after the elapsing of time for 10 minutes. Up to 20 minutes both have cumulative infiltration of 25 mm but after that conservation agriculture exceeded with higher infiltration rate of 84 mm/ha in 20 minutes and 78 mm/ha in 30 minutes period (Figure 3). Zhang *et al.*, (2007) reported the increased infiltration rate by 3.7 times under zero tillage with residue retention after conducting experiment in Paleustalfin, Australia for 24 years. Conservation tillage (no or minimum tillage with crop residue) in rainfed environment is reported to avoid crusting and increase infiltration (Pansak *et al.,* 2008: Fuentes *et al.*, 2009). Jin *et al.*, (2009) and Pansak *et al.*, (2008) reported higher water conserved by conservation tillage, which is partly explained as the system, had crop residue which produces less evaporation and higher infiltration.

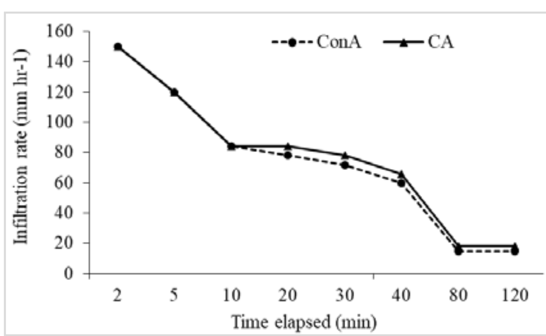

Fig. 2: Infiltration rate of soil as affected by crop establishment methods

CA and soil water evaporation

CA practices reduce the evapotranspiration (Grabowski and Kerr, 2015) and it might be due to the act of crop residues on the soil surface that not only improve aggregate stability, increase infiltration, reduce run-off but also significantly reduces the soil moisture evaporation (Singh *et al.,* 2018). Studies revealed that tillage methods affected the rate of soil evaporation and was also obvious on interaction effects of tillage and residues effect on evaporation. Residue limits the energy reaching the soil surface that limit the relative rate of evaporation in a simple logarithmic function (Steiner, 1989). At Kansas State University's Southwest Research and Extension Center, full-surface residue coverage with corn stover and wheat stubble has been shown to reduce evaporation by 50% to 65% compared to bare soil with no shading (Klocke *et al.,* 2009). Converting to no-tillage has also been shown to reduce irrigation water needs because soil water evaporation is reduced (Pryor, 2006). Mitchel *et al.,* (2012) with the application of wheat residue to a depth of 10 cm in corn (maize) field in California, USA revealed that residues reduced near-surface daily maximum soil temperatures at 1cm below the soil surface by up to 20°F relative to bare-soil conditions. They depicted that more water was retained in the soil under the residues than in the bare-soil plots. Coupling no-tillage with high-residue preservation practices could reduce soil water evaporative losses during the summer season by about 4 inches (10 cm), or 13%, assuming a seasonal evapotranspiration demand of 30 inches (Mitchel *et al.,* 2012). Similarly, from an experiment under maize based cropping system of Rampur, Chitwan during 2015 revealed that no tillage with plastic mulch plot had less evaporation loss compared to conventionally tilled plot.

CA and water-use efficiency

Plant-available water was higher under no-till (Taylor *et al.,* 2012 and Kidson, 2014). Water-use efficiency is also increased and save water by 15-50% through the adoption of CA technologies. It reduces water runoff, better water infiltration and more water in the soil profile throughout the crop growing period. It has potential to increase water application efficiency by over 50 % and irrigation efficiency by 60 % (Pokhrel *et al.,* 2018). In an experiment of crop establishment methods under maize (summer)-wheat (winter) cropping system for two years at Rampur, Chitwan, Nepal, author found that the soil water storage at anthesis stage of wheat was higher in NT with residues compared to CT without residues. The gap was wider at upper layers and was almost equal at lower depths (Figure 3). It might be due to the reduced losses of soil moisture due to evaporation from soil surface.

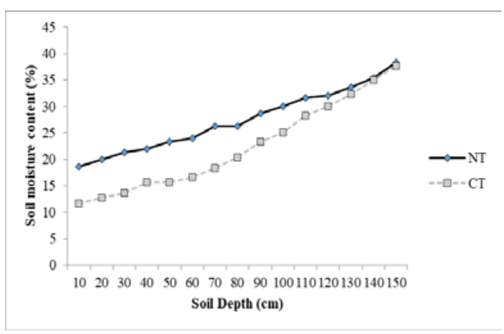

Fig. 3: Soil moisture content at 0-150 cm soil depth under NT and CT at anthesis stage of wheat in 2014 winter season at NMRP, Rampur, Chitwan.

Similarly, soil moisture conservation in NT systems relative to plough tillage (PT) systems has been reported in other studies (Bonfil *et al.,* 1999). While there were no significant differences in volumetric moisture content (VMC) measured at all dates in 2017, there was significant impact of tillage treatments on VMC measured in two out of the five measurement dates in 2018. It is possible that the residue cover in the NT treatment reduced soil water evaporation relative to the PT and strip tollage (ST) treatments, especially in 2018 due to higher mean seasonal temperatures compared to 2017, leading to significantly higher VMC in NT at these two measurement dates in 2018. CA based on no tillage system alters the partitioning of the water balance, decreasing soil evaporation and increasing infiltration and deep percolation, leading to increased yields and water use efficiency (Wang *et al.,* 2012). Water use efficiency is increased and save water by 15-50% through the adoption of CA technologies. It reduces water runoff, better water infiltration and more water in the soil profile throughout the crop growing period. It has potential to increase water application efficiency by over 50 % (Karki and Shrestha, 2015).

CA and crop yields under rainfed condition

In a study carried-out by Karki *et al.*, (2014) under rainfed maize-tori (rapeseed) system of Western hills of Nepal, grain yield of maize and tori was significantly higher over conventional agriculture. Similarly, Karki *et al.*, (2014) also carried out an experiment under maize based rainfed ecosystem of central terai, Nepal during 2013 and 2014. System yield was significantly the highest (11.29 t/ha) in NT with residue kept and intercropping of maize with soybean during summer and wheat during winter was followed. Obviously, the least system yield was observed in no tilled, residue removed and sole crop of maize followed by winter fallow (7.59 t/ha). In an experiment of tillage and crop rotation under rainfed condition, there was an increase in yield in no-tillage with rotation over no-tillage without rotation (Rusinamhodzi *et al.*, 2011). Reduced tillage practices combined with crop residue retention on the soil surface can increase moisture infiltration (Shaver *et al.*, 2007), reduce erosion and increase water use efficiency (Johnston *et al.*, 2002). Crop residues accumulating on the soil surface form a barrier to water loss by evaporation, decrease soil temperatures. The removal of stover in marginally dry years showed a tendency to result in lower grain yields (Linden *et al.*, 2000). Rusinamhodzi *et al.*, (2011) reported that overall effect on maize yield while reduced tillage (with or without mulch) and continuous maize from 5 years experimentation had negative effect on yield compared with the control.

CA and economics

Where CA leads to similar or greater yields, profitability is generally improved due to reduced costs of land preparation and labor, and reduced water requirements (Kumar *et al.*, 2018 and Devkota *et al.*, 2019). Many studies on CA based practices have been carried out under maize based rainfed ecosystems of Nepal and their findings were in agreement with each other and have been depicted in table below. Benefit cost ratio is the ratio of gross returns to cost of cultivation which can also be expressed as return per rupee invested.

Table 1. The economics of various studies carried out by various authors in Nepal

References	Economic analysis (benefit cost ratio)		Remarks
	Conventional tillage without residue	No tillage with residue	
Karki *et al.*, (2014)	1.7	2.5	Hills (maize-wheat/tori)
Paudel *et al.*, (2015)	2.3	2.5	Terai (maize+soybean-wheat)
Khatri and Karki (2015)	2.42	2.53	Terai: (maize+soybean-wheat)
Karki *et al.*, (2015)	2.43	3.3	Terai (maize-maize)
Karki *et al.*, (2015)	1.18	1.36	Hill (maize-wheat/tori)

Constraints of CA under rainfed agriculture

Lack of appropriate seeders and planters under limited soil moisture content on soil, trade-offs among various options for crop residue (as a soil cover/mulch for CA and livestock feeding and burning of residues, fuel etc.), inadequate package of practices for soil moisture management, weeding and intercultural practices and nutrient management, unavailability of skilled manpower are the key constraints of adoption of CA in Nepal. Conventional tillage-based mindset of the policy makers, technicians and farmers is another constraint to promote the CA based practices under rainfed agriculture in Nepal.

Conclusion

CA provides resilience to changing patterns of rainfall, builds and maintains the soil fertility by adding organic matter, moisture and minimize soil loss by erosion. By increasing or stable yields, CA can increase food security and add extra income for the rainfed farmers. In order to promote the CA based practices under rainfed farming in Nepal, there should be an appropriate farm machineries/tools, adequate biomass as residues and integrated crop management technologies. NARC in close collaboration with international and national organizations should have a long-term policy to promote CA based practices under rainfed condition in Nepal.

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Effect of seedbed preparation methods and herbicide application on yield and economics of dry direct-seeded rice at Parwanipur, Nepal

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Abstract

Field experiments were conducted during the 2016 and 2017 normal season (June-November) dry direct-seeded rice (DDSR) at RARS Parwanipur to assess the effect of various combinations of herbicides mixture under seedbed preparation to evaluate different attributes of weed control efficiencies (WCE) coupled with grain yield and economics of DDSR. The experiment was laid out in two factors factorial strip plot design with four replications. Treatments consisted of nine levels of weed management practices that include weed free, weedy check, Pendimethalin, Bispyribac sodium, Ethoxysulfuron, Pendimethalin followed by (*fb*) Bispyribac sodium, Pendimethalin *fb* Ethoxysulfuron, Bispyribac sodium tank mix with Ethoxysulfuron and Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron as horizontal factor whereas two levels of seedbed preparation methods (stale seedbed and normal seedbed) as the vertical factor. The result of the experiments revealed lower weed intensity (WI) and higher weed control efficiency (WCE), net return and benefit-cost (B:C) ratio with Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron in both the years 2016 and 2017. Grain yield was significantly higher with weed free treatment followed by Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron in both the years due to higher WCE and lower WI which resulted in better growth and development of DDSR. Therefore, the Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron is a better option for DDSR under Parwanipur condition during main season rice DDSR rice production.

Keywords: direct-seeded rice, herbicide, tank mixture, weed control efficiency, weed index

Introduction

Puddled transplanted rice (PTR) is the major system of rice production in Nepal. These days due to the scarcity of manual labor weed control has become a menace to rice growers. In direct seeded rice (DSR), there are fewer labor requirements and can also be harvested earlier than PTR systems which facilitate the timely planting of subsequent crops. However, weeds are the main biological constraints in DSR (Chauhan and Johnson, 2010) and can cause yield loss of more than 90% if weeds are not controlled timely (Chauhan and Johnson, 2011). Herbicides are the most common for weed control in DSR (Mahajan *et al.*, 2014). However, the use of a single-herbicide can't control all weed species; so, herbicides tank mixture proved to be superior as it broadens the spectrum of weed control (Damalas, 2005). But, extensive use of herbicides causes the risk of herbicide resistance, so, integrated weed management strategies, that includes preventive, cultural and chemical methods is desirable for effective weed control in DSR (Chauhan *et al.*, 2012). In cultural weed management, a stale seedbed system reduces weed emergence as well as the soil weed seed bank (Rao *et al.*, 2007). Therefore, this experiment was conducted to evaluate the effect of herbicides/ herbicides mixture and seedbed preparation methods in weed management in dry direct-seeded rice.

Materials and methods

Field experiments were conducted at the Regional Agricultural Research Station (RARS), Parwanipur, Bara, Nepal during the rainy season (June to November) of 2016 to 2017. The geographical location of the site was at an altitude of 120 m above mean sea level, 27°20' N (latitude) and 84°53' E (longitude). The experiment was conducted in a strip-plot design with four replications. The treatment consisted of nine levels of weed management practices (Weed free, Weedy check, Pendimethalin @ 1000 g a.i. /ha, Bispyribac sodium @ 25 g a.i. /ha, Ethoxysulfuron @ 18 g a.i. /ha, Pendimethalin @ 1000 g a.i. /ha *fb* Bispyribac sodium @ 25 g a.i. /ha, Pendimethalin @ 1000 g a.i. /ha *fb* Ethoxysulfuron @ 18 g a.i. /ha, Bispyribac sodium @ 25 g a.i. /ha tank mix with Ethoxysulfuron @ 18 g a.i. /ha and Pendimethalin @ 1000 g a.i. /ha *fb* tank mixture of Bispyribac sodium @ 25 g a.i. /ha and Ethoxysulfuron @ 18 g a.i. /ha) in horizontal plots whereas two levels of seedbed preparation methods (stale seedbed and normal seedbed) in the vertical plots. The size of the individual plot was 13.5 m^2 (4.5 m x 3 m). The rice variety Radha-4 was seeded manually continuously in line with a row spacing of 20 cm with a seed rate of 45 kg/ha. Rice was sown with the fertilizer dose of 100:30:30 N, P_2O_5 and K_2O kg /ha, respectively. The full amount of Phosphorus and Potassium and 1/3rd N was applied as basal application and the remaining 2/3rd of nitrogen were applied at 25 days after seeding (DAS) and 45 DAS in two equal splits. Zinc sulphate @ 25 kg /ha was also applied at final land preparation.

Normal seedbed was maintained by one deep ploughing followed by three light ploughings and planking while stale seedbed was maintained by one deep ploughing followed by three light ploughings and planking and field was irrigated and left for 20 days to allow to germinate initial flushes of weeds and then Glyphosate 47% SL (4 ml /litre of water) was applied to the appeared weeds before the sowing of crops. For weed control efficiency, observation regarding the weed density was recorded within each plot with the help of a quadrate (0.5 m x 0.5 m) at two places at 30, 60 and 90 DAS and in the case of weed index, grain yield from weed free plot and treatment plot for which weed index to be worked out was recorded. For the leaf area index, plants were taken from a 25 cm row length of the destructive sampling row. Number of tiller /m^2 was counted from marked one meter of the row of each plot. For dry matter accumulation, plant samples were taken from 25 cm row length of destructive sampling row and expressed in g /m^2. Grain yield was measured from an area of 4.9 m^2 from the net plot area and expressed in t /ha at 14% moisture. MSTAT-C software was used for data analysis. All the recorded data were subjected to analysis of variance and Duncan's multiple range test (DMRT) for mean separations. Treatments differences were considered statistically significance at 0.05 levels of significance.

Results and Discussions

The maximum temperature ranged from 30.02°C to 34.00°C and 29.32°C to 33.71°C during the rice growing season in 2016 and 2017, respectively. The minimum temperature ranged from 14.46°C to 26.80°C and 15.36°C to 26.73°C during the rice-growing season of 2016 and 2017, respectively. The total annual rainfall during the crop season of 2016 and 2017 was 937.6 mm and 1235.07 mm, respectively. The soil texture of the experimental plot was sandy clay loam. The soil pH was slightly acidic (5.6 and 5.5), medium in soil organic matter (3.31 and 3.32 %) and total nitrogen (0.17 and 0.18 %), low in available phosphorus (7.19 and 7.28 kg/ha) and medium in available potassium (221.68 and 219.76 kg/ha) during 2016 and 2017, respectively.

Weed control efficiency and weed index

Among the weed management methods, significantly higher WCE was obtained in weed free while lower WCE in weedy check treatment in both the years 2016 and 2017 (Table 3). Higher WCE was due to weed free by hand weeding while lower WCE was due to higher weed infestation during the crop season. Similar results were also reported by (Saravanane *et al.*, 2016). Ranjit and Suwanketnikom (2003) also reported hand weeding as the most effective method of weed control in direct-seeded rice. Further, concerning the herbicide treatments, at 30 and 60 DAS, maximum WCE was recorded under Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron which was statistically similar with Pendimethalin *fb* Bispyribac sodium in both the years. At 90 DAS, significantly highest WCE was recorded by Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron in both the years which was statistically similar with Pendimethalin *fb* Bispyribac sodium in 2016. In these treatments, the involvement of pre-emergence herbicide (Pendimethalin) recorded a significantly higher role in effectively controlling weeds in dry direct seeded rice. Similar results were also reported by Bhurer *et al.*, (2013a). Higher WCE under these treatments were due to the higher efficiency of these herbicides to control weeds (Gaurav *et al.*, 2015).

Significantly, higher WI was observed in weedy check treatment while lower in Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron in both the years. Higher weed index was due to severe crop-weed competition for nutrients, soil moisture and light resulting in reduced growth attributes and grain yield of directed seeded rice. Similar results were also observed by (Rajaput, 2013). The lower values of WI was due to the efficient control of weeds by pre-emergence herbicide followed by tank mixtures of post-emergence of herbicides which improved growth of crops and reduction in the crop weed competition. Hence, higher yield. The lowest weed index in tank mixture of herbicide was also reported by (Khaliq *et al*., 2012a). The effect of seedbed preparation methods on WCE and WI was not significant in both years.

Table 1. Weed control efficiency (%) and weed index (%) as influenced by weed management practices and seedbed preparation methods of DDSR during 2016-2017, Parwanipur, Bara, Nepal

Treatments	Weed control efficiency (WCE) %						Weed index (WI) %	
	30 DAS		60 DAS		90 DAS			
	2016	2017	2016	2017	2016	2017	2016	2017
Weed management practices								
Weed free	89.57^{a}	90.01^{a}	95.88^{a}	95.88^{a}	95.21^{a}	95.93^{a}	-	-
Weedy check	-	-	-	-	-	-	59.79^{a}	65.06^{a}
Pendimethalin (Pend)	53.28^{f}	36.65^{e}	41.77^{f}	41.77^{e}	38.76^{f}	45.62^{g}	40.00^{b}	49.50^{b}
Sodium Bispyribac (Bispy	69.39^{de}	61.90^{cd}	70.56^{de}	66.01^{d}	72.40^{d}	71.49^{e}	30.83^{c}	31.60^{c}
Ethoxysulfuron (Ethoxy)	65.63^{e}	57.87^{d}	64.62^{e}	60.33^{d}	61.73^{e}	64.57^{f}	29.32^{c}	32.60^{c}
Pendimethalin *fb* Bispy	78.47^{bc}	74.79^{abc}	79.80^{bc}	80.10^{bc}	83.61^{bc}	82.56^{c}	14.04^{e}	14.96^{e}
Pendimethalin *fb* Ethoxy	77.38^{c}	71.61^{bcd}	73.89^{cd}	76.76^{c}	79.72^{c}	78.48^{cd}	16.72^{e}	19.26^{de}
Bispy tank mix with Ethoxy	73.50^{cd}	68.51^{bcd}	71.12^{de}	73.99^{c}	72.51^{d}	74.03^{de}	22.19^{d}	22.53^{d}
Pend *fb*tank mix of Bispy and Ethoxy	83.08^{b}	80.28^{ab}	84.30^{b}	85.59^{b}	86.53^{b}	89.89^{b}	7.41^{f}	7.94^{f}
LSD ($P<0.05$)	5.06	14.82	6.92	6.81	5.50	4.71	3.68	6.24
Seedbed preparation methods								
Stale seedbed	66.16	59.65	65.64	63.76	66.70	66.72	24.72	26.95
Normal seedbed	65.02	59.86	63.68	63.79	64.52	66.57	24.33	27.16
LSD ($P<0.05$)	ns	ns	ns	ns	ns	ns	ns	ns
CV %	10.96	11.76	14.89	10.90	18.91	8.95	26.47	27.18
Grand mean	65.58	60.18	64.65	64.49	65.61	66.95	24.47	27.05

Note: *fb-followed by, means followed by the common letter/s within a column are not significantly different based on DMRT at P <0.05*

Growth attributes and grain yield

The LAI, tiller/m^2, dry matter accumulation and grain yield differed significantly due to weed management practices (Table 4). Weed free recorded significantly highest LAI during both the years which was statistically at par with Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron and Pendimethalin *fb* Bispyribac sodium in 2016 and Pendimethalin *fb* tank mixture of

Bispyribac sodium and Ethoxysulfuron, Pendimethalin *fb* Bispyribac sodium, Pendimethalin *fb* Ethoxysulfuron and Bispyribac sodium tank mix with Ethoxysulfuron in 2017. Higher LAI in these treatments was due to the effective control of weeds and lower crop-weed competition throughout the crop growth period. Higher values of LAI in weed free treatment in direct seeded rice was also reported by Singh *et al.,* (2017). Similarly, Khaliq *et al.,* (2012b) reported the highest LAI of direct seeded rice from weed free treatment and tank mixtures of Bispyribac sodium and Ethoxysulfuron. Higher LAI in weed free and Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron was also observed by Marasini (2018). Significantly lower number of tiller /m^2 was recorded in weedy check while a significantly higher number of tiller /m^2 was recorded with weed free treatment which was superior over rest of the treatments and it was followed by Pendimethalin *fb* tank mix of Bispyribac sodium and Ethoxysulfuron and Pendimethalin *fb* Bispyribac sodium in both the years of experiment. A higher number of tiller/m^2 in these treatments was due to higher weed control efficiency which resulted in crop absorbing the required amount of nutrient, water and sunlight for their growth and tillering behaviour. Weed free recorded significantly higher dry matter accumulation which was followed by Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron in both the years of experimentation. Higher dry matter accumulation in such treatments was due to higher leaf area index. Khaliq *et al.,* (2012b) reported higher LAI led to more interception of radiation over a longer time.

A minimum grain yield was recorded in weedy check while a maximum grain yield recorded in weed free condition in both years (Table 4). The grain yield in 2017 was higher than in 2016 due to favorable total rainfall which was well distributed during the crop growth stages of rice resulting in better crop growth and development. Higher grain yield in weed free treatment was also reported by Bhurer *et al.,* (2013b). All the herbicide treatments produced significantly higher grain yield over the weedy check. Similar results were also observed by Sharma *et al.,* (2016) and reported it was due to the reduced crop weed competition. Among the herbicide treatments, significantly higher grain yield was recorded in the Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron. Thus, the higher grain yield was observed with the involvement of pre-emergence herbicide i.e. Pendimethalin followed by post-emergence herbicides as compared to sole application of herbicides either pre-or post-emergence herbicides which were due to increased growth attributes, higher weed control efficiency and lower weed index recorded in these treatments. The involvement of Pendimethalin as an effective pre-emergence herbicide for weed control in direct-seeded rice was also reported by Bhurer *et al.,* (2013b). Significantly higher grain yield of direct-seeded rice from Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron was also reported by Kumar *et al.,* (2018) which was similar to that of weed free situation. Similarly, higher grain yield from Pendimethalin followed by a tank mixture of post-emergence herbicides was also reported by (AGD, 2013).

Effect of seedbed preparation methods (stale seedbed and normal seedbed) on growth attributes and yield were not significant in both the years (Table 4). The reason for the not significant effect could be due to land preparation done at the same time in both seedbed systems but there was rainfall few days after application of irrigation in stale seedbed which resulted in germination of some weeds in normal seedbed also. Similarly, due to the application of irrigation, the soil became compact in stale seedbed which required slight intensive tillage for seeding of rice and caused exposed of more weed seeds from the lower depth of soil and germinated in the stale seedbed. Similar findings were also reported by Marhatta *et al.,* (2017).

Economics of DDSR

The highest total cost of cultivation was found in weed free treatment followed by Pendimethalin *fb* tank mixture of Bispyribac Na and Ethoxysulfuron while the lowest value was incurred in weedy check treatment in both the years (Table 2). The higher cost of cultivation in weed free plot was attributed to the higher labor cost required for intensive weeding while the lower cost of cultivation was observed with weedy check plot due to not additional cost incurred for managing weeds. Significantly, the higher gross return was recorded with weed free and lowest for weedy check treatment (Table 2). A similar observation was also reported by Kashid *et al.*, (2015). However, weed free condition recorded highest gross return having a high cost which indicated that the treatment was uneconomical (Chakraborti *et al.*, 2017). Among the herbicide applied treatments, a significantly higher gross return was observed with Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron.

Table 2. Growth attributes and yield as influenced by weed management practices and seedbed preparation methods of DDSR during 2016-2017, Parwanipur, Bara, Nepal

Treatment	LAI		Tiller /m^2		DM accumulation (g /m^2)		Grain yield (t/ha)	
	60 DAS		60 DAS		60 DAS			
	2016	2017	2016	2017	2016	2017	2016	2017
Weed management practices								
Weed free	2.35^{a}	2.38^{a}	556.80^{a}	646.60^{a}	318.70^{a}	329.40^{a}	4.29^{a}	4.68^{a}
Weedy check	1.55^{e}	1.66^{e}	246.90^{f}	375.60^{f}	148.50^{e}	156.90^{f}	1.72^{g}	1.66^{g}
Pendimethalin (Pend)	1.84^{d}	1.90^{d}	419.00^{e}	518.90^{e}	217.20^{d}	221.10^{e}	2.58^{f}	2.40^{f}
Sodium Bispyribac (Bispy)	1.91^{d}	2.01^{cd}	422.60^{e}	547.60^{de}	226.30^{d}	235.10^{e}	2.98^{e}	3.25^{e}
Ethoxysulfuron (Ethoxy)	2.11^{c}	2.08^{bcd}	434.60^{de}	548.90^{de}	248.30^{c}	252.70^{d}	3.04^{e}	3.20^{e}
Pendimethalin *fb* Bispy	2.18^{abc}	2.22^{abc}	469.40^{bc}	593.10^{bc}	262.80^{c}	271.90^{c}	3.69^{c}	4.05^{c}
Pendimethalin *fb* Ethoxy	2.14^{bc}	2.21^{abc}	462.40^{cd}	572.10^{cd}	259.40^{c}	268.20^{cd}	3.58^{c}	3.84^{cd}
Bispy tank mix with Ethoxy	2.13^{bc}	2.19^{abc}	442.40^{cde}	558.30^{cd}	255.10^{c}	267.50^{cd}	3.34^{d}	3.68^{d}
Pend *fb* tank mix of Bispy and Ethoxy	2.30^{ab}	2.31^{ab}	495.10^{b}	609.50^{b}	289.50^{b}	299.40^{b}	3.98^{b}	4.38^{b}
LSD (P<0.05)	0.16	0.21	28.09	35.12	18.01	17.23	0.15	0.29
Seedbed preparation methods								
i. Stale seedbed	2.07	2.11	440.50	554.40	247.70	258.20	3.24	3.47
ii. Normal seedbed	2.04	2.10	437.10	550.20	246.90	253.40	3.25	3.45
LSD (P<0.05)	ns	ns	ns	ns	ns	ns	ns	ns
CV %	7.51	11.52	10.58	9.76	10.19	10.93	8.14	10.65
Grand mean	2.06	2.11	438.79	552.29	247.31	255.80	3.24	3.46

Note*: fb- followed by, means followed by the common letter/s within a column are not significantly different based on DMRT at P <0.05, LAI – leaf area index, DM – dry matter*

Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron recorded significantly highest net return which was statistically at par with weed free treatment in both the years 2016 and 2017 while it was also statistically at par with Pendimethalin *fb* Bispyribac sodium in 2017. Higher net returns were the result of higher grain and straw yield (Rajaput, 2013). Chakraborti *et al.*, (2017) reported the lowest net return from weedy check treatment which was due to greater rice-weed competition resulting in poor growth of the crop. All the weed management treatments recorded a significantly higher B:C ratio over weedy check treatment (Table 3). Significantly, the highest B:C ratio was recorded with Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron in both the years. This was statistically at par with Pendimethalin *fb* Bispyribac sodium and Pendimethalin *fb* Ethoxysulfuron in 2016 and Pendimethalin *fb* Bispyribac sodium, Pendimethalin *fb* Ethoxysulfuron and Bispyribac sodium tank mix with

Ethoxysulfuron in 2017. Highest B:C ratio in these treatments was due to higher weed control efficiency, lower weed index, higher yield and low cost of cultivation due to saving of labor cost. Effect of seedbed preparation methods on gross return, net return and B:C ratio was not significant.

Table 3. Economic analysis as influenced by weed management practices and seedbed preparation methods of DDSR during 2016-2017, Parwanipur, Bara, Nepal

Treatments	Total cost NRs /ha ('000)		Gross return NRs /ha ('000)		Net return NRs /ha ('000)		Benefit cost ratio	
	2016	2017	2016	2017	2016	2017	2016	2017
Weed management practices								
Weed free	67.42	74.51	131.10^{a}	143.8^{a}	63.64^{a}	69.24^{a}	1.94^{c}	1.93^{bc}
Weedy check	46.42	50.51	58.64^{g}	52.07^{f}	12.22^{f}	1.55^{e}	1.26^{e}	1.04^{e}
Pendimethalin (Pend)	51.78	56.40	82.18^{f}	77.38^{e}	30.40^{e}	23.92^{d}	1.58^{d}	1.44^{d}
Sodium Bispyribac (Bispy)	51.16	55.58	98.53^{e}	104.9^{d}	47.37^{d}	49.28^{c}	1.93^{c}	1.89^{c}
Ethoxysulfuron (Ethoxy)	49.43	53.81	97.61^{e}	102.8^{d}	48.19^{d}	48.97^{c}	1.97^{bc}	1.91^{bc}
Pendimethalin *fb* Bispy	56.52	61.47	115.40^{c}	126.6^{b}	58.93^{b}	65.09^{ab}	2.04^{ab}	2.06^{ab}
Pendimethalin *fb* Ethoxy	54.79	59.70	113.30^{c}	119.9^{bc}	58.49^{b}	60.22^{b}	2.07^{ab}	2.01^{abc}
Bispy tank mix with Ethoxy	52.77	57.28	105.80^{d}	115.9^{c}	53.06^{c}	58.61^{b}	2.01^{bc}	2.03^{abc}
Pend *fb* tank mix of Bispy and Ethoxy	58.13	63.17	123.00^{b}	136.3^{a}	64.91^{a}	73.14^{a}	2.12^{a}	2.16^{a}
LSD (P<0.05)			4.38	7.78	4.38	7.79	0.08	0.13
Seedbed preparation methods								
Stale seedbed	57.06	62.16	102.90	109.10	45.88	47.60	1.79	1.75
Normal seedbed	51.48	56.16	102.80	108.60	51.28	52.41	1.98	1.91
LSD (P<0.05)			ns	ns	ns	ns	ns	ns
CV %			7.47	9.19	15.82	20.01	7.84	9.50
Grand mean			102.84	108.83	48.57	50.00	1.88	1.83

Note: *fb- followed by, means followed by the common letter/s within a column not significantly different based on DMRT at P <0.05*

Conclusions

Pendimethalin *fb* tank mixture of Bispyribac sodium and Ethoxysulfuron treated plots recorded highest weed control efficiency and lower weed index with higher values of growth attributes, yield, gross return, net return and B: C ratio other than weed free check treatment in dry direct-seeded rice. The effect of seedbed preparation methods however was not significant.

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Effect of spacing and plant density on yield performance of determinate soybean variety Tarkari Bhatmas-1 under mid hill condition

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Abstract

Field experiments consisting nine spacing: three row to row (inter row: 43 cm, 50 cm and 60 cm) and three plant to plant (intra row: 10 cm, 15 cm and 20 cm) with plant population ranging from 8-23/m^2 were evaluated in randomized complete block design (RCBD) with four replications from 2014-2016 in Agronomy Farm, Lalitpur, Nepal. Seeds were sown on 29 May 2014, 31 May 2015 and 26 May 2016. Chemical fertilizers 30 N:60 P_2O_5:30 K_2O kg/ha were applied as basal dose. Combined analysis showed significant variation in final plant stand, grain yield and numbers of pod/plant amongst different inter row and intra row spacing, while other parameters were not statistically significant. Grain yields were at par at inter row spacing of 43-60 cm and intra row spacing of 10-15 cm (11-23 plants/m^2). Grain yield was reduced by 7-21% when intra row spacing was more than 10 cm, with the greatest reduction in wider intra row spacing of 20 cm. Greater number of pods/plant in wide spacing indicated the ability of soybean to compensate for low plant population to some extent. Plant grew taller in narrow intra row spacing than wider spacing, but seed size was not affected by spacing. Wider intra row spacing was found to have greater influence in term of grain yield than inter row spacing in case of early maturing determinate variety under Khumaltar condition. Inter row spacing of 43-60 cm and intra row spacing of 10-15 cm were found to be optimum for early maturing determinate soybean under Kathmandu valley and similar environments.

Keywords: Determinate, plant density, soybean, spacing, yield

Introduction

Soybean (*Glycine max* L. Merr) is the fifth important grain legume in terms of acreage after lentil, grass pea, pigeon pea and black gram. In 2018/19, soybean was cultivated in 25179 ha with production of 31567 t and productivity of 1254 kg/ha (MoALD, 2020). Soybean is an important summer legume in mid hills and valley which occupies about 80% of total soybean area and production. Some of the major production constraints are mungbean yellow mosaic virus (terai, inner terai), anthracnose, pod blight, bacterial pustule, frog eye leaf spot (mid hill), pod blight, hairy caterpillar, flower drop, micronutrient deficiencies and soil moisture stresses (Shrestha *et al*., 2012). Soybean plays an important role in the hill cropping system, where it is mostly grown in mixture with maize, relay crop in maize or in paddy bund. However, soybean is becoming popular as sole crop in terai and inner terai due to high yield potential and high demand of soya meal in poultry industry. Though globally soybean contributes 25% of the edible oil, and about two-thirds of the world's protein concentrate for livestock feeding (Agarwal *et al*., 2013) soybean is considered as grain legume crop in Nepal as domestic production is consumed either as roasted beans or green pods as vegetables, processed products: tofu, soya milk, nugget or as livestock and poultry feed to some extent.

Nepal Agricultural Research Council (NARC) had released seven soybean varieties (1977-2006) for cultivation in terai and mid hills under sole, bund planting and intercropping with maize. These released varieties are mostly of photosensitive, medium maturity with indeterminate growth habit except Tarkari Bhatmas-1. Best time of sowing Tarkari Bhatmas is third week of Baisakh for seed type and third week of Jestha for fresh pod (AGD, 2019). General recommendation of soybean seed is 60 kg/ha to maintain 400,000 plant population/ha with spacing of 50 cm x 5 cm (Chaudhari, 1984b). Varietal characteristics, planting time and growing environments (temperature, rainfall, soil etc) seems to have profound effect on yield performance of soybean as shown in various research conducted in Nepal and elsewhere. Higher yield of soybean in narrow inter row spacing of 35 cm than wide spacing of 60 cm under Rampur condition might be due to short growing period available under terai condition. Similar yield increase in narrow row spacing in early planted as compared to wider spacing or low plant population had been reported by Matsuo *et al*., (2018) and Staggenborg *et al*., (2008). Intra row spacing of 40 cm gave higher seed yield in Lumle and Pakhribas conditions (LAC, 2039; Kelly, 1977). Extremely low plant population (6/m^2) in wider row spacing 60 cm x 20 cm might have attributed to poor seed yield in Pakhribas condition. In case of tall and late maturing Lumle-1 variety, wider intra row spacing of 20 cm (inter row 50 cm) produced the highest grain yield as compared to farmers practice of random planting and narrow intra row spacing of 10 cm (Chand *et al*., 1993). Optimum soil moisture is required for germination; however, excess soil moisture inhibits seedling emergence, damage to cotyledons, and early determinate variety is more prone to waterlogging that results in retardation of growth and consequently a complete crop failure. Optimum population or plant spacing varied depending upon growing environments, time of planting and varieties. Most of the recommendations on plant spacing made so far were for medium to late maturing indeterminate varieties, therefore early determinate soybean variety Tarkari Bhatmas-1 was evaluated to find out optimum plant population and planting geometry under mid hill condition.

Materials and Methods

Field experiments were conducted to evaluate the optimum plant population in soybean variety Tarkari Bhatmas-1 under upland condition at Khumaltar during 2014 to 2016. Total of nine spacing: three inter row i.e., row to row spacing of 43 cm, 50 cm and 60 cm, and three intra row i.e., plant to plant spacing within a row of 10 cm, 15 cm and 20 cm, with plant population ranging from 80,000 to 3,30,000 per hectare were evaluated in randomized complete block design with four replications (Table 1). Plot size of 4 m x 3 m was used. Chemical fertilizers of 30 N: 60 P_2O_5:30 K_2O kg/ha were applied at the time of land preparation. Sowing was done on 29 May 2014, 31 May 2015 and 26 May 2016. Seeds were treated with Bavistin @ 2 g/kg seed before seeding, while insecticide Furadan granules were applied in open furrow at the time of sowing. Thinning was done to retain single plant per hill after about a month of seeding. Cultural operation such as weeding and earthing up were done when needed. Ten plants were randomly selected for measuring plant height, number of pods/plant, unfilled pods/plant, number of branches/plant, number of seeds/pod at physiological maturity. Final plant stand was counted from inner rows excluding one border row at each side. Grain yield and straw dry matter were recorded from net plot area (excluding 1 border row at each side). Two hundred seeds were counted to estimate 100 seed weight. Grain yield and seed weight were adjusted to 12% moisture content. Subsample straw was oven-dried to estimate straw dry matter yield.

Table 1. Spacing, number of rows per 12 m^2 and plant population used in the experiment

SN	Spacing (cm)		Treatment	Population/ha	No. of rows	Plant stand/m^2
	Row	Plant to plant				
1	43	10	43 cm x 10 cm	2,30000	7	23
2	43	15	43 cm x 15 cm	1,50,000	7	16
3	43	20	43 cm x 20 cm	1,10,000	7	12
4	50	10	50 cm x 10 cm	2,00000	6	20
5	50	15	50 cm x 15 cm	1,30,000	6	13
6	50	20	50 cm x 20 cm	1,00000	6	10
7	60	10	60 cm x 10 cm	1,60,000	5	17
8	60	15	60 cm x 15 cm	1,10,000	5	11
9	60	20	60 cm x 20 cm	80,000	5	8

Weather condition

During cropping season i.e., from third week of June to September mean maximum temperatures were 28.6 ^oC in 2014, 28.8 ^oC in 2015 and 27.9 ^oC in 2016, while mean minimum temperatures were 20.5 ^oC, 19.9 ^oC and 20 ^oC, respectively in 2014, 2015 and 2016 (data not shown). Similarly, total growing period rainfall from seeding to maturity were 678 mm in 2014 (29 May to 19 Sept), 659 mm in 2015 (31 May to 19 Sept) and 813 mm in 2016 (26 May to 16 Sept) (data not presented). Mean minimum temperature was slightly lower while slightly greater mean maximum temperatures were recorded in 2015 as compared to 2014 and 2016 (Figure 1). Total rainfall received from seeding to vegetative stage were 214 mm, 326 mm and 259 mm, respectively in year 2014, 2015 and 2016 (data not shown). Similarly, rainfalls during reproductive stages were 464 mm in 2014, 334 mm in 2015 and 554 mm in 2016.

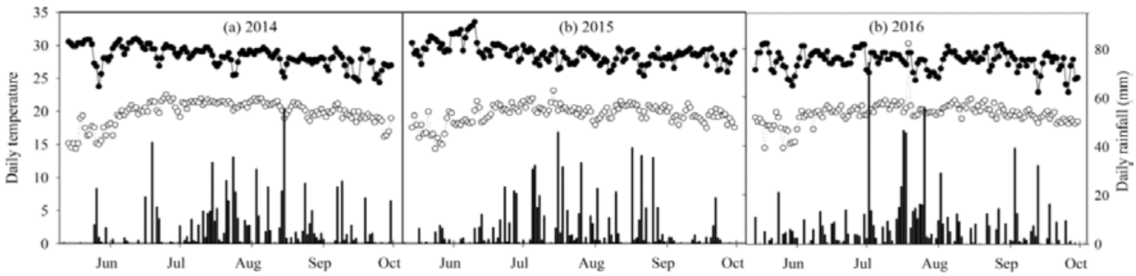

Fig. 1: Daily mean maximum (-●-), minimum (-○-) temperatures and rainfall (solid bar) during soybean growing season in Khumaltar (2014-2016)

Results and discussion

Crops reached 50% flowering and 90% maturity in 50 and 110 days after sowing (data not presented). Plant population at harvest varied significantly in all year, with highest numbers of plants at harvest (16-24/m^2) in narrow spacing of 43-50 cm x 10 cm and the lowest of 9-14/m^2 in wider spacing of 50-60 cm x 20 cm (Table 2). Grain yield did not vary significantly among spacing in 2014 (Table 4) that might be due to relatively higher number of plants at harvest in wider spacing than prescribed. In 2015, mean grain yield was 1991 kg/ha was reported in narrow spacing of 43 cm x 10-15 cm, 50 cm x 10 cm and the lowest of 1516 kg/ha in wider intra row spacing of 20 cm. In 2016, mean grain yield lower in wider spacing of 60 cm x 20 cm than other spacing studied.

Table 2. Plant population at harvest and grain yield as affected by spacing in soybean variety Tarkari Bhatmas-1 at Khumaltar (2014-2016)

SN	Spacing (inter row x intra row)	Plant stand at harvest (m^2)			Grain yield (kg/ha)		
		2014	2015	2016	2014	2015	2016
1.	43 cm x 10 cm	24	16	20	2441	1986	2660
2.	43 cm x 15 cm	19	14	18	2543	1925	2472
3.	43 cm x 20 cm	18	11	15	2483	1522	2525
4.	50 cm x 10 cm	23	17	17	2486	2061	2481
5.	50 cm x 15 cm	18	12	15	2665	1729	2533
6.	50 cm x 20 cm	14	11	14	2153	1546	2840
7.	60 cm x 10 cm	21	12	15	2662	1786	2724
8.	60 cm x 15 cm	17	10	13	2616	1749	2502
9.	60 cm x 20 cm	13	9	12	2473	1480	1704
	Spacing p value	<.001	<.001	0.007	0.118	0.048	0.008
	LSD (<0.05)	5	3	4	-	397	500
	CV (%)	17	16	19	9	16	14

Combine analysis showed non-significant difference in plant height, number of main branches/plant, unfilled pods/plant, 100 seed weight, straw dry matter and harvest index among spacing treatments except pods/plant, final plant stand and grain yield (Figure 3, Tables 3, 4). Spacing x year interaction was significant for grain yield and seed weight (Tables 3, 4). The mean values for final plant stand showed decreasing trends with increasing intra row plant to plant spacing in all three inter row spacing (Figure 2a). Final plant stand ranged from 15-20/m^2 in spacing of 43-60 cm x 10 cm and spacing of 43-50 cm x 15 cm as compared to wider spacing of 50-60 cm x 20 cm (11-13/m^2).

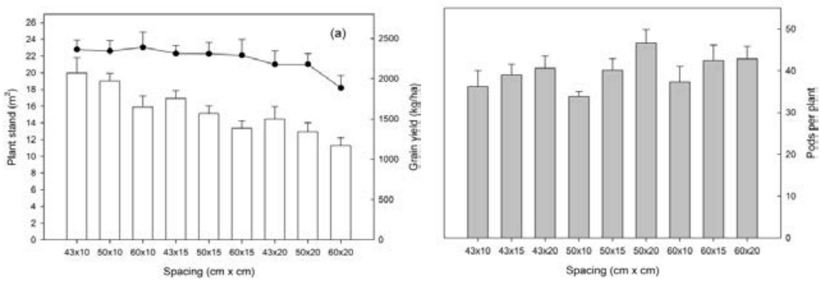

Fig. 2: (a) Mean plant stand at harvest (open bar), grain yield (-●-), and (b) pods/plant of soybean variety Tarkari Bhatmas-1 as affected by inter and intra row spacing at Khumaltar (2014-16)

Plants grew taller in narrow intra row spacing of 10-15 cm as compared to wider intra row spacing of 20 cm (Table 3). Number of pods/plant was higher in wider intra row spacing of 15-20 cm, while narrow intra row spacing of 10 cm had comparatively low pods (Figure 2b). There was a general trend of decrease in plant height with increasing intra row spacing, while higher number of pods/plant with increasing intra row spacing. Mean number main branches/plant, unfilled pods/plant, 100 seed weight and HI ranged from 2-3 4-6, 22.2 g and 0.43, respectively among various spacing. Minimum straw dry matter production in wider spacing of 60 cm x 20 cm (2221 kg/ha) and the maximum in narrow spacing of 43 cm x 10 cm (2783 kg/ha) might be related to plant stand and plant height. Grain yield was significantly low in wider intra row spacing of 20 cm only (Figure 2a). In early maturing short statured determinate variety, plant density of 15-20/m^2 with the best arrangement inter row spacing of 43-60 cm and intra row spacing of 10-15 cm was found to be optimum in terms of grain yield production than wider intra row spacing of 20 cm where plant population was less than 11/m^2. Plant population did not have any influence on plant height, number of main branches/plant, unfilled pods/plant, 100 seed weight, straw dry matter and harvest index might be due to determinate growth habit and short growing season. However, soybean showed greater plasticity or has capacity to attain grain yield in lowest plant population as low plant density was often compensated by increased number of primary and secondary branches (Carpenter and Board, 1997; Subedi *et al*., 1992 and Enyi, 1973), greater number of filled and total pods/plant (Subedi *et al*., 1992 and Enyi, 1973). Weber *et al*., (1966) reported more severe plant competition at higher plant densities and hence taller plants, few branches, lodged more, and set fewer pods and seed thus low seed yield as compared to lower densities.

Table 3. Yield and yield parameters of soybean variety Tarkari Bhatmas-1 in Khumaltar (2014-2016)

SN	Treatments	Plant height (cm)	Unfill pods/plant	100 seed weight (g)	Straw dry matter (kg/ha)	HI
	Spacing (S)					
1.	43 cm x 10 cm	51	5	22.3	2783	0.43
2.	43 cm x 15 cm	50	5	22.1	2663	0.43
3.	43 cm x 20 cm	47	6	22.3	2659	0.41
4.	50 cm x 10 cm	50	5	22.7	2595	0.44

SN	Treatments	Plant height (cm)	Unfill pods/plant	100 seed weight (g)	Straw dry matter (kg/ha)	HI
5.	50 cm x 15 cm	49	5	22.4	2645	0.43
6.	50 cm x 20 cm	47	6	21.9	2732	0.41
7.	60 cm x 10 cm	51	4	22.4	2645	0.44
8.	60 cm x 15 cm	45	6	22.0	2521	0.45
9.	60 cm x 20 cm	47	5	22.1	2221	0.43
	Mean	49	5	22.2	2607	0.43
	Year					
1.	2014	51	4	23.3	2959	0.43
2.	2015	43	6	20.7	2136	0.42
3.	2016	51	6	22.7	2727	0.45
	Spacing (S) - p value	0.420	0.220	0.436	0.117	0.22
	LSD (<0.05)	-	-	-	-	-
	Year (Y) - p value	<.001	<.001	<.001	<.001	0.004
	LSD (<0.05)	3.4	0.8	0.38	204	0.02
	S*Y - p value	0.993	0.799	0.011	0.473	0.853
	LSD (<0.05)	-	-	1.15	-	-
	CV (%)	15	33	4	17	9

There was a positive correlation of plant population with plant height (r^2=0.32**), grain yield (r^2=0.35**), seed weight (r^2=0.24**) and straw dry matter (r^2=0.36**), but negative with numbers of pods (r^2=-0.21**), unfilled pods (r^2=-0.17**) and number of main branches (r^2=-0.18**). However, Enyi (1973) reported decreased total dry matter/plant, number of nodes/plant, number of pods/plant and number of branches/plant in soybean var. 3H55F4/149/1 with increasing plant population from 7 to 44/m^2. Low light intensity under the plant may lead to a reduction in the number of side branches, number of pods/plant and number of nodes with pods (Enyi, 1973). There was a significant variation in parameters recorded among years (Table 3) while spacing x year interaction was significant for maturity days, grain yield and seed size (Tables 4). In 2015, crop grew shorter, matured early, reduce grain yield by 42% and seed size by 10-13% as compared to year 2014, 2016 (Table 4). In year 2015, total rainfall received from seeding to vegetative period was 20-34% greater than the rainfall received during the same period in 2014 and 2016. On the other hand, reproductive period was much drier in 2015 as indicated by 39-66% less rainfall stage as compared to 2014 and 2016. In 2015, excess soil moisture during early growth period might have resulted in low plant density, while soil moisture deficits during reproductive period might have contributed to poor growth, early maturity, lighter seed weight and low dry matter production than 2014 and 2016.

Table 4. Yield and yield parameters of soybean variety Tarkari Bhatmas-1 at Khumaltar

Year	Final stand (m^2)	Flowering days	Maturity days	Main branch/ plant	Seeds /pod	Pods/ plant	Grain yield (kg/ha)
2014	19	50	110	2	2.0	35	2503
2015	12	51	108	2	2.0	38	1754
2016	15	49	113	3	2.4	46	2493
Mean	15	50	110	2	2.1	40	2250
Spacing (S) - p value	<.001	0.976	0.002	0.137	0.573	0.043	0.007
LSD (P<0.05)	2	-	0.57	-	-	7.4	256.3
Year (Y) - p	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Year	Final stand (m^2)	Flowering days	Maturity days	Main branch/ plant	Seeds /pod	Pods/ plant	Grain yield (kg/ha)
value							
LSD (P<0.05)	1.3	0.5	0.3	0.3	0.05	4.3	148
S x Y - p value	0.866	0.848	<.001	0.604	0.641	0.878	0.024
LSD (P<0.05)	-	-	0.3	-	-	-	420.9
CV (%)	18	2	1	29	5	23	14

Conclusion

In soybean, varietal traits, planting time, soil type and growing season temperatures and rainfall determine the success of the crop. In photo insensitive determinate variety Tarkari Bhatmas-1, intra row spacing of 43-60 cm and intra plant spacing of 10-15 cm was with plant density of 11-23/m^2 was found optimum in terms of grain yield under Kathmandu valley and similar environments. Intra row spacing seems to be more critical as compared to inter row spacing as intra row spacing of greater than 15 cm drastically reduced plant density and thus significant reduction in grain yield. Greater number of pods/plant were recorded when intra row spacing increased from 10 cm to 15 cm thereby compensating for low plant population.

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Weed management in groundnut (*Arachis hypogaea* L.) at Nawalpur condition in Sarlahi, Nepal

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Abstract

Groundnut is one of the important summer oilseed crops of Nepal. The area under this crop has decreased considerably in the recent decade due to its high cost of cultivation for weeding and increased labor charge. Crop compete with the repeated flush of diverse weed throughout the growing season which causes substantial yield loss up to 50 -70 %. So, to find out an effective treatment for weed management, an experiment was conducted during 2017 and 2018 with nine treatments laid out in randomized complete block design (RCBD) in three replications. Treatments were constituted by four herbicides, two pre-emergence (pendimethalin and metribuzin) and two post emergences (quizalofop and propaquizafop). Pre emergence herbicide was followed by *(fb)* by hand weeding (HW) in one treatment and by the post emergence herbicides in another treatment. Cover mulch treatment with groundnut pods shell @ 3.0 t/ha was used. Farmer's practice treatment consists of one hand weeding and one intercultural operation while no weeded plot was kept as control treatment. Data on weed dynamics, yield attributes and seed yield were varied among the treatments. Pre emergence herbicide supplemented by one hand weeding proved highly effective in controlling weeds. Pendimethalin @ 1.0 kg a.i/ha *fb* one HW showed superior performance in yield attributes, a high percentage (83.0%) of weed control efficiency (WCE), highest grain yield (2005 kg/ha), high benefits (NRs 222450) and BC ratio 2.84 among the treatments. The treatment metribuzin @ 0.5 kg a.i/ha *fb* one HW was also found as second best treatment with 74.4 % of WCE, yield (1882 kg/ha), benefits of Rs 205060 and BC ratio 2.65.

Keywords: Groundnut, metribuzin, pendimethalin, propaqizalfop, quizaloflop-ethyl, WCE

Introduction

Groundnut (*Arachis hypogaea* L.) or peanuts is one of the major edible oilseed crops cultivated extensively in the world. It is called the king of the oilseeds and is often known as wonder nut and poor men's cashew nut. (Aruna and Sagar, 2018). Groundnut is one of the important summer oilseed crops in Nepal. It is cultivated in 3342 ha with production and productivity of 4,999 mt., and 1,496 kg, respectively (MOALD, 2020). It is one of the important food legume crops of Nepal. It contains 48-50 % oil and 26-28 % protein and rich in fibres, minerals and vitamins. The area under this crop in the nineties was around 10000 ha and decreased in the recent decade due to the high cost of cultivation for weeding and high labor charge (ORP, 2016). Groundnut like in other summer crops is heavily infested with weeds. It is the major constraints that limit the productivity of groundnut. This crop is confronted with the repeated flush of diverse broad-leaved, grassy and sedges throughout the growing season which cause substantial yield loss up to 50 -70 % (Ranjit and Koirala, 1990) and 15-75% (Jat *et al*., 2011). One hand weeding was not sufficient to increase the pod yield of groundnut. It was found that weeding after 40-60 days of weed competition will reduce yield. And weeding after 80 days of crop weed competition has no value and comparable to not weeded check. Combinations of cultural, mechanical and chemical methods of weed management give higher weed control efficiency and economic benefits than that of any individual method. (Jat *et al.*, 2011). During the peak season, it is very difficult to weed groundnut. In such a period, the use of herbicides becomes effective to control weeds. Several studies have reported the effective control of weeds in groundnut with the use of herbicides. Yadav *et al*., (1983) reported Fluochlorain 1.0–1.5 kg/ha, oxyflourfen 0.1-0.2 kg/ha and Pendimethalin 1.0- 1.5 kg/ha gave significantly more yield than the weedy check treatment. Pre emergence herbicide pendimethalin (Patel *et al*., 2013) and post-emergence herbicides quizalofop-ethyl (Samant and Mishra, 2014) was found effective to control weeds in groundnut. Pendimethalin controls weed from emerging, particularly during the early crucial development phase of the crop (Kaur *et al*., 2014). Quizalofop-ethyl effectively manages narrow leaf weeds in broad-leaved crops. The experiments were set up to evaluate the promising herbicides for effective weed management, to increase yield and to produce higher benefits.

Materials and Methods

The field experiment was conducted during the summer season of 2017 and 2018 at the experimental field of the oilseed research program, Nawalpur, Sarlahi. The site is geographically located at latitude 27° 03ʹ86ʺ N, longitude 85° 35ʻ52ʺ E and altitude 144 m. The soil of the field was sandy loam with a soil pH of 5.3. The experiment consists of 9 treatments with four herbicides, one cover mulch and weedy check. The treatment were; T1) Pendimethalin @1.0 kg a.i/ha followed by (*fb*) one Hand weeding (HW), T2) Metribuzin @ 0.5 kg a.i/ha *fb* one HW, T3) Propaquizafop @ 100 g a.i/ha at 20-25 DAS, T4) Quizaloflop-ethyl @ 100 g a. i /ha at 20-25 DAS, T5) Pendimethalin *fb* T3, T6) Pendimethalin *fb* T4, T7) Cover mulch (groundnuts pod shell) @ 3.0 t/ha, T8) Farmers practice (1-Hand weeding + 1-intercultural operation), and T9) Control (not weeded). The experiment was carried out in randomized complete block design (RCBD) with four replications. Plot size was 2.5 m x 4 m (10 m^2) and spacing of 10 cm (plant-plant) x 30 cm (row–row). Pre-release variety, ICGV-07240 (now released as *Sambridhi* was sown manually in line. Sowing of groundnut was carried out on 23 July 2017 and 7 July 2018. Herbicides were applied using Knapsack sprayer using a flat fan nozzle. Groundnut shell was used for cover mulch was applied on the same day after the crop was sown at the rate of 1.75 t/ha. Fertilizers dose of 20:40:20 $N:P_2O_5:K_2O$ kg/ha were applied. Others agronomic practices were carried out during the crop season. Plant height was measured from 10 random plants at maturity. Crop stand was recorded from one running meter at 60 days after sowing (DAS) after the herbicidal effect of all herbicides treatments was observed. Weed data was recorded from the 0.5 m^2 quadrant at 60 DAS. Weed dry weight was measured after oven-dried at 70°C for 72 hours. Weed control efficiency (WCE) was calculated using the formula.

$$\text{WCE \%} = \frac{\text{Weed count in the not weeded plot} - \text{weed count in treated plot}}{\text{weed count in not weeded plot}} \times 100$$

The crop was harvested from the net plot of 6 m^2 and computed into a hectare. For the calculation of economics, total costs (variable and fixed costs) were calculated based on the prevailing prices of all the inputs. Gross return was derived by multiplying the yield by the existing market price (Rs 150). Benefits obtained after deduction of the total cost incurred from gross returns. And benefit-cost ratio obtained by dividing the benefits by the total cost of the individual treatments. Data were analyzed using Excel 2013 and software STAR (Statistical Tool for Agricultural Research).

Results and Discussions

Effect on crop stand

The highest crop count (5.4 and 10.1) was recorded in the treatment Pendimethalin *fb* one HW (T1) in 2017 and the farmers' practice (T8) in 2018 while the lowest (3.6 and 6.1) was found in the treatment cover mulch (T6) and not weeded control in 2017 and 2018, respectively. The treatments mean was insignificantly different. Although there is the effect of treatment on crop stand however the difference is not significant. Covering of soil surface due to groundnut shell do not favor germination of all seeds in cover mulch treatment and by the suppression of germinated crops by the emerged weeds in the unweeded control treatment reduced the crop stand in these treatments. The high crop stands in weed control treatment might be due to the existence of minimum competition between weeds and crops for available resources such as light, space, nutrients and moisture. Effective control of weed in weed control treatment due to herbicides render good growth and crop stand was reported by Singh and Giri, (2001).

Effect on weed dynamics

Weed density/m^2 vary among the different weed control treatments. Fewer weeds were observed in the herbicides sprayed plot than in the control. Weed ranged found from 15.3 to 107.3 weeds/m^2 in 2017 and

13.0–70 weeds/m^2 in 2018. The lowest number of weeds (21.3 and 13) weeds/m^2 was recorded in Pendimethalin *fb* one HW in 2017 and 2018 respectively. Similarly, metribuzin *fb* one HW also recorded less number of weeds and the mean difference is par with Pendimethalin *fb* one HW. The highest numbers of weeds 107.3 and 70.3 were found in the control (not weeded plot). Propaquizafop and Quizaloflop applied plots also recorded higher number of weed revealing these two post emergence herbicides did not affect weeds in such conditions. Farmers practice plots recorded comparatively less weed than the control. Treatments mean difference is statistically significant. Reduction in weed numbers by applying pendimethalin and one hand weeding was reported by Praveen *et al.,* (2019). Application of pendimethalin at 1.5 kg/ha as pre-emergence effectively controlled both broad-leaved and grassy weeds compared to the unweeded check was also observed by Aruna and Sagar (2018). Similarly, the use of pre emergence herbicide Fluchloralin and pendimethalin @ 1.5 kg/ha was found effective in controlling weeds in groundnut was reported by Jat *et al.,* (2011).

Table 1. Weed density, weed dry weight and weed control efficiency of groundnut as influenced by weed management practices in Sarlahi, **Nepal**

Treatment	Weed density/0.5/m^2		Weed dry weight (g/0.5/m^2)		WCE (%)		
	2017	2018	2017	2018	2017	2018	Mean
1.Pendimethalin *fb* one HW	3.8 (15.3)	3.6 (13)	3.8 (3.0)	4.4 (3.5)	84.26	81.68	83.0
2.Metribuzin *fb* one HW	4.6 (21.6)	4.5 (21.0)	4.6 (4.3)	4.5 (6.1)	79.67	69.09	74.4
3.Propaquizafop	6.7 (44.6)	5.8 (33.6)	6.7 (8.9)	5.8 (12.7)	57.29	51.29	54.3
4.Quizaloflop ethyl	7.5 (57.0)	5.0 (26.3)	7.5 (11.4)	5.0 (8.7)	44.14	62.89	53.5
5.Pendimethalin *fb* T3	6.5 (42.0)	5.0 (24.6)	6.5 (8.4)	5.0 (8.0)	60.11	64.61	62.4
6.Pendimethalin *fb* T4	7.0 (48.6)	4.4 (21.3)	7.0 (9.7)	3.6 (2.8)	53.36	68.62	61.0
7.Cover mulch	7.2 (52.6)	5.1 (25.0)	7.2 (10.5)	5.1 (18.1)	48.26	64.60	56.4
8.Farmers practice	6.3 (38.6)	4.8 (22.6)	6.3 (7.7)	4.8 (6.4)	62.50	67.48	65.0
9.Control	10.3(107.3)	8.4 (70.3)	10.3(21.4)	8.4 (22.0)	-	-	-
Grand mean	6.7	5.2	6.7	5.2	61.20	66.28	
LSD (P<0.05)	2.5	3.4	2.5	3.4	27	43.8	
CV, %	13.7	22.5	13.1	22.5	15.32	23.95	

Note: *Figures in parentheses indicate original values, data subject to square root transformation (SQRT(x+1); Fb =followed by*

Weed dry weight

Less weed dry weight was recorded in the herbicides applied plots compared to control. Pendimethalin *fb* one HW recorded the lowest weed dry weight of 3.8 and 3.6 g in 2017 and 2018. Metribuzin *fb* one HW also recorded considerably less dry weight. Whereas, the highest weed dry weight of 10.3 and 8.4 g was found in unweeded control in the respective years. Similar to weed density the post emergence herbicides Propaquizafop and Quizaloflop applied plots also measured high weed dry weight.There was significant difference among the different treatments whereas the mean difference between Pendimethalin fb one HW and Metribuzin *fb* one HW were at par. Reduced weed dry weight was also observed by Ranjit and Sharma (1986) in herbicides applied compared to control. Parwar *et al.,* (1988) also reported integrated use of manual weeding with chemical reduced weed dry weight significantly than hand weeding alone.

Weed control efficiency

The highest weed control efficiency (WCE) was recorded in the pendimethalin *fb* one HW compared with other treatments. Metribuzin *fb* one HW and farmers practice treatments also showed a higher value of WCE. WCE % of 81.26 % (2017) and 81.68 % (2018) was found in pendimethalin *fb* one HW. The treatment mean differences of WCE % in treatment pendimethalin *fb* one HW, Metribuzin *fb* one HW and farmers practice were at par. The lowest WCE was observed in Quizaloflop ethyl (44.4 %) in 2017 and Propaquizafop (51.2 %) in 2018 (table 1).

Yield attributes and yield

Pods/plant: The highest numbers of pods per plant were recorded in the treatment Farmers practice and in metribuzin *fb* one HW in 2017 and 2018 respectively (Table 2). The numbers of pods per plant ranged from 12 – 27 (2017) and 15-47 (2018). The mean treatment difference among the treatments Pendimethalin *fb* one HW (T), Metribuzin *fb* one HW (T2) and Farmers practice (T8) were at par. Increased pods number due to integration of pendimethalin with hand weeding was also reported by Patra and Naik, (2001) and Aruna and Sagar, (2018).

Shelling

The shelling percentage of the different treatments ranged from 73.6-78.6 % (2017) and 73-76.6 % (2018). The highest value of shelling % was observed in the treatment farmers practice (T8) in 2017 and in Pendimethalin *fb* one HW (T1) in 2018.The treatments mean difference was significant only in 2017.

Table 2. Crop stand and yield attributes in groundnut as influenced by weed management practices, Sarlahi Nepal

Treatment	Crop stand /m		Pods/plant		Percentage of Shelling		100 grain weight (g)	
	2017	2018	2017	2018	2017	2018	2017	2018
1.Pendimethalin *fb* one HW	5.4	9.6	23	32	78.3	76.6	51.6	51.0
2.Metribuzin *fb* one HW	4.6	6.4	22	47	77.3	73.3	43.0	50.0
3.Propaquizafop	4.0	6.9	14	24	76.0	73.4	47.3	50.0
4.Quizaloflop ethyl	4.0	6.5	14	18	74.6	73.3	49.0	49.0
5.Pendimethalin *fb* T3	5.3	6.9	16	20	75.0	76.5	49.0	50.0
6.Pendimethalin *fb* T4	4.6	7.8	17	24	75.0	73.0	43.0	50.0
7.Cover mulch	3.6	6.6	21	16	76.0	73.3	50.0	50.0
8.Farmers practice	4.6	10.1	27	24	78.6	73.3	44.0	50.0
9.Control	4.6	6.1	12	15	73.6	73.0	42.6	46.6
Grand mean	5.5	7.4	18.5	24.7	76.0	74.04	46.6	49.6
LSD (P<0.05)	ns	ns	7.7	14.7	2.6	ns	0.04	ns
CV %	17.1	25.1	24.2	34.3	2.08	7.5	7.9	3.8

Note: *fb =followed by, ns; nonsignificant*

Hundred seed weight

The 100 grain weight ranged from 42.6 -51.6 g and 46.6 -51.0 g in 2017 and 2018.The highest grain weight was measured in Pendimethalin *fb* one HW whereas the lowest value was found in control. The mean difference was significant in 2017 only.

Grain yield

The grain yield of the different treatments range from 0.39 -1.34 t/ha (2017) and 0.79 -2.00 t/ha (2018) and the treatments mean are significantly different (table 3). The highest mean grain yield of 2.01 tones was recorded in the pre-emergence application of herbicide Pendimethalin *fb* one HW and the second-highest (1.88 t/ha) yield was obtained in pre-emergence application of herbicide metribuzin *fb* one HW. The grain yield of these two treatments is statistically at par. The lowest yield was recorded in control (1.38 t/ha). The grain yield in 2017 was comparatively lower than in 2018 due to late sowing and heavy rainfall at the crop branching stage in 2017. Meteorological data could't be presented due to the dysfunctional of the Met station of the Oilseed Research Program. The highest yield in the herbicides supplemented by one hand weeding treatment viz., Pendimethalin *fb* one HW and metribuzin *fb* one HW might be due to the weed-free environment which facilitated crop for better peg initiation and development at the critical growth stages of groundnut which tends to increase the number of pods and yield. A similar, finding was also observed by Kumari *et al*., (2020).

Effect on Economics

The total costs of the different experimented treatments ranged from Nepali Rupees (NRs 55000 – 95000. The highest total cost was calculated in the treatment Farmers practice while the lowest was found in control. The total benefits derived in the different treatments ranged from NRs 63800 - 222450 with the highest benefits in Pendimethalin *fb* one HW and the lowest in control (Table 3). The benefit-cost ratio ranged from 1.16 -2.84 and similarly, the highest BC ratio was obtained in Pendimethalin *fb* one HW and the lowest in unweeded control. Similarly, higher benefits and benefit-cost ratio was also reported by Rao *et al*., (2011) by using pre-emergence herbicides in groundnut.

Table 3. Grain yield and economics of groundnut as influenced by weed management practices, Sarlahi, Nepal

Treatment	Grain yield (t/ha)			Total cost (NRs)	Total Benefits (NRS)	B:C ratio
	2017	2018	Mean			
1.Pendimethalin *fb* one HW	1.34	2.67	2.01	78300	222450	2.84
2.Metribuzin *fb* one HW	1.33	2.43	1.88	77240	205060	2.65
3.Propaquizafop	0.78	1.63	1.21	58500	122250	2.09
4.Quizaloflop ethyl	0.64	1.43	1.04	61592	94108	1.53
5.Pendimethalin *fb* T3	0.92	1.80	1.36	61800	142050	2.30
6.Pendimethalin *fb* T4	0.75	2.07	1.41	64892	146008	2.25
7.Cover mulch	0.99	1.27	1.13	61000	108200	1.77
8.Farmers practice	1.09	2.13	1.61	95000	146500	1.54
9.Control	0.39	1.19	0.79	55000	63800	1.16
Grand mean	0.91	1.85	1.38	68147	138936	2.02
LSD (P<0.05)	0.47	0.85		-	-	-
CV %	30	26		-	-	-

Note: *fb =followed by*

Conclusion

Application of pre emergence herbicides follow by or supplemented by one hand weeding proved effective in controlling all types of weeds and increasing yield of ground nut in the experiment. Post emergence herbicides quizalofop and propaqizafop applied alone or after the pre emergence herbicides exhibit poor control of weeds and yield in sandy loam soil conditions in low soil pH. Pendimethalin @1.0 kg a.i/ha *fb* one HW was effective in controlling weeds and resulted in high yield and economics. Alternatively, application of metribuzin @ 0.5 kg a.i/ha *fb* one HW also found effective in weed management, higher yield and economics

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Effect of tillage method, crop residue and nutrient management on growth and yield of wheat in rice-wheat cropping system at Bhairahawa condition

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Abstract

Wheat (*Triticum aestivum* L), grown under traditional practices becoming less productive and less profitable in Nepal, due to ever-increasing input prices and intensive land preparation. A field experiment was conducted to find alternate practices for enhancing productivity of wheat at the National Wheat Research Program, Bhairahawa during the winter season of 2018/19 and 2019/20. The experiment plot was designed on strip-split plot design with 3 replications. Three tillage methods, surface seeding (SS), zero tillage (ZT), and conventional tillage (CT) were assigned in vertical strips with two levels of crop residue management: residue removed (R_0) and residue retention (R_{50}) in horizontal blocks, whereas three levels of nutrient management: recommended dose of NPK (F100), 25% higher dose of NPK (F125) and farmer's practice (FP) were assigned in subplots. Data regarding growth, yield attributes, and yield were recorded and analyzed by Genstat. In the first year, ZT was better in terms of number of tillers at maximum tillering stage, maximum leaf area index, effective tiller per square meter, number of grain per spike, and straw yield compared to SS and CT; whereas in the second year SS was better in terms of growth, yield attributes and yield as compared to ZT and CT. In the first year, $R_{(0)}$ produced significantly higher straw yield but significantly lower harvest index (HI) than $R_{(50)}$ whereas in second year $R_{(50)}$ produced significantly higher thousand grain weight, grain yield and HI. The application of 25% more nutrients than the recommended dose resulted significantly better most of the growth, yield attributes, and yield during both years. On the average of two years, ZT produced more yield than CT and SS by 26.6% and 3.0% respectively. The short term ZT significantly increased the bulk density as compared to SS and CT. Based on the research results, it can be suggested that the traditional practices of wheat can be replaced by ZT with retention of previous crop residues and the application of 25% more nutrients than the recommended dose.

Keywords: Conventional tillage, residue retention, surface seeding, zero tillage

Introduction

Wheat is the third most important crop after rice and maize in Nepal, covering 0.73 million hactares area with production of 1.88 million tons and productivity of 2.55 t/ha (MOAD, 2017). About 57% of the wheat area is concentrated in terai, where wheat is mostly grown after puddled transplanted rice. Traditionally wheat is grown after clean intensive tillage to create a friable seedbed that leads to a long turnround period resulting in delayed wheat planting (Tripathi *et al*., 2005), loss of nutrients (Dobermann and Fairhurst, 2002), green house gas (GHG) emission (Gupta *et al*., 2004) and environmental pollution. The major reasons for the low productivity of wheat are delay in sowing, deterioration of soil physical structure due to intensive tillage, depleted soil fertility, and imbalanced use of nutrition (Aslam *et al*., 1989). Furthermore, labour scarcity and high cost of inputs (fuel, fertilizer, and machinery) make wheat production less profitable (Tripathi *et al*., 2003). Decreasing soil productivity and profitability are the fundamental causes of unsustainable wheat production in Nepal. There are several improved management practices developed under the frameworks of conservation agriculture (CA) like, zero- or minimum-tillage in wheat, residue management that improved the water, and nutrient use efficiency, maximize the yields, increase profitability, conserve the natural resource base, and reduce risk due to both environmental and economic factors (Gathala *et al*., 2013; Ladha *et al*., 2016). However, many researchers had reported the superiority of conventional practices of wheat over conservation practices

(Alsayim *et al*., 2018; Leghari *et al*., 2015; Surin *et al*., 2013; Shahzad *et al*., 2016; Mandal *et al*., 2018). Franchini *et al*., (2012) reported that wheat yield was not influenced by tillage systems. Also, there are so many evidences of getting better results of wheat under conservation agriculture practices over conventional practices (Mohammad *et al*., 2012; Veettil and Krishna, 2012; Aziz *et al*., 2012; Ali *et al*., 2016; Kahlon and Dhingra, 2019; Zamir *et al*., 2010; Ali *et al*., 2013). The past research results varied with ecological and agronomic management practices, although the same practices may not be applicable in all wheat growing ecologies. There is a need to develop crop-specific resource conservation production practices for each agro-ecological zone (Lafond *et al*., 1996). In Nepal, the adoption of CA is in the primary stage and its expansion requires intensive efforts to develop solid CA-based technologies with full package of practices. Thus the present study was designed to evaluate the effect of tillage methods, crop residue, and nutrient management practices on the growth and yield of wheat in the rice-wheat cropping system at Bhairahawa, Rupandehi, Nepal.

Materials and Methods

Experimental site

The two-year experiment was conducted at the National Wheat Research Program (NWRP), Bhairahawa, Rupandehi, Nepal during the winter season of 2018/19 and 2019/20. Geographically this research station is located at 27^0 32’ north latitude and $83^0$25’ east longitudes with the elevation of 104 masl, which lies in the western Terai of Nepal. The climate is of sub-tropical type with three distinct seasons: summer, rainy, and winter. The soil texture of the experiment site (15 cm depth) was ‘Silty Clay Loam’ (sand 15%, Silt 52%, clay 33%). The soil was medium in organic matter (3.5%), Total Nitrogen (0.14%), and available P_2O_5 (32.9 mg/kg) and low in available K_2O (54.5 mg/kg). The soil pH was slightly alkaline (7.7).

Experimental details

The treatments included factorial combinations of three tillage methods, (a) surface seeding (SS), (b) zero tillage (ZT), and (c) conventional tillage (CT); and two levels of residue management (R_0: Residue removed, and R_{50}: 50% residue retention of previous rice crop, arranged in strip plots, three fertilizers levels (F100: recommended dose of fertilizer i.e. 100:50:50 N:P_2O_5:K_2O kg/ha F125: 25% higher than recommended dose; and FP: Farmer’s practice i.e. 80:40:15 N:P_2O_5:K_2O kg/ha) in sub-sub plots and were arranged in a strip-split plot design with three replications. To identify farmer’s practice dose, a farmer’s field survey was conducted in Rupandehi district, 30 farmers were randomly selected who had once adopted zero tillage in wheat. Based on their information an average NPK dose was calculated. In 2018/19, surface seeded wheat was broadcasted and zero tilled wheat was sown on line manually as like zero-till machine on 24th November and conventionally tilled wheat was also sown in the line by making a narrow furrow in prepared soil by plowing and planking on 30th November whereas in 2019/20, SS, ZT and CT all were sown on 7th December. A newly released variety ‘BL 4341’ was used in this experiment and sown with a seed rate of 120 kg/ha for ZT and CT and 150 kg/ha for SS. All the other required agronomic practices were followed uniformly in all the plots throughout the growing period. [In NWRP condition, there is no significant difference in yield of wheat sown from 10th November to 10th December since last 5 years.]

Measurements

The days required for heading and maturity were recorded when 50% of plants got heading and maturity. The plant height was taken from randomly selected and marked ten plants at harvest. Similarly, the number of tillers was counted from a specific row of 4m length and converted later into the number of tillers per square meter. Destructive plant samples were taken from 25cm row length (area of 0.05 m^2) for the estimation of leaf area index and above-ground dry matter. Dry matter was determined by drying the samples at a temperature of 70 ^oC in a hot air oven for 72 hours and weighed and expressed in g/m^2. The leaf area was recorded from the automatic leaf area meter, and the leaf area index was calculated as dividing the leaf area by ground area. The grain yield and straw yield was taken from the net harvested area of 8.0 m^2. Seed moisture was taken by using a seed moisture meter for yield correction at 12% moisture level. The harvest index was calculated from grain yield and biological yield at 0% moisture. Twenty spikes from each plot were randomly taken and the number of total spikelets and the number of total seed per spike were counted manually based on which sterility percentage was calculated.

Data analysis: Data were put on a Microsoft Excel sheet and analyzed by using the computer software' Genstat' 18th edition.

Results and Discussions

Days to heading and days to maturity

In 2018/19, the days to 50% heading were significantly affected by tillage methods (Figure 1). The longest days to heading was found on the CT plots (93 days) which was statistically at par with SS plots, where ZT had significantly shorter days to heading (86) than both CT and SS plots. Significantly longer days to heading (92 days) was found in residue retention (R_{50}) plots as compared to residue removed plots. But there was no significant effect of nutrient management for days to 50% heading. The days to maturity was also significantly affected by tillage methods. The longest days to maturity (106 days) was found with CT plots, followed by SS (104 days) and ZT (101 days). The residue and nutrient management had no significant effect on days to maturity. In 2019/20, days to 50% heading and physiological maturity were significantly affected by tillage methods only. The longer days to heading (94 days) was recorded in CT plots which found significantly longer than ZT (92 days) and SS plots (90 days), where, ZT plots have significantly longer days to heading than SS plots. Similarly, the longest days to maturity (123 days) was recorded in CT plots which remained significantly longer than ZT and SS plots, where, ZT and SS plots were statistically at par with each other.

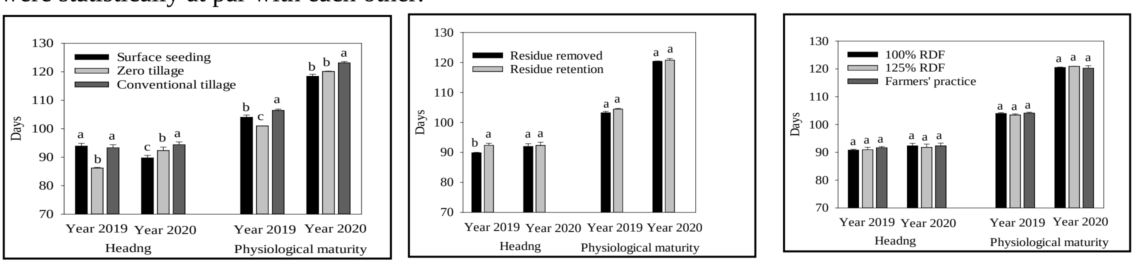

Fig. 1: Days to fifty percent heading and physiological maturity as influenced by the establishment methods, residue and nutrient management practices of wheat in the rice-wheat system at Bhairahawa, Rupendehi, 2019-2020

Biometric characteristics

Plant height

In 2019, the final plant height was significantly affected by nutrient management where the tillage method and residue management had no significant effect (Table 1). But in 2020, the tillage method and nutrient management had significant effect on the plant height, where residue management had no significant effect. The SS and ZT plots produced significantly taller plants than CT plots. F100 and F125 fertilizer levels produced significantly taller plants than FP treatment, where F100 and F125 were statistically similar. Zamir *et al.*, (2010) found significantly increased plant height in ZT than CT. This might be due to higher organic matter contents in ZT which directly affected the vegetative growth of wheat. Similar results were found by (Kahlon and Dhingra, 2019) and (Ali *et al*., 2013). Alsayim *et al*., (2018), De Vita *et al*., (2007) and Bartaula *et al*., (2019) found no significant difference in plant height due to tillage treatments. Bartaula *et al*., (2019) recorded the highest plant height at 125 N kg/ha as compared to 100, 75, and 50 N kg/ha.

Number of tillers per square meter at maximum tillering stage

The maximum number of tillers was observerd at 60 days after sowing in both years. Tillage method and nutrient management had a significant effect on the number of tillers per square meter, whereas the effect of residue management had no significant effect in both years. In 2019, the highest number of tillers per square meter was produced by ZT plots followed by CT and SS, where ZT and CT were statistically at par with each other and the SS plots produced significantly fewer numbers of tillers than ZT and CT plots. But in 2020, significantly higher number of tillers per square meter was recorded in the surface seeding. The higher dose of nutrients F125 produced the maximum number of tillers per square meter, which is significantly higher than FP in 2019, and FP and F100 in 2020 (Table 1).

Leaf area index

The maximum leaf area index (LAI) was found highest at 75 days after sowing in both years. Tillage methods and nutrient management had a significant effect on maximum LAI, whereas residue management had no significant effect (Table 1). In 2019, ZT produced significantly higher LAI than CT, and CT produced significantly higher LAI than SS (Table 1). This result was in contrast with (Shahzad *et al.,* 2016), where they found low LAI in ZT wheat as compared to CT.

Table 1. Growth parameters as influenced by the establishment methods, residue and nutrient management practices of wheat in rice-wheat system at Bhairahawa, Rupendehi, 2019-2020

Treatments	Final plant height (cm)		No. of tillers per m^2 at max. tillering stage		Maximum leaf area index		Dry matter at heading (g/m^2)	
	2019	2020	2019	2020	2019	2020	2019	2020
Establishment methods								
Surface seeding	76.0	73.7^{a}	374.1^{b}	345.8^{a}	1.4^{b}	1.2^{a}	464.8	391.5^{a}
Zero tillage	88.1	70.6^{a}	413.7^{a}	272.4^{b}	2.1^{a}	1.0^{b}	657.1	317.8^{b}
Conventional tillage	84.2	59.1^{b}	406.4^{a}	218.1^{c}	1.6^{b}	0.9^{c}	555.9	216.1^{c}
p-value	0.17	0.00	0.04	0.01	0.02	0.00	0.09	<.001
SEm (±)	3.61	1.10	7.70	13.01	0.11	0.03	44.21	7.73
LSD (P<0.05)	14.17	4.30	30.24	51.07	0.44	0.12	173.59	30.36
CV, %	7.50	2.80	3.40	8.10	11.30	5.30	13.70	4.30
Residue management practices								
Residue removed	82.7	66.7	408.4	280.9	1.8	1.0	572.8	321
Residue retention	82.8	68.9	387.8	276.7	1.6	1.1	545.8	295
p-value	0.98	0.40	0.25	0.26	0.07	0.07	0.19	0.07
SEm (±)	0.62	1.40	9.09	1.88	0.05	0.02	9.63	4.89
LSD (P<0.05)	3.78	8.51	55.31	11.46	0.30	0.11	58.60	29.73
CV, %	1.30	3.60	4.00	1.20	5.00	3.00	3.00	2.70
Nutrient management practices								
F100	83.9^{a}	67.7^{b}	396.8^{ab}	275.9^{b}	1.48^{b}	1.05^{b}	529.3^{b}	320.4^{b}
F125	84.3^{a}	71.1^{a}	421.6^{a}	305.0^{a}	2.01^{a}	1.14^{a}	633.8^{a}	363.7^{a}
Farmer's practice (FP)	80.2^{b}	64.6^{c}	375.9^{b}	255.3^{c}	1.66^{b}	0.90^{c}	514.8^{b}	241.3^{c}
p-value	<.001	<.001	0.01	<.001	<.001	<.001	<.001	<.001
SEm (±)	0.68	0.50	9.72	3.46	0.08	0.02	13.84	4.24
LSD (P<0.05)	1.99	1.46	28.36	10.10	0.23	0.05	40.40	12.39
CV, %	3.50	3.10	10.40	5.30	19.70	6.90	10.50	5.80
Grand mean	82.77	67.80	398.10	278.80	1.71	1.03	559.30	308.50

Note: F100 = 100:50:50 N, P_2O_5, K_2O kg/ha; F125 =125:62.5:62.5 N, P_2O_5, K_2O kg/ha; Farmer's practice=80:40:15 N, P_2O_5, K_2O kg/ha; same letter in the column indicates no difference.

Whereas in 2020, SS plots had significantly higher LAI than ZT and CT plots and ZT had significantly higher LAI than CT plots. In both years, F125 nutrient dose produced significantly higher LAI than F100 and FP dose but in the first year F100 and FP were statistically at par to each other. Ghadikolayi *et al*., (2015) reported that increased nitrogen rates significantly increased LAI. Similar results were reported by Potter *et al*., (1995) and Sinclair and Horie (1989), who found that LAI and crop growth were affected by nitrogen rates.

Dry matter production

In 2019, only nutrient management had significant effect on dry matter production at heading whereas in 2020 tillage methods and nutrient management had significant effect (Table 1). The SS plots produced significantly higher dry matter than ZT and CT plots, where ZT plots also produced significantly higher dry matter than CT plots in 2020. During both the years, dry matter at F125 nutrient dose had significantly higher than dry matter of F100 and FP dose.

Yield attributing characteristics

Effective tiller per square meter

Tillage method and nutrient management significantly affected the effective tiller per square meter, but residue management had no significant effect in both the years. In 2019, the ZT and CT plots produced significantly higher number of effective tiller than SS plots, where ZT and CT plots were statistically at par with each other (Table 2).The result agreed with the result of (Ali *et al.*, 2013). In the second year, the SS plots produced significantly higher effective tiller than ZT and CT, where ZT and CT were statistically similar. Fertilizer levels of F125 produced significantly higher number of effective tiller than FP dose, but statistically at par with F100 in 2019 and significantly higher than the number of effective tillers produced at F100 in 2020. This result is in line with the findings of Bartaula *et al*., (2019), who reported that the maximum number of effective tiller per meter square was recorded highest at 125 kg N per hectare followed by 100 kg N per hectare, where 50 kg N per hectare recorded the lowest values.

Number of grain per spike

In 2019, the number of grain per spike was significantly affected by tillage method and nutrient management, but residue management had no significant effect (Table 2). The ZT plots produced significantly higher number of grains per spike than SS and CT plots, where SS and CT plots were statistically at par. Similar results were reported by (Zamir *et al*., 2010). Whereas, in contrast, Leghari *et al*., (2015) noted maximum number of grain per spike under CT, while this number declined under reduced tillage and no-tillage. In 2020, only nutrient management had significant effect on the number of grains per spike. F125 nutrient dose produced significantly higher number of grains per spike than F100 and FP doses during both the years. Similar results were reported by Bartaula *et al*., (2019).

Thousand grain weight

Nutrient management had a significant effect on thousand grain weight (TGW) in both years while the effect of residue management was significant only in 2020 (Table 2). Similar results were obtained by Alsayim *et al*., (2018). In 2019, F100 nutrient dose produced significantly higher TGW than F125 and FP doses, whereas in 2020, significantly higher TGW was recorded in the treatment F125. Meena *et al*. (2020) reported that residue retention did not affect TGW statistically as compared to residue removal. Residue retention plots produced significantly higher TGW than residue removed plots in 2020.

Table 2. Yield attributes as influenced by the establishment methods, crop residue and nutrient management practices of wheat in the rice-wheat system at Bhairahawa, Rupendehi, 2019-2020

Treatments	Effective tillers per m^2		No. of grains per spike		Thousand grain weight (g)		Sterility (%)	
	2019	2020	2019	2020	2019	2020	2019	2020
Establishment methods								
Surface seeding	181.2[b]	275.4[a]	28.2[b]	27.8	40.5	38.85	36.2	50.6
Zero tillage	224.1[a]	205.7[b]	35.1[a]	26.6	38.9	37.46	36.0	51.8
Conventional tillage	211.9[a]	173.8[b]	29.8[b]	22.9	39.4	39.08	36.4	54.7
p-value	0.03	0.02	0.05	0.17	0.07	0.26	0.89	0.18
SEm (±)	6.99	14.31	1.31	1.51	0.34	0.63	0.698	1.124
LSD (P<0.05)	27.46	56.17	5.12	5.92	1.32	2.48	2.739	4.413
CV, %	5.9	11.4	7.3	10.1	1.5	2.8	3.3	3.7
Residue management practices								
Residue removed	213.6	218.1	31.5	23.8	39.4	37.8[b]	36.0	53.6
Residue retention	197.9	218.5	30.6	27.8	39.9	39.2[a]	36.4	51.1
p-value	0.13	0.95	0.32	0.07	0.34	0.03	0.69	0.16
SEm (±)	4.45	4.80	0.51	0.81	0.27	0.18	0.662	0.786
LSD (P<0.05)	27.09	29.21	3.07	4.90	1.66	1.07	4.031	4.78
CV, %	3.7	3.8	2.8	5.4	1.2	0.8	3.2	2.6
Nutrient management practices								
F100	204.9[ab]	218.3[b]	29.5[b]	26.3[b]	40.4[a]	38.4[b]	36.8[a]	52.2[b]
F125	215.6[a]	239.3[a]	33.3[a]	28.1[a]	39.4[b]	39.4[a]	34.4[b]	49.3[c]
Farmer's practice (FP)	196.8[b]	197.3[c]	30.4[b]	22.9[c]	39.1[b]	37.6[c]	37.5[a]	55.6[a]
p-value	0.01	<.001	<.001	<.001	0.00	<.001	0.001	<.001
SEm (±)	4.06	3.39	0.55	0.40	0.22	0.14	0.553	0.512
LSD (P<0.05)	11.84	9.88	1.61	1.16	0.65	0.41	1.614	1.494
CV, %	8.40	6.60	7.50	6.50	2.40	1.60	6.5	4.1
Grand mean	205.70	218.30	31.04	25.78	39.61	38.46	36.21	52.35

Note: *F100 = 100:50:50 N, P_2O_5, K_2O kg/ha; F125 = 125:62.5:62.5 N, P_2O_5, K_2O kg/ha; Farmer's practice=80:40:15 N, P_2O_5, K_2O kg/ha; same letter in the column indicates no difference.*

Sterility percentage

The tillage method and residue management had no significant effect on sterility percentage in both years. In 2019, FP and F100 nutrient dose had significantly higher sterility percentage than F125 dose, where FP and F100 were statistically similar (Table 2). In 2020, FP dose had significantly higher sterility percentage than F100 and F125 doses, where F100 also had significantly higher sterility percentage than F125 dose.

Grain yield

In 2019, tillage methods and residue management had no significant effect on grain yield but nutrient management showed significant effect (Table 3). Ali *et al*., (2013) reported non significant difference in grain yield of winter wheat among tillage practices. The F125 nutrient dose produced significantly higher grain yield than F100 and FP doses, where F100 dose produced significantly higher grain yield than FP dose. A similar result was found by Mandal *et al*., (2018). The increase in grain yield may be due to the availability of NPK at various critical crop growth stages in an optimal amount which might have accelerated photosynthetic activities resulting in better yield attributes of wheat (Kumar and Yadav, 2005). In 2020, the grain yield was significantly affected by tillage methods, residues, and nutrient management. The SS plots produced significantly higher grain yield than ZT and CT plots, whereas ZT plots produced significantly higher grain yield than CT plots. Due to the heavy rainfall in the early growth stage, CT wheat was more prone to excess water stress which might have resulted in growth retardation and hence the poor yield. Chaosu *et al*., (2019) found a negative effect of CT on wheat production. Furthermore, in silty clay loam soil, the zero tillage did not favor the roots to proliferate down into the deeper layers of the soil profile to extract nutrients that led to lower growth and yield of wheat, which might be the reason for the low yield of ZT wheat in the experiment. Shahzad *et al*., (2016) recorded minimum wheat grain yield under zero tillage condition.The residue retention plot produced significantly higher grain yield than residue removed plots. Similar result was found by Meena *et al*., (2020). It might be due to the addition of nutrients to the soil after decomposition of rice residue leading to enhancement in soil organic carbon (Lollato *et al*., 2019). Similarly, F125 nutrient dose produced significantly higher grain yield than F100 and FP doses, where F100 dose also produced significantly higher grain yield than FP dose. The different fertilizer doses produced grain yields differently, the higher dose produced higher grain yield. Similar results were reported by Ghadikolayi *et al*., (2015), Alijani *et al*., (2012) and Hejazi *et al*., (2010). Analysis of average grain yield of two years experiment showed that residues and nutrient management had no significant effect on mean grain yield, where tillage method had significant effect (Table 3). The ZT and SS plots produced significantly higher grain yield than CT, where ZT and SS were statistically similar. The ZT produced 26.6% higher grain yield than CT and 3% higher than SS, where SS also produced 23% higher grain yield than CT.

Straw yield

In 2019, the straw yield was significantly affected by the tillage method, residue, and nutrient management but in 2020 residue management practices had no significant effect. The ZT plots produced significantly higher straw yield than SS plots, where CT plots were statistically at par with ZT and SS plots in 2019 but in 2020, significantly higher straw yield was produced from SS plots followed by ZT and CT plots. The ZT plots also produced significantly higher straw yield than CT plots (Table 3). The residue removed plots produced significantly higher straw yield than residue retention plots in 2019. F125 nutrient dose produced significantly higher straw yield than F100 and FP doses.

Table 3. Grain yield, straw yield, and harvest index as influenced by the establishment methods, residue and nutrient management practices of wheat in the rice-wheat system at Bhairahawa, Rupendehi, 2019-2020

Treatments	Grain yield (kg/ha)		2years Mean	Straw yield (kg/ha)		Harvest index (%)	
	2019	2020	(kg/ha)	2019	2020	2019	2020
Establishment methods							
Surface seeding	1825	2887[a]	2356[a]	2802[b]	3253[a]	0.40	0.47[a]
Zero tillage	2855	1997[b]	2426[a]	4065[a]	2568[b]	0.41	0.43[b]
Conventional tillage	2263	1570[c]	1916[b]	3463[ab]	2180[c]	0.39	0.41[b]
p-value	0.07	<0.001	0.018	0.03	0.003	0.37	0.01
SEm (±)	217.20	69.30	76.5	200.4	89.2	0.01	0.01
LSD (P<0.05)	852.90	272.20	300.4	786.7	350.1	0.04	0.03
CV, %	16.3	5.6	5.9	10.1	5.8	4.2	2.5
Residue management practices							
Residue removed	2427	1968[b]	2198	3865[a]	2522	0.39	0.43[b]
Residue retention	2201	2335[a]	2268	3022[b]	2813	0.42	0.45[a]
p-value	0.10	0.00	0.252	0.02	0.054	0.06	0.04
SEm (±)	55.50	10.3	31.2	87.1	49.70	0.01	0.003
LSD (P<0.05)	337.70	62.6	189.8	529.9	302.50	0.03	0.02
CV, %	4.2	0.8	2.4	4.4	3.2	2.3	1.0

Treatments	Grain yield (kg/ha)		2years Mean	Straw yield (kg/ha)		Harvest index (%)	
	2019	2020	(kg/ha)	2019	2020	2019	2020
Nutrient management practices							
F100	2312[b]	2165[b]	2239	3477[b]	2654[b]	0.40	0.44
F125	2482[a]	2423[a]	2453	3760[a]	2941[a]	0.40	0.45
Farmer's practice (FP)	2148[c]	1866[c]	2007	3092[c]	2406[c]	0.41	0.43
p-value	<.001	<.001	<.001	<.001	<.001	0.19	0.17
SEm (±)	47.9	38.7	27.3	66.3	59.3	0.00	0.01
LSD (P<0.05)	139.8	113.1	79.6	193.6	173.1	0.01	0.02
CV, %	8.80	7.60	5.2	8.20	9.40	4.80	5.90
Grand mean	2314	2151	2233	3443	2667	0.40	0.44

Note: *F100 = 100:50:50 N, P_2O_5, K_2O kg/ha; F125 = 125:62.5:62.5 N, P_2O_5, K_2O kg/ha; Farmer's practice=80:40:15 N, P_2O_5, K_2O kg/ha; same letter in the column indicates no difference.*

Harvest index

In 2019, the harvest index was not significantly affected by the tillage method, residue, and nutrient management. In 2020, tillage method and residue management had a significant effect on HI (Table 3). The SS plots produced significantly higher HI than ZT and CT plots, where ZT and CT were statistically at par. Similarly, residue retention plots produced significantly higher HI than residue removed plots. Ali *et al*., (2013) and Bartaula *et al*., (2019) reported the non-significant effect of tillage on harvest index

Bulk density and soil moisture

After the first year experiment of wheat and rice, the tillage method and residue management had shown a significant effect on soil bulk density. Significantly higher bulk density was found in ZT plots as compared to CT plots, where bulk density of SS plots was statistically at par with both ZT and CT plots (Fig. 2). Higher bulk density in ZT might be due to the lack of mechanical operations resulting into reduced pore volume and soil compaction (Shahzad *et al*., 2016; Du *et al*., 2010; Jemai *et al*., 2012; Xu and Mermoud, 2001; Thomas *et al*., 2007). ZT induces more soil compaction in the upper layer than CT (Thomas *et al*., 2007). In contrast, frequent cultivation under CT tends to disturb the soil structure by breaking clods and reducing bulk density and mechanical impedance (Chatterjee and Lal, 2009), with simultaneous improvement in soil porosity (Meek *et al*., 1992; Rashidi and Keshavarzpour, 2011), as was observed in this study. Similarly, residue retention plots had significantly lower bulk density than residue removed plots. There were no significant effects of any treatment on soil moisture level after one year of experiment.

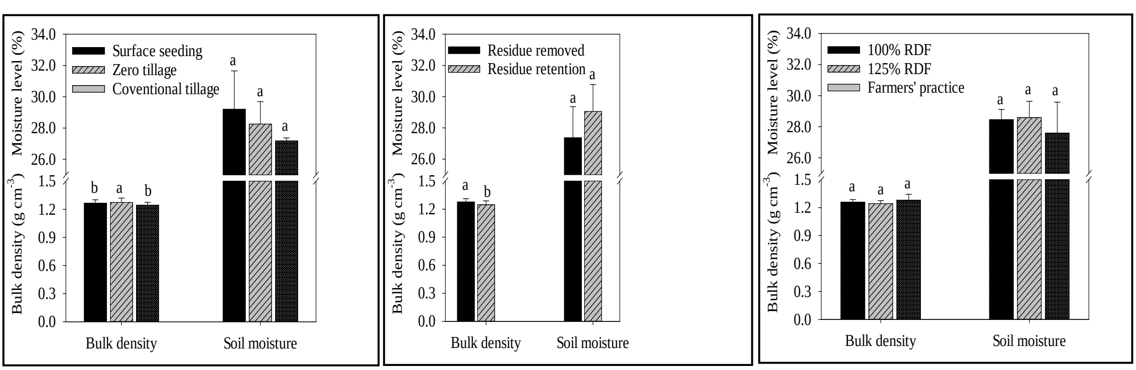

Fig. 2: Soil bulk density (g/cm^3) and soil moisture status (%) after the first-year wheat and rice harvest as influenced by the establishment methods, residue and nutrient management practices in rice-wheat system at Bhairahawa, Rupendehi, 2018-2019

Conclusion

Based on the results of two years experiment, it can be concluded that wheat can be grown under a zero tillage system with previous crop (rice) residues retention and application of 25% higher NPK fertilizer than the recommended dose in the Terai region of Nepal. Surface seeding of wheat can also be a better option especially in the year when the winter rain is high or in the well irrigated conditions.

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Effect of plant densities and fertilizer rates on grain yield of spring maize in inner Terai condition

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Abstract
To improve the yield of spring season maize in the inner terai of Nepal, the effect of increasing fertilizer levels for increasing planting densities on growth, yield attributes, and yield of open-pollinated maize variety were analyzed through the field experimentation in 2019. The treatments included factorial combinations of three planting densities, (a) 55556/ha, (b) 66667/ha, and (c) 83333/ha; and four fertilizers levels (research-based recommendation i.e., 120:60:40 $N:P_2O_5:K_2O$ kg/ha, 144:72:48 $N:P_2O_5:K_2O$ kg/ha, 180:90:60 $N:P_2O_5:K_2O$ kg/ha, and site-specific nutrient management (SSNM) based nutrient expert model recommendation i.e., 140:40:40 $N:P_2O_5:K_2O$ kg/ha) arranged in a split-plot design with three replications. Data on growth, yield attributes, and yield were analyzed by using R Studio. Growth was higher under the highest planting density and higher fertilizer levels applied treatments. The higher ($p<0.05$) heat use efficiency was recorded under the highest planting density and the higher levels of fertilizer application. The final plant population was 5.33% lower in the plant density of 55556/ha, 8.8 and 15.7% lower respectively for plant densities of 66667/ha and 83333/ha. Both the barrenness and sterility percentage were higher ($p<0.05$) for the highest planting densities and the lowest for the lowest plant density. Higher ($p<0.05$) number of kernels per cobs were recorded in the lowest plant density and the highest amount of fertilizer application. For the lowest and the highest plant densities, the leaf area index increased the grain yield whereas longer grain filling duration and less amount of barrenness and sterility increased ($p<0.05$) the grain yield for all plant densities. The final number of plant populations was the most important parameter to increase ($p<0.05$) the yield under lower plant density whereas the number of kernels per row or cob was the most important attribute to increase ($p<0.05$) the yield of maize under higher plant density. Due to a higher ($p<0.05$) number of final plant populations and comparable yield attributes, the grain yield of the highest planting density was significantly ($p<0.05$) higher. From the significant ($p<0.05$) quadratic response of plant density on the grain yield, a density of 102,950 /ha was estimated as optimum. The increased in amount of fertilizers (144:72:48 $N:P_2O_5:K_2O$ kg/ha, 180:90:60 $N:P_2O_5:K_2O$ kg/ha) gave higher grain yield. The plant densities of 66667/ha and 83333/ha were better whereas the present recommended dose of N: $P_2O_5:K_2O$ should be increased or need-based SSNM must be adopted to obtain the more profits from open-pollinated spring maize under the central inner Terai.

Keywords: Fertilizer levels, nutrient expert, plant densities, spring maize

Introduction
Maize (*Zea mays* L.) is the second most important crop of Nepal after rice in terms of both area cultivation and production. The national average yield of maize (2.35 t/ha) (MOF, 2017) is far below than the attainable yield of >8.0 t/ha (Devkota *et al*., 2016). Current maize production of 1.3 million tons is not sufficient to meet the national demand thus yields of maize must be increased by 57% (CBS, 2014; KC *et al*., MOF, 2017; TrendEconomy, 2020). The feed demand is increasing at 11% per annum, demands a huge amount of maize. As the possibility of expanding the area in the future is very limited, the required extra production has to come through an increase in productivity. Poor crop management practices, low soil fertility, extreme climatic conductions, etc are the main causes of low productivity (Raza *et al*., 2019). The crop environment was manipulated through agronomic management such as seed rate, plant population, and fertilizer, which influence the growth and ultimately the grain yield (Lomte and Khuspe, 1987). The haphazard and inefficient use of inputs not only reduced the yield and profitability but also caused the wastage of time and effort which leads to weak agricultural economic growth.

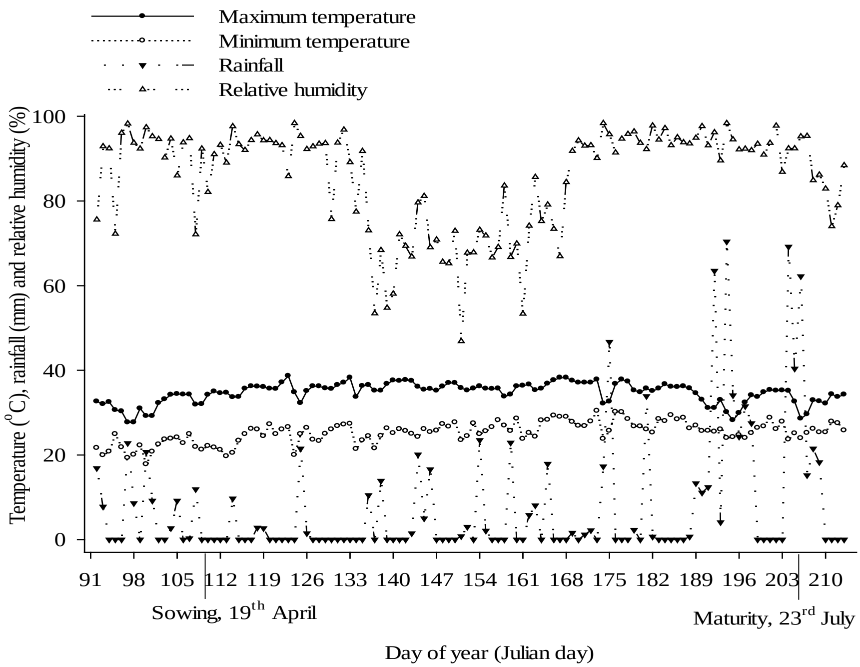
Maize is a unique member of the Poaceae family because of its low tillering capacity, monoecious floral habit, and shorter flowering period, due to which the yield of the maize is greatly influenced by the planting densities (Rehman *et al*., 2011). For the specific agro-ecology, growing season there always exists certain optimum planting densities for each variety which optimizes the use of available resources. Varietal differentiation on plant height, leaf number, individual leaf area, leaf length, vertical leaf angle, and leaf area distribution on the main stem is very common (Edmeades and Lafitte, 1993). Several factors including water and nutrient availability, maturity duration, and row spacing determine the optimum level of their plant population (Haarhoff and Swanepoel, 2018), which is regarded as the major yield contribution factor (Satorre and Maddonni, 2018).

Nitrogen management is the key practice for obtaining the yield potential of maize crop (Sampath *et al*., 2013). Muhammad Arif (2015) reported interaction between nitrogen and plant densities that higher plant densities require maximum dose of nitrogen produced maximum yield. However, increasing the application of nitrogenous fertilizers only negatively affected the nitrogen use efficiency and the environment. For the optimum growth and the better yield, maize crop requires an adequate supply of macro-nutrients particularly nitrogen, phosphorus, and potassium. These elements are important for the formation of chlorophyll, nucleotides, phosphotides, and alkaloids as well as in many enzymes, hormones, and vitamins that optimized the grain yield (Eweetzes *et al*., 2008). It is, therefore, pertinent to explore varying supply of nutrients particularly nitrogen, phosphorus, and potassium needed for optimum growth and high yield. Increasing the planting densities demands the more amount of all these nutrients, rather than a particular one. Even the research-based existing fertilizer recommendations advise using the fixed rates of nitrogen, phosphorus, and potassium. But the need for supplemental nutrients is strongly associated with the crop-growing conditions, crop and soil management, and climate. In this aspect, the site-specific nutrient management (SSNM) based nutrient management tool, nutrient expert (NE) is a suitable option. Therefore, a study was planned to find out the effect of planting density and fertilizer levels of different recommendation dose on the physiological aspects of yield attributes of maize during the hot spring of 2019 in the central inner terai of Nepal.

Materials and Methods

Site description

The experiment was carried out in National Maize Research Programme (NMRP) at Rampur, Chitwan located in the central Terai region of Nepal (27°40′ N latitude, 84°19′ E longitude, and 228 masl) during spring season 2019. The experimental field had sandy loam soil with a slightly acidic pH. The total soil N and available potassium were medium; while organic carbon was low and available phosphorus was very high according to the standard rating of the Directorate of Soil Management, Ministry of Agriculture Development, Government of Nepal, Kathmandu, Nepal. The experimental site lies in the subtropical humid climate belt of Nepal. The area has a sub-humid type of weather condition with cool winter, hot summer, and a distinct rainy season with an annual rainfall of about 2000 mm. The weather data during the cropping season was recorded from the metrological station of the National Maize Research Program (NMRP), Rampur, Chitwan (Figure 1). Comparatively higher rainfall was recorded during the ripening phase (fertilization to maturity).



Average maximum temperature = 35.42°C (range: 28.20-38.65°C)

Average minimum temperature = 25.83°C (range: 19.70-30.40°C)

Average mean temperature = 30.63°C (range: 26.20-34.10°C)

Average relative humidity = 84.89% (range: 46.84-98.37%)

Total rainfall = 657.90 mm (range: 0-70.40 mm)

Fig. 1: Minimum and maximum daily temperature (°C), daily rainfall (mm) and daily relative humidity during the experimental period at Rampur, Chitwan, Nepal, 2019 (Source: NMRP, 2019)

Experimental design and treatments

The experiment was carried out by using a split-plot design, comprising two factors- plant densities (55556/ha, 66667/ha, and 83333/ha) as main plots, and four fertilizers levels (120:60:40 $N:P_2O_5:K_2O$ kg/ha as the research-based recommendation, 144:72:48 $N:P_2O_5:K_2O$ kg/ha, 180:90:60 $N:P_2O_5:K_2O$ kg/ha, and SSNM based nutrient expert dose 140:40:40 $N:P_2O_5:K_2O$ kg/ha) in subplots, and each treatment arranged with four replication. The fertilizer dose was determined using Nutrient Expert software prepared by the International Plant Nutrition Institute (IPNI). The experimental plots were 16.4 m^2 (4.8 m × 3.5 m) in size.

Crop management

The field was ploughed two times and planking and leveling were done to bring the soil under good tilth. Maize seeds were sown on 19th April with a handheld maize planter with 2 seeds per hill, and maintaining a spacing of 60 cm × 25 cm. Atrazine, a pre-emergence herbicide, was applied @ 1.5 kg a.i./ha followed by one hand weeding at 20 days after sowing (DAS). Thinning was conducted at 13 DAS and one plant per hill was maintained. Irrigation was applied when the crop showed the symptoms of temporary wilting. The full dose of phosphorus and potassium were applied for all plots. The half dose of N was applied as basal, and the remaining N was applied at two equal splits (first split at 32 DAS and second split at 45 DAS).

Sampling and measurements

Leaf area and above-ground biomass were measured from the destructive sampling of four randomly selected plants from each plot. Dry matter was determined by drying the samples at a temperature of 70°C in a hot oven for 72 hours and weighed and expressed in kg/ha. The leaf area was recorded from the automatic leaf area meter, and the leaf area index was calculated by dividing the leaf area by ground area.

Cobs were harvested manually from the net plot area of 8.4 m^2 (4 rows). The total numbers of barren plants were counted in each net plot, and it was converted to the number of barren plants/ha. Dehusking of cobs was done separately for each plot on the threshing floor. After shelling of grains, seeds were carefully separated and dried and weighed and moisture percent recorded. After removing the cobs, the cut stalks were sun-dried for a few days and weighed, dry weight was also recorded by drying a subsample of stover. The final plant population at harvest, the number of kernels per cob, and thousand-grain weight were recorded. For determining the numbers of grains per cob and sterility percentage, ten cobs were selected randomly, grains separated from the cob, and grains counted. After threshing, seeds were cleaned and weighed. A sample of 250 grains was weighed from each replication to derive a thousand-kernel weight. Total biomass (dry matter basis) and grain yield (adjusted to a moisture content of 13%), recorded on the plot basis and were converted to kg /ha for statistical analysis.

$$\text{Barrenness percentage} = \frac{\text{Number of barren plants in net plot area } (8.4\ \text{m}^2)}{\text{Total number of plants in the net plot area } (8.4\ \text{m}^2)} \times 100$$

$$\text{Sterility percentage} = \frac{\text{Total unfilled length of cob (cm)}}{\text{The total length of the cob (cm)}} \times 100$$

Days to tasseling, silking, and physiological maturity stages were recorded from the second row of each plot. A particular stage was supposed to be completed while 75% of the observed plants show the characteristics of that phase and numbers of days were counted from the day of sowing. Tasseling-silking interval of maize was determined by the differencing between tasseling and silking days. The calculation of the heat summation unit mostly called the growing degree days (GDD) and their further mathematical derivations like pheno-thermal index (PTI) and heat use efficiencies (HUE) for 75% attainment of the tasseling, silking and physiological maturity were calculated according to the following formulae (Thavaprakaash *et al.*, 2007):

$$\text{Growing degree days (GDD)} = \frac{\text{Maximum temperature} - \text{Minimum temperature}}{2} - \text{Base temperature } (10^0\text{C})$$

$$\text{Pheno-thermal index (PTI)} = \frac{\text{GDD}}{\text{Growth days (number of days)}}$$

$$\text{Heat use efficiency (HUE)} = \frac{\text{Grain yield (kg /ha)}}{\text{GDD}}$$

Statistical analysis

The data were subjected to analysis of variance, and Duncan's multiple range test at α level 0.05 (DMRT) for mean separations (Gomez and Gomez, 1984). Correlation and regression analysis was done for selected parameters. Dependent variables were subjected to analysis of variance using the R Studio for strip-split plot design. SPSS v.16 was used for the regression analysis, and Sigma Plot v. 7 was used for the graphical representation.

Results and Discussions

The influence of the mulching materials and nitrogen levels on the growth, yield attributes, and their relation to the grain yield are presented and discussed as follows.

Plant densities and fertilizers levels influence plant growth

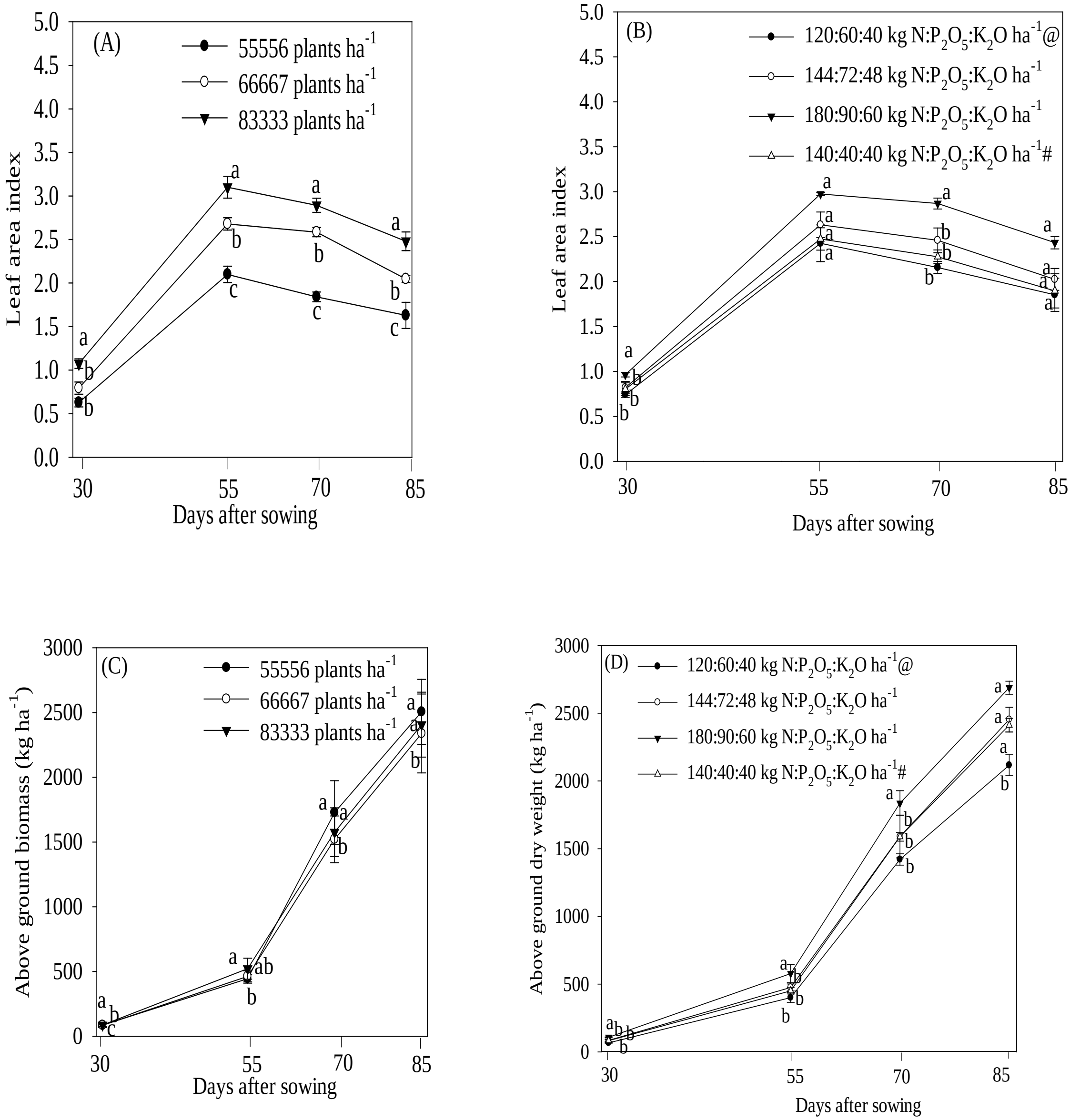
The leaf area index (LAI) was increasing up to 70 DAS and decreased thereafter due to the senescence of lower leaves (Figure 2). LAI was significantly ($p<0.05$) influenced by the plant densities at all dates of observations but fertilizer levels influenced the LAI only at 30, and 70 DAS (Table 1). The significantly ($p<0.05$) higher LAI was recorded on the plant density of 83333/ha as compared to the lower plant densities (66667/ha and 55556/ha). Except at 30 DAS, the LAI was significantly ($p<0.05$) higher for plant density of 66667/ha than the LAI of 55556/ha planting density, but at 30 DAS both were statistically at par ($p>0.05$) for LAI. At 30 and 70 DAS, the highest LAI was recorded on the highest level of fertilizer application (180:90:60 $N:P_2O_5:K_2O$ kg/ha), which was significantly ($p<0.05$) higher than the LAI recorded for other fertilizers levels. All these fertilizer levels were statistically similar ($p>0.05$) for the LAI.

Table 1. Mean square from analysis of variance (ANOVA) for the effects of plant densities and fertilizers levels on evaluated traits of spring maize at Rampur, Chitwan, Nepal, 2019

Source of variation	Replication	Densities (D)	Error(a)	Fertilizer levels (F)	D x F	Error(b)
GDD for Tasseling	5169.33	3258.09	1642.88	5764.34	563.95	4922.32
GDD for silking	323.40	8361.35**	2706.09	768.34	8077.84	6040.18
GDD for PM	7370.73	1519.48	4047.91	932.08**	754.07	1589.29
HUE	1.11	0.03**	0.08	0.01**	0.001	0.001
PTI for tasselling	0.387	0.203**	0.129	0.304	0.137	0.596
PTI for silking	0.001	0.006**	0.003	0.001	0.007	0.005
PTI for PM	0.005	0.001	0.003	0.001**	0.001	0.001
LAI at 30	0.30	0.17*	0.10	0.03*	0.04	0.02
LAI at 55	0.83	0.72**	0.51	0.43	0.46	0.32
LAI at 70	2.98	0.23**	0.60	0.11**	0.13	0.17
LAI at 85	0.74	0.45*	0.37	0.28	0.43	0.25
Dry weight at 30	8095	2451**	1676	468**	128	180
Dry weight at 55	76695	14153*	24725	2498**	13494	12765
Dry weight at 70	1266470	166233**	38912	34938**	82126	79419
Dry weight at 85	2074403	185603**	184615	297162**	112958	99579
Final plant population	308744856	86111111**	62139918	38317330	742226 79	3327617 7
Bareness percentage	23.15	1.34**	7.72	5.77	14.57	11.54
No. of cobs/plant	0.0017	0.0037	0.0020	0.0007	0.0118	0.0055
No. of kernels/cob	254.54	990.17*	1238.35	612.10**	1382.52	596.46
Sterility percentage	1.05	0.40*	4.06	1.29	2.11	3.84
Grain yield	8527610	301634**	667741	29824**	15311	24300
Stover yield	3281026	462474*	3632432	697327**	513512	1372265
Harvest index	115.48	6.27	22.13	9.51	2.10	12.24
Thousand kernel weight	199.58	709.62	361.58	430.79	664.76	596.29
Net return	7111.08	213.30**	608.49	67.32**	16.27	33.73
B:C ratio	1.54	0.03*	0.14	0.02*	0.001	0.01

Note: **, significant differences at 0.05 level of significance; **, significant differences at 0.01 level of significance*

The total dry weight was significantly ($p<0.05$) influenced by both plant densities and the fertilizer levels at all dates of observations (Table 1). The highest total dry weight was recorded for 83333/ ha at all dates of observations which was significantly ($p<0.05$) higher than the total dry weight of the planting density of 55556/ha but statistically similar ($p>0.05$) with the total dry weight of planting density 55556/ha. At 30, 55, and 70 DAS, the highest total dry weight was recorded on the highest level of fertilizer application (180:90:60 $N:P_2O_5:K_2O$ kg/ha), which was significantly ($p<0.05$) higher than the total dry weight recorded for other fertilizers levels. All these fertilizer levels were statistically similar ($p>0.05$) for the total dry weight. Whereas at 85 DAS, all the fertilizer levels were statistically similar ($p>0.05$) with each other except the 120:60:40 $N:P_2O_5:K_2O$ kg/ha which had the minimum total dry weight.



Note: *Treatments means followed by a common letter (s) are not significantly different among each other based on DMRT at 0.05 level of significance.*

Fig. 2: Leaf area index and above-ground biomass of spring maize as influenced by the plant densities and fertilizers levels at Rampur, Chitwan, Nepal, 2019

The improved growth parameters (LAI and dry weight) on the highest levels of the fertilizers is due to better utilization of all nutrients when applied in a balanced way. Nitrogen has a positive effect on cell division and elongation resulting in increased leaf length and rapid leaf development (Walch-Liu *et al*., 2000). Increase leaf area index under the higher fertilizer levels due to the delays leaf senescence, sustaining leaf photosynthesis, and maintenance of leaf area duration (Liu *et al*., 2017). Under the reduced supply of phosphorus, LAI reduced greatly due to a reduction in the hydraulic conductance of roots, and leaf growth hampered because of a reduction in the turgor pressure of cells in the elongating zone (Xu *et al*., 2017). Beadle and Long (1985) suggested that increasing light interception by optimizing LAI should increase photosynthesis and therefore biomass production. The improved growth parameters could be due to better enzymatic activation, increase protein synthesis, improve nitrogen uptake, and utilization under higher levels of potassium (Asif and Anwar, 2007).

Plant densities and fertilizers levels influence different heat summation unit

The growing degree day for 80% attainment of the tasseling was not influenced ($p>0.05$) by both the planting densities and the fertilizers levels whereas the GDD for silking was significantly ($p<0.05$) influenced by the plant densities and GDD for physiological maturity was significantly ($p<0.05$) influenced by the fertilizer levels. The highest planting densities and the highest fertilizer levels require more amount of GDD for the attainment of 80% phenological stages. The heat used efficiency (HUE) was significantly ($p<0.05$) influenced by both the planting densities and the fertilizer levels. The HUE for the highest planting density (83333/ha) was significantly ($p<0.05$) higher than the HUE of the lower plant densities. The lowest levels of fertilizers, i.e., research-based recommendation resulted significantly ($p<0.05$) lower HUE than the other fertilizer levels. Pheno-thermal index (PHI) for 80% tasseling and silking was significantly ($p<0.05$) influenced by the planting densities. The planting density of 66667 /ha had significantly ($p<0.05$) higher PHI for tasseling whereas the planting density of 83333/ha has significantly ($p<0.05$) higher PHI for silking. The PHI for 80% physiological maturity was influenced significantly ($p<0.05$) by the fertilizer levels where the highest dose of fertilizers had significantly ($p<0.05$) higher PHI of physiological maturity than the other fertilizer levels.

Table 2. Growing degree day, heat use efficiency, and pheno-thermal index of spring maize as influenced by the plant densities and fertilizers levels at Rampur, Chitwan, Nepal, 2019

Treatments	Growing degree day (^oC)			HUE (kg/ha day /^oC)	Pheno-thermal index (day ^oC/day)		
	Tasseling	Silking	Physiological maturity		Tasseling	Silking	Physiological maturity
Plant densities							
55556/ha	1625.51	1704.03^b	2652.07	1.30^c	27.47^b	27.71^b	28.65
66667/ha	1662.15	1726.22^b	2670.31	1.54^b	27.97^a	27.73^b	28.66
83333/ha	1664.90	1797.20^a	2672.86	1.71^a	27.52^b	27.79^a	28.66
SEm (±)	11.70	15.02	18.37	0.08	0.10	0.02	0.02
LSD (P<0.05)	ns	58.95	ns	0.32	0.41	0.06	ns
CV(a), %	2.46	2.99	2.39	18.64	1.30	0.20	0.19
Fertilizer levels							
120:60:40 $N:P_2O_5:K_2O$ kg/ha@	1656.15	1757.97	2651.18^b	1.28^b	27.65	27.76	28.64^b
144:72:48 $N:P_2O_5:K_2O$ kg/ha	1647.29	1722.17	2647.62^b	1.59^a	27.66	27.73	28.64^b
180:90:60 $N:P_2O_5:K_2O$ kg/ha	1643.40	1761.39	2713.76^a	1.69^a	27.44	27.76	28.70^a
140:40:40 $N:P_2O_5:K_2O$ kg/ha#	1656.58	1728.39	2647.76^b	1.51^a	27.87	27.73	28.64^b
SEm (±)	23.39	25.91	13.29	0.02	0.26	0.02	0.01
LSD (P<0.05)	ns	ns	39.48	0.06	ns	ns	0.03
CV(b), %	4.25	4.46	1.50	4.10	2.79	0.25	0.12
Grand mean	1650.86	1742.48	2665.08	1.52	27.66	27.74	28.66

Note: *ns, non-significant; @, research-based recommendation; #, nutrient expert dose. Treatments means followed by common letter(s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.*

Influence of plant densities and fertilizers levels on yield attributes

The average final plant population was 61111/ha, ranged from 52222 to 70278/ha (Table 3). The final plant population was significantly ($p<0.05$) influenced by the panting density. The final plant population was 5.3% lower in the planting density of 55556/ha, 8.8% lower in the planting density of 66667/ha and 15.7% lower in the 83333/ha panting density. The highest number of final plant populations (70278/ha) was recorded at the highest level of planting density, followed by a planting density of 66667/ha (60833/ha) and the lowest (52593/ha) in the lowest planting density. The final plant density was not influenced ($p>0.05$) by the fertilizer levels. The average barrenness was 13.70% and ranged from 11.78 to 16.10% among the different treatments. The barrenness percentage was significantly ($p<0.05$) influenced by the planting densities but not ($p>0.05$) by the fertilizer levels. Among the different planting densities, significantly higher barrenness (16.1%) was recorded on the plant density of 83333/ha which was significantly higher than the barrenness on the planting density of 66667/ha and 55556/ha. Both planting density and fertilizer management practices did not influence ($p>0.05$) the number of cobs per plant.

The decrease in per plant biomass reduces in photosynthetic rate per plant which increased plant barrenness as plant population increased (Ciampitti and Vyn, 2011; Edmeades and Daynard, 1979; Maddonni and Otegui, 2004). Delay in the cob differentiation and the growth of the primordia of cob than the tasseling are associated with more barrenness under plant densities (Jacobs and Pearson, 1991). Besides the competition for the assimilates, hormonal (auxin) alternation on the cob development before flowering is also associated with higher plant density for the barrenness (Wilson and Allison, 1978). At the 6-7 leaf stage shoot apex is differentiated into the tassel (Ritchie *et al.*, 1992). After the tassel initiation, it produces a large amount of auxin which stimulated the growth in terms of plant height and dry matter production. Due to high densities, intercepted solar radiation per plant is less (Gardner *et al.*, 1985). Under the low density, the light of high intensity inactivates by oxidation (Salisbury and Ross, 1992) but under the higher densities greater concentration of bioactive auxin is present. Therefore, a high plant population may promote auxin apical dominance over the cobs, contributing to barrenness (Sangoi and Salvador, 1998). Uner higher plating density, the delay in the initiation of the cobs and fewer primordia developed into normally functional florets at the time of flowering, the sterility increased and the number of kernels per cobs decreased. Tollenaar and Daynard (1978) reported abortion of spikelets, lack of pollination and fertilization or abortion of young kernels are also associated with increasing the sterility under dense population. Whereas Jacobs and Pearson (1991) observed that the reduction in kernel number per ear under dense population due to a reduction in the number of spikelets differentiated per ear. The fertilization percentage of the differentiated spikelets determined the number of kernels per cob. Constraints on the growth factors under dense planting delay the specific developmental stages and reduce both spikelet number and silk extrusion, contributing to lessen the number of fertilized spikelets due to non-synchronization of pollen shed and silking of individual spikelets (Jacobs and Pearson, 1991). Therefore, high plant densities may promote limitations in carbon and nitrogen supply to the ear, favoring abortion after fertilization resulting in higher sterility (Luís Sangoi, 2001).

Table 3. Yield attributes as influenced by the different population densities and fertilizer levels on the spring maize at Rampur, Chitwan, Nepal, 2019

Treatments	Final plant population	Barrenness (%)	Number of cob/plant	Number of kernels /cob	Sterility (%)	1000 kernel weight(g)
Plant densities						
55556/ha	52222[c]	11.77[b]	1.11	308.60[a]	5.86[b]	264.58
66667/ha	60833[b]	13.36[b]	1.08	292.89[b]	7.66[a]	253.04
83333/ha	70278[a]	16.08[a]	1.06	279.79[b]	8.04[a]	241.33
SEm (±)	2276	0.80	0.01	10.16	0.58	5.49
LSD (P<0.05)	8934	3.15	ns	39.88	2.28	Ns
CV(a), %	12.90	20.23	4.16	11.98	28.05	7.52

Treatments	Final plant population	Barrenness (%)	Number of cob/plant	Number of kernels /cob	Sterility (%)	1000 kernel weight(g)
Fertilizer levels						
120:60:40 $N:P_2O_5:K_2O$ kg/ha@	60617	14.80	1.05	274.63[b]	7.74	251.45
144:72:48 $N:P_2O_5:K_2O$ kg/ha	61481	13.86	1.11	293.71[b]	7.15	255.91
180:90:60 $N:P_2O_5:K_2O$ kg/ha	61235	12.19	1.10	320.87[a]	6.75	249.13
140:40:40 $N:P_2O_5:K_2O$ kg/ha#	61111	14.11	1.08	285.84[b]	7.10	255.45
SEm (±)	1923	1.13	0.02	8.14	0.65	8.14
LSD (P<0.05)	ns	ns	ns	24.19	ns	ns
CV(b), %	9.44	24.73	6.82	8.31	27.28	9.65
Grand mean	61111	13.74	1.09	293.76	7.18	252.98

Note: *ns, non-significant; @, research-based recommendation; #, nutrient expert dose. Treatments means followed by common letter(s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.*

The number of kernels per cob was significantly ($p<0.05$) influenced both by the plant densities and fertilizer levels (Table 3). The highest number of kernels per cob (308.6) was recorded from the cob of the lowest planting density, which was significantly higher than the number of kernels per cob of higher planting. The planting density of 66667 and 83333/ha were also similar to each other in terms of the number of kernels per cob at a 0.05 level of significance. In the case of fertilizer levels, the highest number of kernels per cob was recorded from the fertilizer levels of 180:90:60 $N:P_2O_5:K_2O$ kg/ha (319.5), which was significantly ($p<0.05$) higher than the number of kernels per cob from the other fertilizer levels. The lower doses of fertilizers were statistically at par ($p>0.05$) with each other for the number of kernels per cob. The sterility percentage was significantly ($p<0.05$) influenced only by the planting densities, where the significantly ($p<0.05$) lower sterility percentage was recorded for the lowest planting density. Thousand kernel weight was not influenced ($p>0.05$) both by the plating density and the fertilizer levels.

Influence of plant densities and fertilizers levels on yield and profitability

The mean grain yield of the experiment was 4043 kg/ha and ranged from 3991 kg/ha to 4587 kg/ ha. The grain yield was significantly ($p<0.05$) influenced by plant densities as well as fertilizer levels (Table 4). The grain yield was significantly ($p<0.05$) higher (4558 kg/ha) at higher plant density and decreased with lower plant density. The grain yield at 66,666/ha was significantly ($p<0.05$) lower than grain yield at 83333 plants per ha and significantly ($p<0.05$) higher than grain yield (3454 kg/ha) at 55556 plants/ha. The relationship between the plating density and grain yield was quadratic and significant at a 0.01 level of significance (Figure 3B). The highest level of yield was obtained by the planting density of 102,950/ha. Increasing the maize population and inhibiting individual growth redundancy are the recent tactics of achieving high maize grain yields (Argenta *et al*., 2001 cited in Yu *et al*., 2019). Maize is more sensitive to variations in plant density than other members of the grass family mainly due to lack of tillering, just opposite of other members of the grass family, cannot compensate for low leaf area and very few numbers of reproductive units by branching (Gardner *et al*., 1985). Sarlangue *et al*. (2007) reported the maize grain yield was significantly influenced by the planting densities. Only under the proper plant density, highest yield can be managed (Monneveux *et al*., 2005). Monneveux *et al*. (2005) also reported that the yield increment under the high plant densities for those genotypes which have lower vigor and lower intra-plant competition. In the present study, the high yield was obtained with the plant density of

83333/ha (Table 4), which is much more than the planting densities recommended per ha by the National Maize Research Program. The tolerance with this level of high plant density was due to the less vigorous growth open-pollinated (OP) variety Arun 2 and shorter plant height (data not sown). However, the number of kernels decreased and the barrenness and sterility percentage increased, which was in agreement with the previous study (Andrade *et al.*, 2002). Due to the higher interplant competition for the resources results in a lower number of kernels per ear (Boomsma *et al.*, 2009; Tollenaar *et al.*, 2006); grain yield increments are attributable to the increased number of cob (Grassini *et al.*, 2011; Ittersum and Cassman, 2013) due to the high number of plants per unit area (Dawadi and Sah, 2012). Thus, for grain yield, the positive effects of high planting densities surpassed the negative effects of interplant competition. Hashemi *et al*. (2005) and Dawadi and Sah (2012) reported the negative relationship between yields attributes with increasing plant density. Increased plant density increased grain yield quadratically (Novacek *et al.*, 2013; Mitchell *et al.*, 2014; Stanger and Lauer, 2006). Some researchers indicated responses other than quadratic (Hammer *et al.*, 2009; Robles *et al.*, 2012).

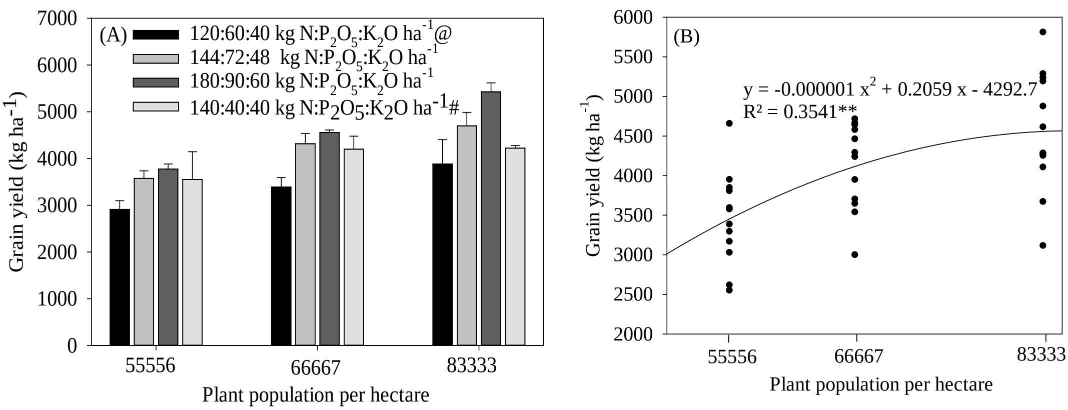


Fig. 3: (A) Grain yield (kg/ha) as influenced by the different population densities and fertilizer levels, (B) the quadratic regression of pant densities on the grain yield of the spring maize at Rampur, Chitwan, Nepal, 2019

The grain yield of maize was the highest (4587.4 kg/ha) at the fertilizer level of 180:90:60 N:P_2O_5:K_2O kg/ha, and this treatment was statistically similar ($p>0.05$) with grain yield (4197.5 kg/ha) at 144:72:48 N:P_2O_5:K_2O kg/ha but significantly ($p<0.05$) higher than grain yields (3396.7 kg/ha) at fertilizer levels of 120:60:40 N:P_2O_5:K_2O kg/ha and 140:40:40 N:P_2O_5:K_2O kg/ha (3991.0 kg/ha). The grain yields at 144:72:48 N, P_2O_5, K_2O kg/ha and at 140:40:40 N:P_2O_5:K_2O kg/ha were also statistically similar ($p>0.05$).

The higher levels of combined application of nitrogen, phosphorus, and potassium significantly increased the growth parameters, yield attributes, and ultimately the grain yield of maize in the present experiment. Balanced nutrition must be achieved to optimize maize productivity. A close association exists between the maize grain yield and whole plant and grain concentration of nitrogen, phosphorus, and potassium (Setiyono *et al.*, 2010). Nitrogen improves the crops growth thereby affects crop yields through its influence on the yield components. Ittersum and Cassman (2013) also reported the higher values of the yield components (kernel per cob, thousand kernels weight, and the number of cobs per unit area). Within the optimum levels of nitrogen, the number of kernels per cobs, and thousand-grain weight increased (Xu *et al.*, 2017). Concerning grain yield, several studies reported the increase in maize grain yield with the application of increasing nitrogen levels (Abebe and Feyisa, 2017; Davies *et al.*, 2020; Galindo *et al.*, 2019; Pasley *et al.*, 2019; Skonieski *et al.*, 2019).

The sterility decreased under higher levels of phosphorus thus increased the number of kernels per cob. The deficiency of phosphorus led to incomplete pollination, which delayed the silking and tasseling time and thereby resulted in the longer sterile tip of the cobs (Pellerin *et al*., 2000). Therefore, the application of appropriate phosphorus levels to maize should reduce the lengths of barren ear tips, increased the number of kernels per cob, and thus increase grain yield. (Xu *et al*., 2017) reported a similar finding that sterile tip length negatively affects the kernel number than grain yield. Dai *et al.* (2013) indicated that contribution to increases in grain yield is more by the phosphorus than nitrogen and potassium fertilizer on the North Plain of China. Potassium also improved growth, yield attributes, and grain yield. Amanullah *et al*. (2016) reported that the highest level of potassium (90 kg/ha) significantly increased the yield components (number of kernels per cob, thousand kernel weight), grain yield, and shelling percentage. Potassium increased the photosynthetic activities (Bukhsh *et al*., 2009), translocation of assimilated from the leaves to the cob (Hussain *et al*., 2007) that maximizes the number of kernels per cob.The stover yield was also significantly ($p<0.05$) influenced both by planting densities and the fertilizer levels. The stover yield was the highest at the planting density of 83333/ha, which was significantly ($p<0.05$) higher than the stover yield obtained by the planting density of 55556/ha and statistically at par ($p>0.05$) with 66667/ha. Regarding the fertilizer levels, a significantly ($p<0.05$) higher sterility percentage was recorded for the highest fertilizer levels which were significantly ($p<0.05$) higher than the stover yield of other fertilizer levels. The harvest index was neither influenced ($p>0.05$) by the planting densities nor by the fertilizer levels.

Table 4. Grain yield (kg/ha), stover yield (kg/ha), harvest index (%), net return (NRs. '000) and B:C ratio as influenced by the different population densities and fertilizer levels of the spring maize at Rampur, Chitwan, Nepal, 2019

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index(%)	Net return (NRs. '000)	B:C ratio
Plant densities					
55556/ha	3454[c]	7020[b]	29.78	50.35[b]	1.78[b]
66667/ha	4117[b]	7745[ab]	31.47	70.50[a]	2.08[a]
83333/ha	4558[a]	8508[a]	31.64	82.84[a]	2.26[a]
SEm (±)	111	257	1.11	7.12	0.11
LSD (P<0.05)	434	1011	ns	27.96	0.43
CV(a), %	9.47	11.49	12.42	36.33	18.6
Fertilizer levels					
120:60:40 $N:P_2O_5:K_2O$ kg/ha@	3397[c]	7184[b]	28.99	49.48[b]	1.77[b]
144:72:48 $N:P_2O_5:K_2O$ kg/ha	4198[ab]	7520[b]	32.51	72.47[a]	2.10[a]
180:90:60 $N:P_2O_5:K_2O$ kg/ha	4587[a]	8828[a]	30.83	81.30[a]	2.20[a]
140:40:40 $N:P_2O_5:K_2O$ kg/ha#	3991[b]	7498[b]	31.52	68.34[a]	2.09[a]
SEm (±)	181	317	1.54	1.94	0.03
LSD (P<0.05)	539	942	ns	5.75	0.10
CV(b), %	13.45	12.26	14.93	8.55	4.90
Grand mean	4043	7758	30.96	67.90	2.04

Note: *ns, non-significant; @, research-based recommendation; #, nutrient expert dose. Treatments means followed by common letter(s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.*

The average net return and B:C ratio were NRs. 67.90 thousands/ha and 2.04 respectively, which were significantly ($p<0.05$) influenced by the plant densities and the fertilizer levels. Among the different plant densities significantly ($p<0.05$) higher net return (NRs. 82.83 thousands/ha) was obtained from plant density of 83333/ha followed by 66667/ha (NRs. 70.50 thousands/ha) and 55556/ha (NRs.50.35

thousands/ha) which were significantly ($p<0.05$) different from each other. For fertilizer levels, significantly ($p<0.05$) higher net return (NRs.81.30 thousand ha^{-1}) was obtained at the highest fertilizer levels (180:90:60 $N:P_2O_5:K_2O$ kg/ha) and the net returns at 120:60:40 $N:P_2O_5:K_2O$; 144:72:48 $N:P_2O_5:K_2O$ kg/ha and at 140:40:40 $N:P_2O_5:K_2O$ kg/ha were statistically similar ($p>0.05$). Among the different plant densities significantly ($p<0.05$) higher B:C ratio (2.26) was obtained from plant density of 83333/ha followed by 66667/ha (2.08) and 55556/ha (1.78) which was significantly ($p<0.05$) different among each other. For the fertilizer levels, a significantly ($p<0.05$) higher B:C ratio (2.20) was obtained from the highest fertilizer levels (180:90:60 $N:P_2O_5:K_2O$ kg/ha). The B:C ratio at 120:60:40 $N:P_2O_5:K_2O$, 144:72:48 N: $P_2O_5:K_2O$ kg/ha and at 140:40:40 $N:P_2O_5:K_2O$ kg/ha fertilizer application were statistically similar ($p>0.05$) each other.Table 5 showed the coefficient of determination between the important growth, developmental parameters, and yield attributing traits on the grain yield under various plant densities. The tasseling silking interval was the highly variable characters for all plant densities, the relationship between the final plant population, barrenness, and sterility percentage on the grain yield was significant for the lowest plant density whereas, in the plant density of 66667/ha, grain filling duration and barrenness percentage had the significant association with the grain yield and in the highest plant density. The relationship between the LAI at 70 DS, barrens and sterility percentage and number of grains per cob or row with the grain yield was significant.

Table 5: Linear regression results including coefficient of variation, slope, and slope significance for the relationship between grain yield with different biometrical observations, yield attributes, and yield for different plant densities at Rampur, Chitwan, Nepal, 2019

Independent variables	Plant densities								
	55556/ha			66667/ha			83333/ha		
	CV(%)	R^2	Slope	CV (%)	R^2	Slope	CV(%)	R^2	Slope
LAI at 30 DAS	20.90	0.25	2163.11	22.32	0.06	746.13	13.92	0.26	2474.13
LAI at 70 DAS	12.86	0.28	1255.92	12.69	0.19	705.44	19.93	0.57**	958.86
Tasseling silking interval	44.19	0.02	-67.79	56.89	0.15	-115.64	46.82	0.03	-61.23
Grain filling duration	9.00	0.28	106.55	4.81	0.35*	209.40	9.08	0.30	153.35
Final plant population	3.36	0.43*	0.21	4.16	0.02	0.03	4.62	0.08	0.06
Barrenness (%)	19.11	0.61**	-196.43	23.77	0.36*	-99.92	17.62	0.62**	-203.04
No. of cobs per plant	7.14	0.03	1305.02	6.95	0.04	1372.81	4.89	0.00	728.94
Cob diameter (cm)	3.56	0.02	154.88	5.78	0.10	201.42	5.85	0.18	379.08
Cob length (cm)	2.33	0.13	2273.89	3.06	0.01	-488.57	2.86	0.03	1230.47
No. of rows per cob	4.54	0.02	-153.42	4.27	0.12	-361.43	4.21	0.15	581.35
No. of kernels per row	6.76	0.20	144.23	7.01	0.16	117.75	7.98	0.64**	302.19
No. of kernels per cob	6.88	0.13	9.42	9.01	0.02	3.11	10.09	0.64**	20.73
Thousand kernel weight	3.28	0.24	31.97	5.63	0.01	3.70	13.48	0.01	-2.06
Sterility (%)	25.44	0.41*	-241.48	15.66	0.32	-247.77	19.12	0.42*	-307.26
Stover yield (kg/ha)	11.33	0.03	-0.12	13.58	0.22	0.24	14.30	0.04	0.12

Note: ** significant differences at 0.05 level of significance; **, significant differences at 0.01 level of significance*

Conclusions

Better growth, heat use efficiency, yield attributes and yield were obtained from the highest planting density and higher fertilizer dose. Though the barrenness and sterility percentage were higher at the highest planting density of 83333/ha, higher final plant populations, and comparable other yield attributes, resulted in higher grain yield. The increased amount of fertilizers (144:72:48 $N:P_2O_5:K_2O$ kg/ha, 180:90:60 $N:P_2O_5:K_2O$ kg/ha) increased the grain yield. Due to better net return and B:C ratio, plant densities of 66667/ha and 83333/ha were better whereas the research-based recommendation needed to be increased to grow maize under the central inner Terai.

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Effect of integrated nutrient management in soybean variety Tarkari Bhatmas-1 at Khumaltar condition

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Abstract

Soybean (*Glycine max* L. Merril) is an important summer legume in terms of area and production in Nepal. A field experiment was conducted on the farm of National Agronomy Research Centre, Khumaltar, Lalitpur to evaluate the effect of different combination of nutrients on yield and yield component of soybean variety Tarkari Bhatamas-1. The experiment was laid out in a Randomized Complete Block Design (RCBD) consisting of eight nutrient treatments. These were 30:60:30 $N:P_2O_5:K_2O$ kg/ha (recommended dose), 30:80:30 $N:P_2O_5:K_2O$ kg/ha, 50:60:30 $N:P_2O_5:K_2O$ kg/ha, 50:80:30 $N:P_2O_5:K_2O$ kg/ha, 30:60:30 $N:P_2O_5:K_2O$ kg/ha + compost 10 ton/ha, 30:60:30 $N:P_2O_5:K_2O$ kg/ha + Rhizobium inoculation, 30:60:30 $N:P_2O_5:K_2O$ kg/ha + Biochar (@ 330 g/plot and Compost 20 t/ha with four replications. Results of the pooled analysis revealed that maximum grain yield (2258 kg/ha) and straw dry matter (2735 kg/ha) was obtained with the application of compost 20 t/ha followed by 30:60:30 $N:P_2O_5:K_2O$ kg/ha + compost 10 t/ha (2007 kg/ha) and straw dry matter (2394 kg/ha). The number of nodule and nodule dry weight was not affected by different nutrient combination. The number of pods significantly differed with nutrient combinations. The three years result suggested that 20-ton compost/ha or integration of recommended dose of chemical fertilizer with 10-ton compost/ha had shown the best treatment combination for the sustainable production of soybean at Khumaltar condition.

Keywords: Grain yield, nutrient management, Tarkari Bhatmas-1

Introduction

Grain legumes are an integral part of the Nepalese farming system for crop diversification, increase cropping intensity and maintain soil fertility. They have an important role in nutritional security; sustainability of cereal-based cropping system and in the national economy. Accordingly, soybean (*Glycine max* L. Merril) is one of the important summer legumes in Nepal. It is widely grown in mid-hills as an intercrop with maize or in paddy bund that occupies about 80% in terms of total area and production. In Terai and inner Terai, soybean cultivation as a sole crop is gaining popularity in recent years because of the high demand for soy meal in the poultry industry and its diversified use of grains in terms of livestock feeds and human food. Soybean is a good source of protein (45% to 50%), oil (20%), and rich in Vitamin B, C, E and minerals. In an underdeveloped country like Nepal where the majority of the population suffer from malnutrition, it is used as a portion of good supplemental food with cereal (Shrestha *et al*., 2011). It provides a large amount of edible vegetable oil as well as soybean cake and meal which are high protein supplements in mixed feed rations for livestock (Ngalamu *et al*., 2012). Azhari (1987) reported that soybean contains 20 to 22% of essential amino acids and 40% protein. The study by Malik *et al.* (2006) revealed that soybean contains 18-22% oil which comprises 85% cholesterol-free unsaturated fatty acids in comparison to conventional vegetable and animal fats. Soybean also has many food and industrial uses. Vegetable soybeans are also used in the preparation of innovative products such as green milk, green tofu and green noodles (Shanmugasundaram and Yan, 1999). Vegetable soybeans are characterized by large pods with bigger sized seeds (200-250 mg or more per seed) besides seed being green, soft and sweet. These are rich in protein, fat, phosphorus, calcium, iron, thiamin, riboflavin, vitamin E and flavones. A wide range of vegetable soybean varieties have been cultivated and there is an increased consumption of vegetable soybean in South-East Asian countries (Shanmugasundaram, 1991). The nutritional value and protein content are important characteristics of vegetable soybean, which is superior to meat, cow milk and eggs. Vegetable soybean provides more protein of higher quality and is considered as an excellent protein source compared to vegetable pigeon pea and green peas protein. In addition to domestic consumption, vegetable soybean also has export potential (Patil *et al*., 2017). In Nepal, it occupies an area of 25,179 ha with a total production of 31,567 mt and an average productivity of 1254 kg/ha (MOALD, 2018/19). It has diverse adaptability to varied agro-ecological zones with an altitude ranging from 200 to 2000 m above mean sea level (Sharma, 1994). Demand for soybean has increased with an increase in the poultry business and the majority of soybean meal is being imported from India (Tripathi *et al*., 2015).

Integrated nutrient management practices applied for soybean contributes to the sustainable growth of yield and quality, influences soil health and reduces environmental risks. The use of organic manures with an optimum rate of fertilizers under intensive farming system increased the turnover of nutrients in the soil-plant system. The organic manures along with biofertilizers help in reducing the dose of inorganic fertilizer; which in turn reduces the cost of cultivation and help in improving the soil health (Farhad *et al*., 2017). Balanced fertilization can play a major role to enhance the present yield level. Experimental evidence revealed that the crop is highly responsive to different fertilizers and its yield can be increased remarkably through judicious fertilization (BARI, 1988; Mohamed, 1984; Roy and Singh, 1986; Kazi *et al*., 2002). Although soybean can fix atmospheric N in the soil, this element is necessary for better yield. In recent years, a concept of integrated nutrient supply involving the use of organic manures and inorganic fertilizers has been developed to obtain sustained agricultural production (Gaikwad and Puranik, 1996). Although several field studies have been conducted on nutrient management of soybean in various parts of the world, very few information is available under Nepalese soil conditions. In this context, understanding the different sources of nutrients in increasing soybean production is a felt need of the soybean growers in Nepal. Optimizing the nutrient requirements, selecting the superior sources of the nutrients and judicious use of the nutrients in soybean cultivation is a necessity. Therefore, this study was undertaken to determine the best combination of nutrient for sustainable soybean production.

Materials and Methods

An experiment consisting of eight nutrient management treatments was evaluated in soybean during 2016-2018 at Khumaltar. Nutrient treatments were 30:60:30 $N:P_2O_5:K_2O$ kg/ha (recommended dose, RD), 30:80:30 $N:P_2O_5:K_2O$ kg/ha, 50:60:30 $N:P_2O_5:K_2O$ kg/ha, 50:80:30 $N:P_2O_5:K_2O$ kg/ha, 30:60:30 $N:P_2O_5:K_2O$ kg/ha + compost 10 ton/ha, 30:60:30 $N:P_2O_5:K_2O$ kg/ha + Rhizobium inoculation, 30:60:30 $N:P_2O_5:K_2O$ kg/ha + Biochar (@330 g/plot) and Compost 20 t/ha. The experiment was laid out in RCBD with four replications. Early maturing determinate soybean variety Tarkari Bhatmas-1 was used. Seeding was done on 8 June 2016, 25 April 2017 and 3 May 2018 with a row spacing of 50 cm and 5 cm between plant to plant in a row. The plot size was 3 m x 5 m (6 rows of 5 m long). Chemical fertilizers were applied as basal before seeding. Similarly, 50 g of Rhizobium/plot was mixed with soil and Biochar placed in deep furrows and covered by the soil before seeding. Compost i.e., farmyard manure (FYM) prepared in a compost pit. Thinning was done to one plant per hill a month after seeding. Weeding and earthing up were done as required. Ten plants were randomly selected for measuring plant height, number of pods/plant, unfilled pods/plant, number of branches/plant, number of seeds/pod at physiological maturity. Grain yield and straw dry matter were recorded from a net plot area of 10 m^2. Crops were harvested from the first week of Septemper to third week of September in 2016 to 2018. Two hundred seeds (2016) and 500 seeds (2017, 2018) were counted to estimate 100 seed weight. Grain yield and seed weight were adjusted to 12% moisture content. Subsample straw was oven-dried to estimate straw dry matter yield.

Temperatures and rainfall during growing season

The mean maximum temperatures during soybean growing season were 27.9 ^{o}C, 28.3^{o}C and 28.0^{o}C in 2016, 2017 and 2018, respectively. Similarly, mean minimum temperatures were 20.1^{o}C in 2016, 19.1^{o}C in 2017 and 19.5^{o}C in 2018 (data not shown). Total rainfall during growing season was highest in 2018 (929 mm) followed by 825 mm in 2017 and 815 mm in 2016.

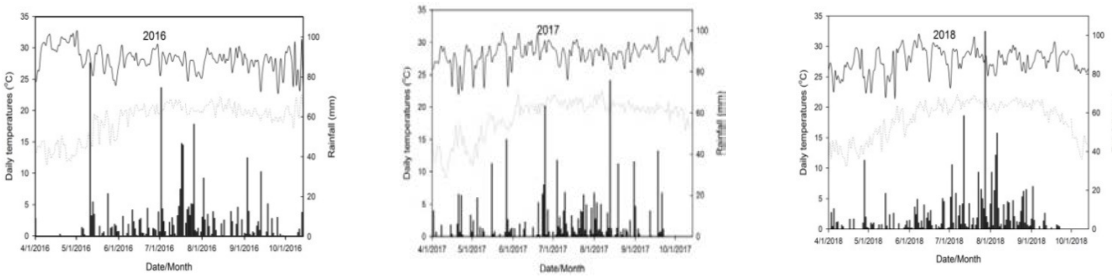

Fig. 1: Daily mean maximum (-●-), minimum (-○-) temperatures and rainfall (solid bar) during soybean growing season in Khumaltar (2016-2018).

Results and Discussions

Plant population

The result showed that the plant stand was significantly affected by treatments in the first year. The plot treated with a recommended dose of NPK with biochar had few numbers of plants stand (Table 1). In the second and third year, there was no significant variation on plant stand, however; few numbers of plant /m^2 were observed on plot treated with the recommended dose of NPK with biochar. But the result of the pooled analysis showed a significant effect on the plant stand.

Table 1. Plant population of Tarkari Bhatmast-1 as affected by nutrient management (2016-2018).

SN	Treatments	Final stand (per m^2)			
		2016	2017	2018	Mean
	Nutrient Management (NM)				
1	30:60:30 $N:P_2:O_5:K_2O$ kg/ha (Recommended dose)	21	19	18	19
2	30:80:30 $N:P_2:O_5:K_2O$ kg/ha	21	17	18	18
3	50:60:30 $N:P_2:O_5:K_2O$ kg/ha	20	19	17	19
4	50:80:30 $N:P_2:O_5:K_2O$ kg/ha	21	18	17	18
5	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + compost 10 t/ha	21	15	16	17
6	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + Rhizobium inoculation	21	18	16	18
7	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + Biochar (@ 330 g/plot)	16	15	15	15
8	Compost 20 t/ha	20	17	16	18
	Mean	20	17	17	18
	P value-NM	0.004	0.06	0.316	<.001
	LSD (<0.05)	3	ns	ns	2
	Year (Y) P value				<.001
	LSD (<0.05)				1
	NMxY				0.628
	CV (%)	9	12	11	12

Yield components

The result of the experiment showed that there was a significant effect of treatments on the mean number of pods per plant. The highest numbers of pods per plant were recorded in RD + Biochar, followed by compost 20 t/ha and RD + compost 10 t/ha. The number of 2-seeded pods/plant was significantly higher in RD+ Biochar application in the first year of the experiment (Table 2).

Table 2. Numbers of pods of soybean variety Tarkari Bhatmas-1 (2016) under different nutrient management at Khumaltar

SN	Nutrient Management	2016			2016	2017	2018	Mean
		1-seeded	2-seeded	3-seeded				
	Nutrient Management (NM)							
1	30:60:30 $N:P_2:O_5:K_2O$ kg/ha (Recommended dose)	7	15	5	27	33	36	32
2	30:80:30 $N:P_2:O_5:K_2O$ kg/ha	7	20	5	32	37	32	34
3	50:60:30 $N:P_2:O_5:K_2O$ kg/ha	8	19	5	32	36	37	35
4	50:80:30 $N:P_2:O_5:K_2O$ kg/ha	7	19	6	32	33	34	33
5	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + compost 10 t/ha	9	19	6	35	43	45	41
6	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + Rhizobium inoculation	6	21	5	32	34	37	34
7	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + Biochar (@ 330 g/plot)	8	27	7	42	36	51	43
8	Compost 20 t/ha	9	22	8	38	43	46	42
	Mean	8	20	6	34	37	40	37
	P value-MN	0.128	0.01	0.17	0.013	0.177	0.002	<.001
	LSD (<0.05)	-	5	-	7	-	9	5
	Year (Y) P value							0.003
	LSD (<0.05)							3
	NMxY							0.481
	CV (%)	20	18	24	15	18	15	18

Plant height and nodulation

Plant height and nodule dry weight were significantly different among nutrient management. The highest plant height (54 cm) and nodule dry weight (48.9 mg/plant) were observed in treatment 30:60:30 $N:P_2:O_5:K_2O$ kg/ha + compost 10 t/ha (Table 3). Inoculation of rhizobium did not show a significant effect on nodulation.

Table 3. Plant dry matter and nodule number and dry weight of soybean variety (Tarkari Bhatmas-1) at 54 days after sowing under different nutrient management at Khumaltar, 2016

SN	Nutrient Management	Plant height (cm)	Plant drymatter (g/plant)	Nodule number/plant	Nodule dry weight (mg/plant)
1	30:60:30 $N:P_2:O_5:K_2O$ kg/ha (Recommended dose)	48	13	114	30.6
2	30:80:30 $N:P_2:O_5:K_2O$ kg/ha	47	10	89	23.1
3	50:60:30 $N:P_2:O_5:K_2O$ kg/ha	49	13	106	28.7
4	50:80:30 $N:P_2:O_5:K_2O$ kg/ha	48	11	104	28.9
5	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + compost 10 t/ha	54	13	132	48.9
6	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + Rhizobium inoculation	49	11	143	28.2
7	30:60:30 $N:P_2:O_5:K_2O$ kg/ha + Biochar (@ 330 g/plot)	46	12	98	29.0

S N	Nutrient Management	Plant height (cm)	Plant drymatter (g/plant)	Nodule number/plant	Nodule dry weight (mg/plant)
8	Compost 20 t/ha	53	12	106	41.3
	Mean	49	12	111	32.3
	P value	0.04	0.828	0.614	0.007
	LSD (<0.05)	5	-	-	12.5
	CV (%)	7	23	37	26

Yearly variation in yield and yield attributing traits

There was a significant yearly variation for all parameters. The nutrient management x year interaction was significantly different for maturity only (Table 4). In 2017, plants were slightly taller and had maximum numbers of unfilled pods. Whereas in 2016, plants were matured earlier than in other years and the seed size was slightly large.

Table 4. Yield parameters of soybean variety Tarkari Bhatmas-1 at Khumaltar

Year	Flowering	Maturity	Plant height (cm)	Main branches/plant	Unfill pods/plant	100 seed weight (g)
2016	48	108	45	3	2	22.7
2017	-	127	46	2	9	22.3
2018	66	122	42	3	7	20.8
Mean						
Year (Y)	<.001	<.001	<.001	<.001	<.001	<.001
LSD (<0.05)	0.3	0.4	2	0.4	1	0.4
Nutrient x Y	0.473	0.045	0.365	0.996	0.384	0.473
LSD (<0.05)		1.2	-	-	-	-
CV (%)	0.9	0.7	8	28	33	4

Grain yield and straw biomass production

Grain yield was not significant among various nutrient management treatments in the first year of the experiment (Table 5). Pooled analysis showed a highly significant difference in grain yield and straw dry matter among nutrient management treatments (Table 5). Application of compost @ 20 t/ha alone and in combination with recommended chemical fertilizers (RD) of 30:60:30 $N:P_2O_5:K_2O$ kg/ha produced 24% and 11% higher grain yield as compared to RD only.

Table 5. Grain yield and straw dry matter production of soybean variety Tarkari Bhatmas-1 under different nutrient management at Khumaltar (2016-18)

SN	Nutrient Management	Grain yield (kg/ha)			Straw dry matter (kg/ha)		
		2016	2017	2018	2016	2017	2018
1	30:60:30 $N:P_2O_5:K_2O$ kg/ha (Recommended dose)	2138	1916	1387	1970	2819	2379
2	30:80:30 $N:P_2O_5:K_2O$ kg/ha	2013	1883	1414	2052	2715	2288
3	50:60:30 $N:P_2O_5:K_2O$ kg/ha	1926	1793	1239	1870	2841	2208
4	50:80:30 $N:P_2O_5:K_2O$ kg/ha	1909	1898	1390	1885	2847	2407
5	30:60:30 $N:P_2O_5:K_2O$ kg/ha + compost 10 t/ha	2341	2165	1517	2178	2647	2358
6	30:60:30 $N:P_2O_5:K_2O$ kg/ha + Rhizobium inoculation	2081	1904	1541	1910	2743	2366
7	30:60:30 $N:P_2O_5:K_2O$ kg/ha + Biochar (@ 330 g/plot)	2045	1940	1318	1931	2545	2140
8	Compost 20 t/ha	2389	2611	1776	2544	3021	2641

SN	Nutrient Management	Grain yield (kg/ha)			Straw dry matter (kg/ha)		
		2016	2017	2018	2016	2017	2018
	Mean	2105	2014	1448	2043	2772	2348
	P value	0.290	<.001	0.004	0.002	0.013	0.018
	LSD (<0.05)	-	264	232	308	226	246
	CV (%)	15	9	11	10	6	7

Table 6. Mean grain yield of Tarkari Bhatmast-1 as affected by nutrient management (2016-2018)

SN	Treatments	Grain yield (kg/ha)	Straw dry matter (kg/ha)	HI
	Nutrient Management (NM)			
1	30:60:30 N:P_2:O_5:K_2O kg/ha (Recommended dose)	1814	2377	0.40
2	30:80:30 N:P_2:O_5:K_2O kg/ha	1770	2339	0.40
3	50:60:30 N:P_2:O_5:K_2O kg/ha	1653	2306	0.39
4	50:80:30 N:P_2:O_5:K_2O kg/ha	1732	2379	0.39
5	30:60:30 N:P_2:O_5:K_2O kg/ha + compost 10 t/ha	2007	2394	0.42
6	30:60:30 N:P_2:O_5:K_2O kg/ha + Rhizobium inoculation	1842	2340	0.41
7	30:60:30 N:P_2:O_5:K_2O kg/ha + Biochar (@ 330 g/plot)	1769	2213	0.41
8	Compost 20 t/ha	2258	2735	0.42
	Mean	1856	2385	0.40
	Genotype (G) P value	<.001	<.001	<.001
	LSD (<0.05)	186	155	0.02
	Year (Y) P value	<.001	<.001	<.001
	LSD (<0.05)	114	95	0.01
	NM*Y	0.808	0.193	<.001
	LSD (<0.05)	-	-	0.03
	CV (%)	12	8	5

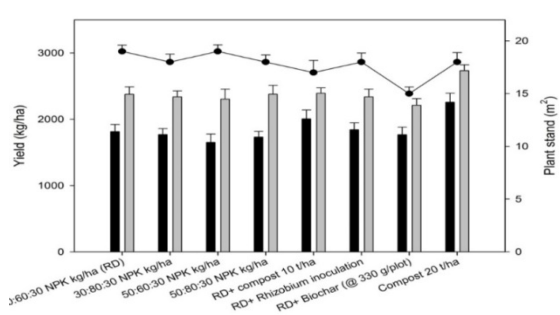

Fig. 2: Final plant stand (-●-), grain yield (black bar) and straw dry matter (gray bar) of soybean variety Tarkari Bhatmas-1 as affected by nutrient management at Khumaltar (2016-18).

Among different nutrient management treatments, few numbers of plant stands were observed from the plot treated with the recommended dose of fertilizer with biochar. This may be due to the presence of some phytotoxic compounds in biochar (Rogovska *et al.*, 2012). However little information is available about the role of biochar in germination. The numbers of pods per plant significantly differed with treatments. The highest number of pods per plant was recorded from the integration of chemical fertilizer with biochar. The result was at par with the integration of recommended dose chemical fertilizer with compost 10 t/ha and compost 20 t/ha alone treated plot. This may be due to the increased uptake of nutrients on biochar treated plot. This result was in line with Mete *et al*. (2015). Similarly, the integration of organic fertilizer with inorganic fertilizer increased the availability of nutrients to the plants. This may be the reason for increasing the number of pods per plant. This result was similar to the findings of Babhulkar *et al.,* (2002). Plant height was significantly influenced by the application of inorganic and organic fertilizer. Integration of organic fertilizers with chemical fertilizers increased the availability of nutrients considerably resulting in a positive effect on growth parameters. These findings are in accordance with the results of Babalad (1999) who had observed increased plant height, the number of trifoliate leaves per plant and the number of branches per plant in soybean due to the application of organic manure and inorganic fertilizers. A similar finding was reported in soybean by another author (Babhulkar *et al*., 2002). Higher nodule weight was observed on plot treated with integration of chemical fertilizer with compost but inoculation of rhizobium had no significant effect on nodule number and nodule weight. This may be due to the buildup of native soil rhizobial population in the Khumaltar Agronomy farm plot. This area was the traditional soybean cultivated area. So, the number of nodules per plant was found in a large number on uninoculated plot also (Maskey and Bhattarai, 2003). The inoculation and chemical fertilization in combination have a significant effect on the total number of nodules/plant (Alam *et al*., 2009).

Grain yield, straw dry matter and harvest index significantly differed with treatments while harvest index was only significant with treatment x year interaction. The seed yield varied from 1653 to 2258 kg/ha in the different treatments. The maximum seed yield (2258 kg/ha) and straw dry matter (2735 kg/ha) were observed with the application of compost 20 t/ha (Tables 5 & 6). The lowest seed yield (1653 kg/ha) was recorded in treatment (50:60:30 N:P_2 O_5:K_2O kg/ha). An increase in grain yield due to FYM may be due to its beneficial effects both on soil and plant by increasing the availability of plant nutrients throughout the growth period resulting in better uptake of nutrients, plant vigor and superior yield attributes (Shivakumar and Ahlawat, 2008). Organic manures along with inorganic fertilizers attribute to higher availability and adsorption of nutrients (Kumar *et al*., 2009). The balanced use of inorganic fertilizer and organic sources of nutrients-maintained soil fertility and physical behaviour resulting in higher soybean yields. Similarly, Chaturvedi and Chandel (2005) found that combined application of 100% recommended dose of NPK+ FYM @ 10 t/ha improved the biological condition which helps to improve the yield of soybean. Ghosh *et al*. (2001) reported that the application of FYM @ 10 t/ha along with the recommended dose of NPK to soybean recorded significantly higher seed yield (2.65 t/ha) compared to NPK alone (1.45 t/ha). This may be due to the continuous supply of nitrogen, phosphorus and potassium to the crop at an early stage from chemical fertilizer and through compost at the later stage of crop growth as slow-release nutrients.

Conclusion

Based on the results, it may be concluded that grain yield and yield attributing characters of soybean can be substantially increased by the integration of organic fertilizer with inorganic fertilizer. More specifically, and application of compost @ 20 t/ha alone or recommended dose of chemical fertilizers of 30:60:30 N:P_2O_5:K_2O kg/ha + compost 10 t/ha produced higher grain yield as compared to other treatments under Khumaltar condition. For the sustainability of soil fertility and soybean crop productivity, judicious use of chemical fertilizers along with organic manures is necessary.

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Review on scope and challenges of direct seeded rice in Nepal

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Abstract

Rice is an important staple food crop of more than half of the population in the world to provide food security and livelihoods. Imminent water crisis due to climate change, water demanding nature of traditionally cultivated rice, increasing scarcity of labor and escalating labor costs drive the search for alternative management methods to increase water productivity, system sustainability and profitability in rice cultivation. Direct seeded rice (DSR) technique has received much attention and popularity nowadays because of its low-input demanding nature that can mitigate emission of green-house gases and adaption to climatic risks. DSR involves sowing of dry seed into a prepared seedbed, pre-germinated seed into a puddled soil surface and standing water. The development of early maturing varieties and use of efficient nutrient management practices along with increased adoption of integrated weed management techniques have encouraged many farmers to switch from transplanted to DSR culture. DSR technology is highly mechanized in some developed countries like USA, Australia, Japan, China, Korea etc. This shift from traditional rice to DSR will substantially reduce crop water requirements, soil organic-matter turnover, enhanced nutrient management, carbon sequestration, weed management, greenhouse-gas emissions and enhance crop intensification. However, weed and nematode infestation, blast, panicle sterility, lack of suitable varieties for DSR and lodging are major challenges. Based on existing evidences, this paper reviews the integrated package of technologies for DSR, potential advantages and challenges associated with it.

Keywords: Food security, green-house gases, priming, tillage

Introduction

Rice is the world's most important cereal crop and a major staple food for more than half (>3.5 billion) of the world's population (CGIAR, 2016) and covered about 11% of the world's cultivated land area (Kumar and Batra, 2017). Rice provides 20% of the world's dietary energy supply, while wheat and maize supplies 19% and 5 %, respectively (Alexandratos and Bruinsma, 2012). Rice cultivated area is decreasing annually and there is no possibility of increasing the area, whereas the world population is increasing very speedily.The major reasons of declining global land area under rice cultivation are urbanization, industrialization, crop diversification and environmental degradation (Mishra *et al.*, 2017). Asia is the center of the global food security, where a total of 90% of the global rice is produced and consumed (Bandumula, 2017). More than half of the world's population with one-thirds of global hungry and poor are living in Asia (Monika, 2013). To meet the global rice demand, it is estimated that about 114 million tons of extra milled rice is needed by 2035, which is equivalent to an overall increase of 26% in the next 25 years (Kumar and Ladha, 2011). The rice production is only possible by increasing rice productivity per unit area and per unit time. Global warming due to increasing greenhouse gases (GHGs) like methane, carbon dioxide, carbon monoxide, sulphur dioxide is threatening the sustainability and productivity of transplanted rice. Farooq *et al.*, (2011) reported that, as compared with other cereal crops like maize and wheat, the conventional transplanted rice (CT-TPR) consumes 2-3 times more amount of water. The high consumption is due to high losses of water through puddling, surface evaporation and percolation. The water scarcity for rice cultivation has been serious matter and is widespread these days. Approximately 18 million ha of irrigated rice in Asia is being projected to suffer from water scarcity by 2025 (Tuong *et al.*, 2002). The adoption of CT-TPR has deleterious effects on soil environment and for the succeeding wheat and other upland crops (Dhakal *et al.*, 2013). It is a widespread concern issue of the population growth and the agricultural production needed to sustain agriculture without environmental degradation (Maskey, 2001).

Rice is a major staple crop of Nepal in terms of area, production and livelihood which fulfills more than 50% of the calorie requirement of the people (Adhikari *et al.,* 2013). The total cultivated area was 1.48 million hectares with 5.43 million tons of production during year 2018 (FAOSTAT, 2019). Rice contributes about 20% to the Agricultural Gross Domestic Product (AGDP) and more than 7% to the total GDP (Joshi and Upadhya, 2020). The productivity growth rate of rice in the last 54 years was only 1.5% in Nepal which has not kept up with the population growth rate of 2.3% and the per capita rice consumption is 137.5 kg which is the highest figure in the world. The reduction of rice area may be due to developmental works like road, buildings, land plotting for buildings etc. The low average yields indicate that there is a considerable yield gap between attainable yields and actual mean yields in farmers' fields in many production situations (Adhikari and Haefele, 2014). Devkota and Phuyal (2017) reported that several factors including high population growth, lack of marketing network, human induced deforestation and desertification have already threatened food security in Nepal. Before 1975, Nepal was once a food exporting country which has become a net food importer because of decline in food production that leads to more malnutrition particularly for children (Adhikari, 2015). Based on the above mentioned evidences, the present paper reviews DSR as an alternative integrated package of technologies with potential scopes, advantages and disadvantages in Nepalese situation.

Methodology

Review was made based on the secondary information from different sources of publications through national and international journals, proceedings, books and internet browsing etc.

Rice growing environment in Nepal

Rice is grown in three agro-ecological regions from terai and inner terai (60m to 900m); mid hills (1000m to 1500m) and high hills (1500m to 3050m) under two water regimes (Irrigated and rainfed) and in two topographic conditions (lowland and upland) (Gadal *et al.,* 2019). The tropical climate is found in terai and inner terai region where as sub-tropical and warm temperate is found in mid hills and mountain areas, respectively (Table 1). Rice is classified based on agro-ecological domains (terai, mid hills and mountain), planting season (spring, summer, rainy and winter), species (*indica*, *japonica* and *javanica*) in Nepal. The Terai region is plane and fertile which is considered as the granary of the country. Terai accounts for about 73% of the country's rice output; the hills produce 24%, and the mountain about 3 % (Adhikari *et al.,* 2013). In general, the monsoon starts in June from eastern part of Nepal and move to central and western part. The success or failure of rice production in Nepal depends on rainfall. About 65% of the rice in Nepal is cultivated under rainfed conditions. Of the total rainfall more than 80% is in between June to September. The year receiving higher rainfall produces more rice and vice versa in the year with less rainfall (Adhikari *et al.,* 2013). There is more rice cultivation and production in eastern parts of Nepal than western. In a very limited area, farmers in the eastern part of Terai produce three rice crops in a year (spring, main season and boro/winter) in few districts (Jhapa, Morang and Sunsari). In the mid hills and valleys (warm sub-tropical climate) with year-round assured irrigation facilities, rice farmers grow spring rice (Chaite Dhan) in addition to main season rice (Adhikari and Haefele, 2014). However, majority of the rice in the mid hills are produced as a single crop in the pond terraces. In the high hills upto 3,050 m irrigated cold tolerance rice is grown once in a year due to its longer growing period and low temperature. Basnet (2008) reported that in Nepal, the rice production area and productivity is decreasing from east to west, which might be due to variation in rainfall and socio-economic conditions of the regions. Rice-wheat and rice-maize are the predominant cropping patterns adopted in Terai and the mid hills in Khet land (irrigated and rainfed lowland) respectively. The rice is commonly grown in Nepal by transplanting seedlings into puddled field which is called CT-TPR. It involves growing seedlings in a nursery bed and later transplanted. The main fields are puddled, leveled and water depth of 5-10 cm is maintained followed by transplantation of 20-25 days old seedlings from nursery (Bista, 2018). The puddled field can reduce water percolation, control weeds, facilitate fast and easy seedling establishment, and create anaerobic conditions to enhance nutrient availability to plants (Sanchez, 1973).

Why DSR ?

Conventional transplanting of rice is more water demanding, laborious, more time consuming, tedious during transplanting due to drudgery and requires a lot of expenditure on raising nursery, uprooting, and transplanting of seedlings (Pathak *et al.,* 2011). Among cereal crops, rice is a two to three times more user of freshwater (Toung *et al.,* 2005). Due to increasing population, lowering of the water table, uncertain supply of irrigation water, declining of water quality, inefficient system of irrigation, competition with non-agricultural sectors, the share of water for agriculture is declining very fast (Kaur and Singh, 2017). It is estimated that only 50-55% of water will be available for agriculture by 2025 as against 66-68% in 1993 (Sivannapan, 2009). The International Water Management Institute estimates that one-third of the Asian population will face water shortages by the year 2020 (Mishra *et al.,* 2017). Pathak *et al.,* (2011) reported that CT-TPR rice cultivation needs 3000 to 5000 litres of water to produce 1 kg rice. It is reported that at global level 70-80% of fresh water is used in agriculture and rice accounts for 85% of this water. In CT-TPR practices, due to heavy use of pesticides and fertilizers caused increased pollution (water, air, soil) in many rice growing areas, which results in human and animal health problems like cancer, reduce fertility, varied metabolic disorder and high infant mortality etc. The CT-TPR practice increases the cost of cultivation during field preparation and water management (Giri, 1996) with potential loss of farm income (Tripathi *et al.*, 2004). The labour requirement for transplanted rice including nursery bed management and transplanting is approximately 50 person days/ha in comparison to 3-7 person days/ha for seed drilled or wet seeded rice (Mann *et al*., 2007). Labor involved in rice transplanting has become scarce and costly these days because laborers are shifting from agriculture to industry, public works, and overseas employment (Devkota *et al.*, 2013). Therefore, for the sustainable rice production, we must focus on alternative crop establishment methods which can reduce water and labor use and can increase rice productivity.

DSR production technology

DSR is the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. Commonly three principal methods of DSR are followed by the farmers in different countries are: dry seeding (sowing dry seeds into dry soil called Dry DSR), pre-germinated seeds are sown on wet puddled soils (Wet DSR) and water seeding (sowing seeds into standing water) (Farooq *et al.,* 2011) (Table 2). DSR technology is developed as a resource conserving technology and as a viable alternative to transplanted rice (Tripathi *et al.,* 2004). DSR practice can be readily adopted by small farmers as well as large farmers in Nepal where the required machinery are also locally available through custom hire (Devkota *et al.,* 2013). The dry seeding is practiced in upland and rainfed lowland, while wet seeding is in irrigated areas (Balasubramanian and Hill, 2002). In DSR, seeds are drilled or dribbled or broadcast on unpuddled soil either after dry tillage or zero tillage or on a raised bed as an agronomic management and technological innovation into dry or moist soils (Chauhan *et al.*, 2015). The principle methods of DSR are:

1. Dry direct seeding (Dry DSR)

The different seeding practices are followed in different countries in Dry DSR. Some of used important practices are: broadcasting of dry seeds on unpuddled soil after either zero tillage or minimum tillage and conventional tillage, dibbled method in a well prepared puddled field, drilling of seeds after conventional tillage, reduced tillage using a power operated seeder, a seed-cum fertilizer drill after land preparation is completed (Kumar and Ladha, 2011). The dry seeding method is traditionally practiced in rainfed upland, lowland, and flood prone areas of Asia (Rao *et al.,* 2007).

Rao *et al.,* (2007) reported that DSR practice was most common before 1950s but was gradually replaced by CT-TPR method. After sowing of seeds using DSR, precise water management during seed emergence (first 7-15 DAS) is of great importance (Kumar *et al.*, 2009). After seed germination, the field does not get saturated during root formation. Field can be saturated at three-leaf stage to ensure proper rooting and seedling establishment as well as germination of weed seeds (Kamboj *et al.,* 2012). Proper repairing and management of bunds also assists in maintaining the uniform water depth and reduce the water losses through seepage and percolation (Humphreys *et al.,* 2010). Water stresses during tillering, panicle initiation and grain filling stages causes heavy losses of grain yield by delay in anthesis and higher grain sterility (Kumar *et al.,* 2017).

2. Wet direct seeding

Wet direct seeding involves the sowing of pre-germinated seeds with a radicle having 1-3mm on or into the puddled soil. In Wet-DSR if seeds are sown into the puddled soil, the seed environment becomes anaerobic, which is called anaerobic Wet-DSR. The aerobic wet seeding practice is increasing in irrigated and rainfed lowland areas (Balasubramanian and Hill, 2002). The rice farmers in developing countries followed wet seeding due to labor shortage because of migration of farm labor from farm job to non-farm jobs (Smith and Shaw, 1966). To prepare pre germinated seeds, the dry seeds are soaked in water for 24 hours followed by incubation for 24 hours in the jute bag (loose pack and sprinkle water 3-4 times within a day), results pre sprouted seeds, which are broadcasted manually (Deo *et al.,* 2019) or sown in line using a drum seeder (Khan *et al.*, 2009). At this period the seedling root will emerge 2−3 mm in length. The seed rate may vary from 80-100 kg/ha (targeted plant population 100−150 plants/m^2) and it would be better if an extra 10-20% seed is added when seed is not pre-germinated. After germination of seed, seedling desiccation may take place due to water stress which should be avoided by intermittent wetting and drying of field. However, there are some disadvantages of wet DSR. More seed damage by birds, snails, rats etc, desiccation of seeds if exposed to direct sunlight for long time, damage by floods (Bhuiyan *et al.,* 1995), increase lodging at maturity due to poor root anchorage on the soil surface (Yamauchi *et al.,* 1995), more weed infestation, higher pest and disease incidence if seed rate is used high (Sittisuang, 1995).

3. Water seeding

This method of water seeding is popular in those areas where red rice or weedy rice is becoming a severe problem (Azmi and Johnson, 2009). This practice is popular in Australia, European countries, USA (Southern Louisiana, Texas, California and Arkansas) and Malaysia to suppress weedy rice or red rice, reduced labor cost and production inputs. The incubated and pre-germinated seeds are sown in standing water on puddled or un-puddled field. Because of heavy weight of seeds, the sown seeds will sink in standing water, allowing good anchorage. The rice varieties that are used under this situation have good tolerance to a low level of dissolved oxygen, low light and other stress environments (Balasubramanian and Hill, 2002). In addition to irrigated areas, water seeding is practiced in areas where early flooding occurs and water cannot be drained from the fields easily.

Advantages of DSR over transplanting

a. Increase water productivity

Both Dry and Wet-DSR are more water efficient technologies and have advantage over CT-TPR (Dawe, 2005). With increasing shortage of water in the world, D-DSR with zero or minimal tillage has potential for saving of water especially for irrigated areas of Asia (Humphreys *et al.*, 2005). Kumar and Ladha (2011) reported that about 12–33% (139–474 mm) lower irrigation water use was found in DSR compared to flooded CT-TPR. Due to these reasons, the total water required amount and crop duration from seed to seed is reduced. (Kumar and Ladha, 2011). Le Xu *et al.,* (2019) reported that among water management practices, the DSR performed best under mild water stress conditions, matching with TPR yield.

b. Minimize the production of greenhouse gases (GHGs)

Rice-based cropping systems are major contributors of GHGs emission (CH_4, N_2O, CO_2) and holds a high potential for global warming. Under anaerobic condition during prolonged flooded condition in the rice field, CH_4 emissions takes place which is varies considerably under different conditions. CH_4 production is directly related to the characteristics of soil (soil chemical and physical properties), climatic conditions (temperature, rainfall) and crop management practices (Harada *et al.*, 2007). The amount of methane production from the rice field accounts to 10-20% (50-100 Tg per year) of the total annual CH_4 emission (Reiner and Aulakh, 2000). Pathak (2010) reported that continued flooded rice field showed highest emission of methane (34%) followed by rainfed flood prone rice (21%), respectively.

c. Good performance of succeeding crops

Sharma *et al*., (2003) reported that repeated puddling in CT-TPR adversely affects the physical properties of soil by dismantling soil aggregates, forming hard-pans at shallow depths by reducing permeability in subsurface layers. This situation can negatively affect the following non-rice upland crop like wheat, barley, mustards etc. This can be corrected by using DSR method instead of CT-TPR.

d. DSR saves the labor requirement

CT-TPR method is highly labor intensive which require more number of labors during nursery establishment, seedling uprooting, land preparation (puddling and labeling) and in transplanting. Rapid economic development in Asia has increased the demand for labor in non-agricultural sectors, resulting in reduced labor availability for agricultural use (Dawe, 2005) and limited number of available labors is more costly for agricultural works. Kumar and Ladha (2011) reported that labor forces in agriculture are declining at 0.1-0.4%, with an average of 0.2% per year in Asia. DSR practices can overcome the crisis of mechanization for land preparation and transplanting practices and help in drudgery reduction (Din *et al.*, 2013). Pandey and Velasco (2002) reported that depending on the nature of the production system, direct seeding can reduce the labor requirement by as much as 50% (Table 1).

Table 1. Pre harvest labour use (man days per ha) in different countries in direct seeding and transplanting

Country / Province	Dry seeding	Transplanting	Reference
1. Philippines			
• Lloilo	40	53	Pandey and Valasco (1998)
• Pangasinan	22	49	Pandey *et al.*, (1995)
2. India			
• Utter Pradesh	72	112	Pandey *et al.*, (1998)
• Bihar	75	152	Singh *et al.*, (1994)
• Orissa	141	152	Fujisaka *et al.*, (1993)
3. Myanmar	19	60	
4. Vietnam			
• Longan	38	68	Farm survey data
5. Thailand	15	29	Isvilanonda (1990).

Challenges of DSR

a. Lack of suitable varieties for DSR

Most of varieties in different countries have been developed for TPR condition. No specific rice varieties have been developed for this purpose till now. The existing varieties for TPR do not appear to be well-adapted initially under oxygen-depleted micro environment. In Nepalese context, those inbred and hybrid varieties which are practiced in DSR under rainfed condition were especially released for TPR. The development of short to medium duration and drought tolerant varieties can grow under water limited condition (Humphreys *et al.*, 2010) and varieties suitable for conservation tillage practices, especially in zero or minimum tillage conditions (Fukai, 2002).

b. Weed management problem

High infestation of weed is a major problem of DSR especially in dry soil conditions (uplands) or in rainfed lowland (Rao *et al.*, 2007). Weeds are more problematic in DSR than in CT-TPR due to DSR seedlings are less competitive with weeds. The initial flush of weeds is not controlled in Wet and Dry-DSR (Kumar *et al.*, 2008a). Xu *et al.*, (2019) reported that weed management was identified as the most important factor limiting the productivity of DSR, and the variation in DSR relative yield exceeded 30% under different weed control levels. In CT-TPR methods, the practice of maintaining standing water itself reduces large amount of weeds and about 2-3 manual weeding can also be economic and feasible (Bista, 2018). Mechanical weeding practice is economically and practically not feasible in commercial farming because of the lower efficiency in weed control and decreasing the pattern of labor availability with increased wages (Bista, 2018).

c. High grain sterility and low yield

DSR can produce comparable yields to CT-TPR but this practice is more prone to yield losses due to inappropriate management practices, unsuitable soil properties and climatic stresses (Xu *et al.*, 2019). As compare to other cereal crops, rice is more drought-sensitive crop during flowering (Liu and Bennett, 2010). Dry seeding is the most common method of crop growing in DSR in which rice grows on marginal soil moisture compared with TPR. Any short period of drought, in particular during the reproductive phase, may be more critical in DSR compared with TPR. Time to anthesis reduces when panicle water potential decreases, resulting in large scale panicle sterility. Panicle transpiration resistance increased rice spikelet fertility during flowering when water stressed.

d. Poor establishment of plant population

Less germination of seeds and poor crop stand establishment are major problems of DSR due to which the final yield of crop can be reduced. The use of poor quality seed, lack of moisture in the field at the time of seeding, infestation of termites for root damage, blast and root knot diseases are major reasons for poor crop establishment.

Conclusion

DSR is a viable and sustainable alternative practice to produce slightly lower or comparable or even higher yield as that of CT-TPR with greater water use efficiency. It appears to be a viable alternative to solve the problems of labor and water shortage. Adoption of DSR practices can meet up the increasing demand of water for rice and reduce drudgery problem. For a successful transition of rice cultivation from CT-TPR to DSR culture, the demand of breeding special rice varieties with improved package of practices is very important issue. The use of DSR practices may change the mineral nutrients dynamics in soil (the availability of most micro elements is reduced in DSR). The water use efficiency (WUE) and water productivity may increase if appropriate land leveling is done in DSR field. Better seed germination, early crop vigour, semi dwarf and earliness may improve WUE and intensive farming. DSR can be a major opportunity for all farmers in water scarce areas with higher efficiency in cost of production and labour use. Poor establishment of plant population is a hindrance in the wide-scale adoption of DSR. However, we should also comprehensively consider the threats from weeds, the lodging problem, insect pests (root knot nematode) and disease (blast), varietal problem, N_2O emission, when we advocate direct-seeded rice in the country.

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Screening of soybean genotypes to short period of flooding

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Abstract
High soil moisture stress owing to heavy rainfall during the early growth stage is the most limiting factor affecting the growth and productivity of soybean in the Terai region of Nepal. This study was conducted to identify the soybean cultivars suitable for high soil moisture stress condition. Sixteen cultivars of soybean were planted under two soil moisture conditions namely, (a) short term flooded and (b) normal growing conditions in two consecutive years 2018 and 2019. Six stress tolerance indices like stress tolerance (TOL), stress susceptibility index (SSI), yield stability index (YSI), yield index (YI), mean productivity (MP) and geometric mean productivity (GMP) were calculated based on seed yields under flooded and normal conditions. The combined analysis showed that soybean cultivar SBO–115 (1912 kg/ha) and TGX 1990–94F (1883 kg/ha) produced significantly the highest seed yield under normal and flooded conditions, respectively. These two cultivars TGX 1990–94F (YI =1.3) and SBO–115 (YI =1.2) also possess the highest value of yield index. In contrast, the yield stability index was found maximum in cultivar LS –77 –16 –16 with a value of 1.4. Similarly, correlation analysis showed that soybean yield under flooded condition had a significant and positive association with yield under normal condition, YI, MP and GMP, while negative association found with TOL and SSI. This study indicated that the cultivars TGX 1990 – 94F, G –1873 and Kavre found to be more stable in two different conditions, while cultivars TGX 1990–94F and SBO –115 found suitable for flooded condition. These cultivars can be used directly or further in the crossing program for breeding high moisture stress tolerance cultivars.

Keywords: Flooding, soybean, stress tolerance

Introduction

Soybean (*Glycine max* L. Merril) is the most important legume crop possessing very good food, nutritional, environmental and industrial values. It is widely cultivated from terai to hilly regions in Nepal, which is mainly grown during the rainy season. The majority of area under soybean cultivation found in hilly areas, but due to increasing its demands in livestock and poultry industries and high production potential, it is becoming popular in plain areas of Terai and inner terai geographical regions (Pokhrel *et al*., 2013). Nepal is importing about 62247 t soybean with an import value of 3 billion, annually (MoALD, 2018). Considering the importance of soybean, there is a need for increasing its production and productivity to ensure food, feed and nutritional security in addition to a means of increasing soil productivity. Though the growth rate of area (1.1%), production (3.6%) and productivity (2.5%) of soybean over 15 years period in the country showed an increasing trend, the productivity of soybean in Nepal (1.3 t/ha) is found substantially below than the World (2.8 t/ha) and the Asian (1.5 t/ha) regions (Pokhrel *et al*., 2018; FAOSTAT, 2020). The area and production of soybean in Nepal were 25179 ha and 31567 t, respectively in the year 2019 (FAOSTAT, 2020). Grain Legumes Research Program, NARC has released eight varieties of soybean such as Hardee, Hill, Ransom, Seti, Cobb, Lumle 1, Tarkari Bhatmas 1 and Puja, on which one variety named Hill has been denotified due to its low productivity (Pokhrel *et al*., 2018).

There are various factors for the low productivity of soybean, among them the soil waterlogging or flooding stress is common abiotic stress caused by heavy rainfall, prolonged periods of rains, excessive irrigation and low water infiltration rate of soils that influence soybean production in the monsoonal areas of Asian region (Kokubun, 2013; Ye *et al*., 2018). VanToai *et al*. (2010) reported as much as a 25% yield reduction of soybean in Asia due to flooding and flood irrigation. The poor seed germination (Wuebker *et* *al*., 2001), deprived nutrients availability (Steffens *et al*., 2005), reduction in the availability of oxygen to roots (Bailey-Serres and Voesenek, 2008), decreased in nodulation (Linkemer *et al*., 1998), leaf chlorosis (Jackson and Colmer, 2005) and increased susceptibility to diseases (Helms *et al*., 2007) are the major effects noted of high soil moisture stress condition resulting in a significant yield reduction in soybean (Linkemer *et al*., 1998). Poor performances of existing soybean varieties and loss of yield due to high soil moisture stress condition are the main concern of soybean cultivation, where the selection of suitable varieties of flooding tolerance is very crucial for obtaining higher yield. There are various quantitative criteria or stress indices such as stress tolerance (TOL), stress susceptible index (SSI), yield stability index (YSI), mean productivity (MP), geometric mean productivity (GMP) and yield index (YI) have been reported for the screening or identification of high soil moisture stress tolerance soybean cultivars (Choudhary *et al*., 2017). All these stress indices are measured based on the performance of soybean cultivars under both the stress and non-stress growing environmental conditions through the function of reducing yield under stress condition. Stress resistance is a relative yield of a cultivar as compared to other cultivars growing under the same growing condition, while the stress susceptibility of a cultivar is measured as the function of the yield reduction under stress condition (Choudhary *et al*., 2017).

Therefore, it is important to study the influence of high soil moisture stress on the yield of the different soybean cultivars under flooded condition. The main objective of this study is to analyze the stress indices for investigating the performance of different soybean cultivars under high soil moisture stress condition, which would help researcher and farmers to develop or choose suitable cultivars under high soil moisture growing environmental condition.

Methodology

The experiments were conducted at Grain Legumes Research Program (GLRP), Khajura, Banke located at 28° 06" 45' N latitude, 81° 35" 58' E longitude and 182 masl in the summer season of two consecutive years 2018 and 2019. Altogether, sixteen cultivars of soybean were used for the experiments. The experiment was laid out in randomized complete block design in two soil moisture conditions namely, (a) flooding or high soil moisture stress condition, maintaining more than 5 cm water level in the plots for 7 days at 30 days after sowing (DAS) and (b) non-stress condition, normal growing condition**.** Water was drained completely after the completion of flooding treatment of 7 days. The individual plot size was 3 m^2, where the soybean cultivars were planted maintaining 50 cm row to row and 10 cm plant to plant distances. Each of the experimental plots was replicated three times in each growing environments. Fertilizers were applied at the rate of 20:40:20 N: P_2O_5:K_2O kg/ha and weeding operation was done at 25 DAS in both the growing environments. The stress tolerance indices as adopted by Choudhary *et al*. (2017) and Anwar *et al*. (2011) were derived in the study as:

$$\text{Stress Tolerance (TOL)} = Y_{ns} - Y_s \quad (1)$$
$$\text{Stress Susceptibility Index (SSI)} = \{1 - (Y_s/Y_{ns})\} \,/\, \{1 - (\hat{Y}_s/\hat{Y}_{ns})\} \quad (2)$$
$$\text{Yield Stability Index (YSI)} = Y_s/Y_{ns} \quad (3)$$
$$\text{Mean Productivity (MP)} = (Y_s + Y_{ns})/2 \quad (4)$$
$$\text{Geometric Mean Productivity (GMP)} = (Y_s \times Y_{ns})^{1/2} \quad (5)$$
$$\text{Yield Index (YI)} = Y_s/\hat{Y}_s \quad (6)$$

Where, Y_s and Y_{ns} are the yields of each cultivar under high soil moisture stress and normal growing conditions, $\hat{Y}_s$ and $\hat{Y}_{ns}$ are the mean yields of all cultivars under stress and normal conditions, respectively.

Soil characteristics

The soil of the experimental plots was found sandy loam with neutral pH (6.7) that contains a low amount of organic matter (1.82%) and nitrogen (0.09%) but a high level of phosphorous (128.82 kg/ha) and potassium (291.01 kg/ha).

Climatic condition of the study area

During the study period from July to November, the study area received 114 mm (2018) and 563 mm (2019) rainfall, where October and November were the coolest months. The mean minimum temperature, maximum temperature and rainfall of the study area are presented in Table 1. Moreover, rainfall was not recorded during the time of application flooding treatment in both the experimental years.

Table 1. Average temperatures and rainfall during study periods of the years 2018 and 2019

Month	2018			2019		
	Min temp (ºC)	Max temp (ºC)	Rainfall (mm)	Min temp (ºC)	Max temp (ºC)	Rainfall (mm)
July	26.1	34.2	20.5	26.61	32.82	392.8
August	26.7	33.3	31.1	26.34	33.51	170.4
September	26.6	36.8	14.0	22.55	33.07	0.0
October	21.3	33.0	47.9	13.91	30.39	0.0
November	13.2	28.3	0.0	10.46	25.68	0.0

Statistical analysis

All the data on yield and stress indices of different soybean cultivars and the correlation coefficient between soybean yields under high soil moisture stress and normal growing conditions were analyzed statistically using statistical software SPSS version 16.0. The mean values of the parameters were tested for significant differences by using Tukey's honest significant difference tests. A probability level ≤ of 0.05 was considered for a statistically significant difference.

Results and Discussions

Growth and yield attributing parameters

The growth and yield attributing parameters of soybean cultivars under normal and high soil moisture stress growing environments are presented in Table 2. The overall means of yield attributing parameters like number of pods per plant, number of seeds per ten pods and hundred seed weight of soybean cultivars were found higher under the normal growing condition as compared to high soil moisture stress condition. In contrast, comparatively a shorter plant height of all the tested cultivars was noted in high soil moisture stress condition. These results are also in line with the findings of (Ara *et al.*, 2015). The tolerant soybean cultivars maintained a greater number of pods and seeds per plant, and seed weight under a high soil moisture stress condition than the sensitive cultivars.

Table 2. Growth and yield attributing parameters of soybean cultivars under short term flooded and normal growing conditions (combined of two years)

Cultivar	Days to flowering		Days to maturity		Plant height, cm		No. of pods per plant		No. of seeds per ten pods		Hundred seeds weight, g	
	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal
TGX 1989–21F	67 [a]	65 [a]	123	121 [abc]	75	72 [bcde]	65	64 [ab]	21 [ab]	23 [ab]	8.7 [cd]	11.0 [abc]
PK 7394	61 [abcd]	59 [abc]	116	114 [c]	80	78 [abc]	81	80 [ab]	22 [ab]	20 [ab]	11.7 [abc]	11.0 [abc]
Kavre	65 [ab]	61 [ab]	121	124 [a]	98	81 [ab]	85	68 [ab]	21 [ab]	19 [ab]	11.3 [abcd]	10.7 [abc]
AGS–376	56 [def]	53 [cd]	122	123 [ab]	79	53 [defg]	62	64 [ab]	19 [ab]	21 [ab]	14.3 [a]	13.7 [a]
SBO–115	59 [bcde]	60 [abc]	119	115 [bc]	101	76 [bc]	84	83 [ab]	20 [ab]	22 [ab]	11.0 [abcd]	10.3 [bc]
LS–77–16–16	51 [f]	51 [d]	118	117 [abc]	80	41 [g]	57	70 [b]	16 [b]	17 [b]	10.0 [bcd]	11.7 [abc]

Cultivar	Days to flowering		Days to maturity		Plant height, cm		No. of pods per plant		No. of seeds per ten pods		Hundred seeds weight, g	
	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal
IARS–87–1	54 [ef]	54 [bcd]	119	120 [acb]	87	51 [fg]	62	56 [b]	25 [a]	22 [ab]	12.3 [ab]	12.3 [abc]
F–778817	55 [def]	53 [bcd]	121	121 [abc]	82	53 [efg]	67	56 [b]	21 [ab]	20 [ab]	14.0 [a]	12.3 [abc]
TGX 1990–38F	59 [bcde]	64 [a]	120	121 [abc]	102	74 [bc]	78	88 [a]	20 [ab]	21 [ab]	10.0 [bcd]	9.3 [c]
Puja	52 [ef]	50 [d]	122	120 [abc]	73	57 [cdefg]	55	54 [b]	19 [ab]	21 [ab]	13.3 [ab]	13.3 [ab]
PI 94159	56 [def]	53 [cd]	121	119 [abc]	74	60 [cdefg]	63	54 [b]	18 [b]	20 [a]	11.3 [abcd]	13.0 [ab]
TGX 1990-94F	63 [qbc]	65 [a]	128	125 [a]	102	97 [a]	82	83 [ab]	20 [ab]	23 [ab]	8.3 [cd]	9.3 [c]
TGX 1987–62F	65 [ab]	63 [a]	118	114 [c]	80	74 [bcd]	91	84 [ab]	22 [ab]	23 [ab]	8.0 [c]	9.3 [c]
TGX 1485–ID	64 [abc]	59 [abc]	123	118 [abc]	79	65 [bcdef]	59	74 [ab]	18 [b]	22 [ab]	11.0 [abcd]	11.7 [abc]
G–1873	57 [cdef]	58 [abcd]	119	118 [abc]	82	66 [bcdef]	79	64 [ab]	18 [b]	20 [ab]	11.3 [abcd]	12.0 [abc]
Co 165	51 [f]	53 [cd]	119	118 [acb]	72	67 [bcdef]	68	65 [ab]	20 [ab]	21 [ab]	11.3 [abcd]	12.0 [abc]
GM	58	58	121	119	82	67	67	71	20	21	11.1	11.4
F-test	**	**	ns	**	ns	**	ns	**	**	*	**	**

Note: n*s indicates non-significance. * and ** indicate significance at $p < 0.05$ and $p < 0.01$, respectively. means followed by the same letter in each column do not differ by Tukey's honest significant difference tests at $P < 0.05$.*

Soybean yield

The effect of soil moisture condition on the yield of soybean cultivars both under the normal and high soil moisture stress conditions are presented in Table 3. The seed yield of the soybean cultivars significantly influenced in both the growing environments. Among the tested soybean cultivars, cultivars SBO–115 (1912 kg/ha), TGX 1990-94F (1886 kg/ha), PK 7394 (1658 kg/ha) and F–778817 (1658 kg/ha) produced the highest yield under normal growing condition, while the cultivars TGX 1990-94F (1883 kg/ha), SBO–115 (1699 kg/ha) and TGX 1987–62F (1603 kg/ha) were identified as the highest yielder in high soil moisture stress condition. The variation in seed yield of different soybean cultivars both under normal and stress environmental conditions was also reported by (Helms *et al*., 2007) and (Ara *et al*., 2015). The overall mean of the soybean cultivars was found higher in normal growing condition compared with high soil moisture stress condition. Although, the mean yield of all soybean cultivars was found higher in high soil moisture stress condition than the normal growing condition in the first year of the experiment, as the year received a very low amount of rainfall during the soybean growing season. In contrast, soybean yield was found about 16% more under the normal growing condition as compared to high soil moisture stress condition in the second year of the experiment. The result of this study is in line with the study of Ye *et al*. (2018) and Linkemer *et al*. (1998), where they noted a significant reduction in yield of soybean by 17% to 56% due to the effects of waterlogging stress. Similarly, Helms *et al*. (2007) also reported about a 20% yield reduction of soybean under three days of waterlogging condition during V_1 (first trifoliate) and V_2 (second trifoliate) stages. The reduction of yield under stress condition might be due to the reduction in root growth, nodule formation, nitrogen fixation, leaf chlorosis and carbon assimilation (Wu *et al*., 2017).

Table 3. Yield (kg/ha) of soybean cultivars under high soil moisture stress and normal growing conditions

Cultivars	Y_{ns}			Y_s		
	2018	2019	Mean	2018	2019	Mean
TGX 1989–21F	506 [ef]	2257 [abc]	1382 [bc]	946 [cde]	1989 [a]	1467 [ab]
PK 7394	997 [abc]	2319 [abc]	1658 [abc]	1396 [abc]	1710 [ab]	1553 [ab]
Kavre	722 [cde]	2371 [abc]	1547 [abc]	1107 [bcd]	1920 [a]	1513 [ab]
AGS–376	581 [def]	2080 [abcd]	1331 [cd]	818 [de]	1659 [ab]	1239 [b]
SBO–115	1250 [a]	2573 [ab]	1912 [a]	1361 [abc]	2038 [a]	1699 [ab]
LS–77–16–16	306 [f]	1394 [d]	850 [d]	573 [ef]	1824 [a]	1199 [b]
IARS–87–1	1030 [abc]	2054 [abcd]	1542 [abc]	999 [bcde]	1811 [a]	1405 [ab]
F–778817	1144 [ab]	2171 [abcd]	1658 [abc]	1191 [bcd]	1709 [ab]	1450 [ab]
TGX 1990–38F	840 [abcde]	2139 [abcd]	1489 [abc]	1467 [abc]	1771 [a]	1619 [ab]
Puja	810 [bcde]	1901 [bcd]	1355 [cd]	1237 [bcd]	1561 [ab]	1399 [ab]
PI 94159	884 [abcde]	1538 [cd]	1211 [cd]	1039 [bcde]	1522 [ab]	1280 [b]
TGX 1990 –94F	1011 [abc]	2761 [a]	1886 [ab]	1746 [a]	2021 [a]	1883 [a]
TGX 1987–62F	1013 [abc]	1912 [bcd]	1463 [abc]	1500 [ab]	1707 [ab]	1603 [ab]
TGX 1485–ID	969 [abcd]	1717 [cd]	1343 [cd]	1340 [abc]	1649 [ab]	1494 [ab]
G–1873	568 [def]	1956 [abcd]	1262 [cd]	978 [bcde]	1580 [ab]	1279 [b]
Co 165	473 [ef]	1797 [bcd]	1135 [cd]	353 [f]	1121 [b]	737 [c]
GM	819	2058	1439	1128	1724	1426
F-test	**	**	**	**	**	**

Note: Y_{ns}: *yield under normal condition.* Y_s: *yield under high soil moisture stress condition. ** indicates significance at p < 0.01. means followed by the same letter in each column do not differ by Tukey's honest significant difference tests at P < 0.05.*

High soil moisture stress indices

The high soil moisture stress indices of different soybean cultivars were calculated based on the seed yield under normal and stress conditions. The high soil moisture stress indices such as TOL, SSI, YSI, MP, GMP and YI of different soybean cultivars are presented in Table 4. A significant difference at $P < 0.05$ was found in YSI, while the variation at $P < 0.01$ was noted in MP, GMP and YI, among the tested soybean cultivars in the experiments. The result revealed that soybean cultivars are differing for the gene controlling seed yield and high moisture stress tolerance indices. The low value of TOL was found in cultivars TGX 1990-94F (2.8), G–1873 (-17.2), Kavre (33.3) and Puja (43.6), which indicates that these cultivars of soybean are more stable in both the growing conditions, stress and non-stress growing environments. The negative value of TOL showed that the higher yield of soybean cultivars under stress condition as compared to normal growing condition. Similarly, the lowest SSI index (-0.2) was found in soybean cultivar TGX 1990-94F, among the tested cultivars, which means that the cultivar is more resistant to a high soil moisture stress condition. In contrast, the highest YSI index was observed in cultivar LS–77–16–16 (1.4). The MP of the soybean cultivars ranged from 936.1 in Co 165 to 1884.7 in TGX 1990-94F. Likewise, a significantly higher GMP index was found in TGX 1990-94F (1881.2) and SBO–115 (1800.5) followed by PK 7394 (1601.2). The result of YI revealed that the soybean cultivar TGX 1990-94F and SBO–115 with the highest YI value of 1.3 and 1.2, respectively, possess the suitability of the cultivars under high moisture condition. In the line of this study, Shannon *et al.* (2005) also noted the variation in yield reduction between the flood-tolerant group of soybean cultivars and flood susceptible group of soybean cultivars in flooded environmental condition.

Table 4. High soil moisture stress tolerance indices of soybean cultivars (combined of two years)

SN	Cultivar	TOL	SSI	YSI	MP	GMP	YI
1	TGX 1989–21F	-85.70	-9.50	1.10 [ab]	1424.40 [c]	1417.90 [cd]	1.00 [abc]
2	PK 7394	105.00	5.90	0.90 [ab]	1605.30 [ab]	1601.20 [abc]	1.10 [abc]
3	Kavre	33.30	1.20	1.00 [ab]	1530.00 [bc]	1524.70 [bcd]	1.10 [abc]
4	AGS–376	91.90	7.90	0.90 [ab]	1284.60 [cd]	1283.10 [cde]	0.90 [bc]
5	SBO–115	212.10	11.70	0.90 [ab]	1805.50 [ab]	1800.50 [ab]	1.20 [ab]
6	LS–77–16–16	-348.30	-48.50	1.40 [a]	1024.30 [de]	1005.60 [ef]	0.80 [c]
7	IARS–87–1	137.20	9.30	0.90 [ab]	1473.60 [bc]	1471.40 [bcd]	1.00 [abc]
8	F–778817	207.70	13.30	0.90 [ab]	1553.90 [ab]	1548.80 [abcd]	1.00 [abc]
9	TGX 1990–38F	-129.40	-12.20	1.10 [ab]	1554.20 [ab]	1549.00 [abcd]	1.10 [abc]
10	Puja	-43.60	-3.10	1.00 [ab]	1377.10 [c]	1374.70 [cd]	1.00 [abc]
11	PI 94159	-69.40	-12.50	1.10 [ab]	1245.70 [cde]	1233.30 [de]	0.90 [bc]
12	TGX 1990–94F	2.80	-0.20	1.00 [ab]	1884.70 [a]	1881.20[a]	1.30 [a]
13	TGX 1987–62F	-140.80	-10.10	1.10 [ab]	1532.90 [bc]	1528.80 [bcd]	1.10[abc]
14	TGX 1485–ID	-151.50	-16.50	1.10 [ab]	1418.70 [c]	1409.70 [cd]	1.00 [abc]
15	G–1873	-17.20	-3.50	1.00 [ab]	1270.30 [cd]	1265.80 [cde]	0.90 [bc]
16	Co 165	397.80	37.40	0.7 [b]	936.10 [e]	911.80 [f]	0.50 [d]
	GM	-	-	1.00	1432.60	1425.50	1.00
	F-test	-	-	*	**	**	**

Note: *TOL: stress tolerance. SSI: stress susceptible index. YSI: yield stability index. MP: mean productivity. GMP: geometric mean productivity. YI: yield index. means followed by the same letter in each column do not differ by Tukey's honest significant difference tests at P < 0.05.*

Correlation among the stress indices

The correlation analysis between soybean yield under normal condition, yield under stress environment and stress indices were calculated to determine the most desirable high soil moisture stress tolerance index (Table 5). This analysis helps to identify the best indices for the selection of high moisture stress tolerance soybean cultivars. The soybean yield under high soil moisture stress condition had a strong positive correlation (r = 0.580) with the soybean yield under normal growing condition, imparting a high potential yield under normal or optimum growing condition also somehow results in improving yield in a high moisture stress environment. The soybean yield under both the growing environmental conditions had a significant correlation with all the indices of high soil moisture stress. Similar results were also recorded by (Choudhary *et al*., 2017) in fenugreek and (Anwar *et al*., 2011) in wheat crops.

Table 5. Correlation coefficients between soybean yields and high soil moisture tolerance indices

Variables	Y_s	Y_{ns}	TOL	MP	SSI	YI	GMP	YSI
Y_s	1							
Y_{ns}	0.580**	1						
TOL	-0.403**	0.511**	1					
MP	0.881**	0.896**	0.077	1				
SSI	-0.349*	0.532**	0.966**	0.119	1			
YI	0.991**	0.586**	-0.386**	0.881**	-0.331**	1		
GMP	0.880**	0.897**	0.080	1.000**	0.125	0.878**	1	
YSI	0.329*	-0.545**	-0.959**	-0.137	-0.993**	0.316*	-0.134	1

Note: Y_{ns}: *yield under normal condition.* Y_s: *yield under high soil moisture stress condition. TOL: stress tolerance. SSI: stress susceptible index. YSI: yield stability index. MP: mean productivity. GMP: geometric mean productivity. YI: yield index. * and ** indicate significance at p < 0.05 and p < 0.01, respectively.*

Conclusion

From this study, it can be concluded that soybean cultivars namely TGX 1990–94F, G–1873 and Kavre were more suitable in two different conditions (high and normal soil moisture). The cultivars TGX 1990–94F and LS–77–16–16 were resistant to high soil moisture stress or more stress tolerance, while SBO–115 and TGX 1990–94F found more suitable for high soil moisture stress condition. Moreover, the results of correlation indicate that the selection of soybean cultivars based on the stress indices MP, YI and GMP can be used in the selection of suitable cultivars for both the environmental conditions.

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Rice trade trend and policy implication in Nepal

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Abstract

This paper examines how rice external trade behaves over the recent six decades including major trading partners in the context of Nepal. Bringing the time series trade data from reliable sources, this study also attempts to highlight import dependency ratio, correlation of population and GDP per capita growth with total import and pin down plausible reasons behind these pictures. The correlation study between import data to population growth and GDP per capita showed a positive correlation with r values 0.71 ($p<0.05$) and 0.99 ($p<0.05$), respectively. National supply sides when combine with domestic production mimics aggregate rice demands and these figures show increasing patterns accompanied by growing imports together with import dependency ratio. India alone dominates the rice trade which accounts for more than 90 percent of Nepal's import in recent years. These noticeable surges in rice imports can be attributed to liberal trade policies of the respective trade partner countries, improvement in incomes, closer proximity, similar languages, and consumer preferences among others. Opening a domestic market for rice cannot be denied theoretically in favor of welfare-improving policy tools, however, it should be carefully considered to protect local farmer's concerns. Though growth in rice productivity is encouraging over the recent previous years, there is ample potential to increase further by integrated programs combining expansion of spring paddy, inputs, irrigation, and technology. Moreover, attention should be paid toward consumer's fine rice preferences aligning farmer's motivations. The introduction of fiscal policy with application of tariff or non-tariff measures at least for a few years can encourage the domestic rice industry. Above policy adjustment can drive Nepal toward its rice self-reliant footing.

Keywords: Export, import, new trade theory**,** rice, trade

Introduction

Paddy is a widely grown and consumed cereal crop in the world. Around 3.5 billion consume paddy globally as a staple food. Importantly, it has been a major dietary contributor across the 17 Asian, 9 American, and 8 African countries (Hedge and Hedge, 2013). Alike in other Asian countries, rice has remained a key food item for almost every family member in Nepal (Pokhrel *et al.,* 2021) and consumption figures show a clear rising trend over the recent couple of years (Pudasaini *et. al.,* 2018). Taken as a major staple and widely consumed food both in terms of frequency of intake in a single day and proportion of households, it dominates over the food basket for human consumption, and importantly people across each groups castes/ethnicity as well each agro-ecological belt take it as the most preferable food item (Dhungel and Achraya, 2017; Ghale, 2017).

Rising rice import figures in a predominantly agricultural country Nepal has sparked public policy debates which is also reflected in national agricultural plan documents such as Agriculture Development Strategy (ADS) and Fifteenth Plan. Agriculture Development Strategy and National Planning Commission plan documents primarily set import substitution strategy for many agricultural commodities including paddy (ADS, 2015; NPC, 2018). Critics opine surging importation of rice is a blow to the agricultural performance blaming that there is series of caveats in policy design or implementation weaknesses or both. Though the productivity and production figures are encouraging, the rising import is not self-explanatory. In addition, bilateral trade between the countries is regarded as an accelerating factor for the economic growth of both the partner countries and often regarding welfare increasing (Bhagavati and Srinivasan, 2002). Accordingly, countries are encouraged to open their border for foreign goods and services, popularly known as open trade policy. While others argue it is not always good to fully open the domestics markets since it may hurt infant industry and adversely affect job markets. Overwhelmingly, many trade economists are in favor of open trade and finance and lead function of the World Trade Organization (WTO) is guided accordingly. In South Asia, Nepal became second in opening its domestic market employing open general licensing (OGL) procedure with the introduction of trade policy in 1981 after Sri Lanka while India follows the same suite a bit later. Additionally, as in other parts of the globe, India, the key trading partner country of Nepal and Nepal itself forged trade treaty along with a wider regional bloc first in 1995 as the South Asian Preferential Trade Agreement (SAPTA) which expanded as more liberal pluralistic one in 2006, South Asian Free Trade Agreement (SAFTA). These outward-looking trading policies together with the improving incomes supported by macroeconomic growths might have contributing factors for the expansion of regional trade that can be attributed to the surge of rice import in Nepal (Regmi *et al*., 2017). Bringing together time series import data from reliable sources, this study attempts to highlight the trend over the decades, pin down plausible reasons behind these pictures. At the end policies and implementation strategies and associated activities get revisit opportunity for possible improvements in the future. Further, the paper briefly highlights salient features of external rice trade picking major trading partners of Nepal and attempt to concatenate related domestic trade and agricultural policies so that we can find few tangible and actionable solutions in favor of growing trade imbalances in agriculture commodities in general, and particularly in rice. This paper is developed discussing the first method, followed by data analysis while the conclusion section closes.

Materials and Methods

The study employed secondary data sources for the analyses. The secondary data was collected from relevant government publications and sources. Time-series data on rice trade for the period (1961-2019) was collected from the Department of Custom, Trade and Export Promotion Centre and Faostat web browser (http://www.fao.org/faostat/en/#data). Rice production time- series data was collected from the Ministry of Agriculture and Livestock Development, Economic Survey of Nepal. Population tim-e series dat was collected from Centre Bureau of Statistics. Gross domestic product (GDP) per capita in purchasing power parity (PPP) was collected from the World Bank (http://datatopics.worldbank.org/world-development-indicators/). Other relevant informations were collected from different journal articles, proceeding articles, books, annual reports and internet. The collected data was analyzed with the help of basic statistical techniques like trend, ratios, percentages and growths. The correlation study between import with population and GDP per capita in PPP (in constant 2011 international dollar) was also assessed in the study.

The import dependency ratio (IDR) expresses the share of available domestic supplies that come from import (http://www.fao.org/3/i2493e/i2493e06.pdf) and was calculated using the formula,

$$IDR = Imports \times 100 / (Production + Imports - Exports)$$

Results and Discussions

Trade flows and balance: 1961-2019

Compiling official data since 1961, we have an opportunity to visualize: export, import, balance of rice to see how these moved throughout study periods. The amount of rice exports and imports varies considerably over years. It is now surprising to know that Nepal was a net rice exporter till the year 1980, however, figures picked other way round right after and seems it could not return as a net exporter again. Grain trade was encouraged by then state, by establishing *dahan/chamal* Export Company in 1974/75 to enable rice export in the country as a government undertaking is an indication of national trade priority (Mallick, 1981). Rice trade flows started to follow reverse order around 1980s; consequently, Nepal became a net rice importer afterward though the amount varies considerably over the study period (Figure 1). When we look at the bilateral flows, figures follow oscillating patterns. Aggregate rice export including paddy husk, milled and brown rice, and broken rice stand 28.66 *lakhs* MT for the period 1961-70, which dropped as little as to 10.88 *lakhs* MT in 1971-80 (Faostat, 2020).

When we look five-year average, rice exports in terms of quantity follow a smooth trend till the 1970s and started to drop slowly first which came down further and reached to its lowest making it almost nil around the year 1985. Most importantly, it could not rebound afterward posing challenges to national agriculture or trade policy. On the other hand, possibly to meet the growing consumers' demand in Nepal, rice import started to grow since the year 1980s. Import growth remains almost stagnant till the year 2005 which surges afterward till now. Striking point is that import demand is noticeable in the immediate past five years.

Correlation of population and GDP per capita growth with total import

Movements of trade flows may depend on various socio-economic factors such as population growth, trade policies, physical infrastructures, level of production, change in consumer preferences and this applies in our case too. Productivity and production of rice and market connectivity play crucial roles as well. Increasing national production and productivity of rice could not able to meet the national demand. The correlation study between import data and population growth and GDP per capita in PPP showed a positive correlation with r values 0.71 ($p<0.05$) and 0.99 ($p<0.05$), respectively. The classical simple scatter plot between import data versus population growth (Figure 1A) and import data versus GDP per capita in PPP (Purchasing power parity) (Figure 1B) was plotted using locally estimated scatterplot smoothing techniques. Import was found to be robust after the country has crossed the 26 million populations. Further, the import data has also increased sharply when the GDP per capita in PPP crossed $2000 (Figure 2). The data coincides with the last decade data on import, population and GDP per capita in PPP (Figure 1, Figure 2). This kind of inference provides as partial information as the country lacks data on many variables, for example, change in consumer preferences, use of in-country production in sectors other than staple food, illegal import and export to border countries etc.

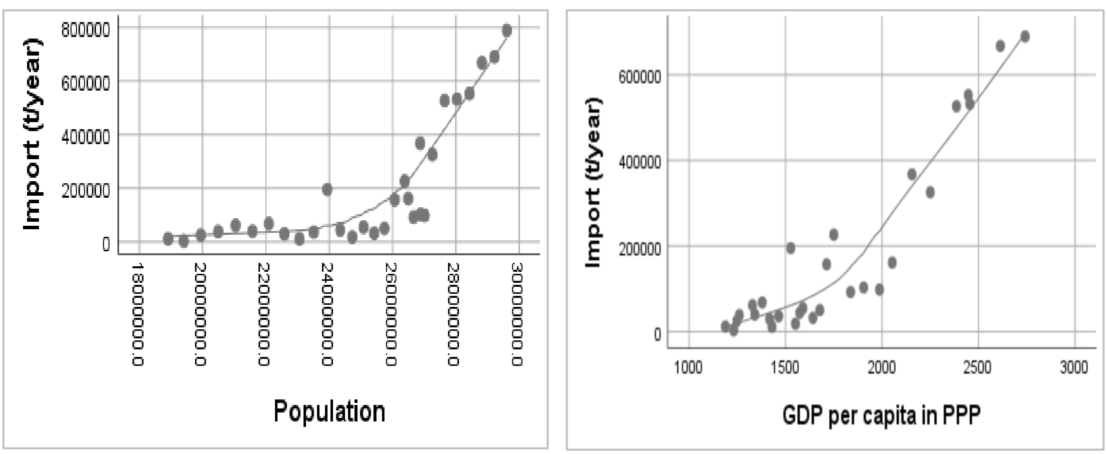

Fig. 1: Scatter plot showing relationship between import quantity and population and GDP per capita in PPP.

Country-wise rice imports to Nepal (milled equivalent) 2008/09-2018/19

Next, we take into account import of rice by country of origin to infer whether a particular country or group of countries has any visible concentration. Picking recent 11-year trade data from Nepal customs, we see that bordering country India remains a major country of origin for rice whether it is milled, or husk, or beaten types (Figure 2). Based on annual changes in total rice imports often exhibits positive growth, remarkably highest in the year 2011 climbing about 3 folds than 2010, while the years 2010 and 2015 witnessed declined imports (Figure 3). Both the volume and values of rice are tabulated to triangulate the import data. Total import increased by six folds in terms of quantity whereas the values of imports reached about 16 folds susceptible to the reporting figures in customs declaration. This type of reliability in trade data is common in many developing countries, based on duty levied against values, we prefer to confine on values when such doubts come in. Besides India, Nepal has imported rice from Japan, Italy, United States, Malaysia, Philippines, and Thailand albeit in a lower amount.

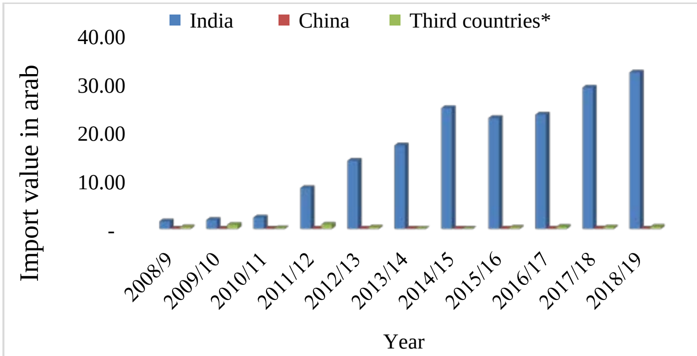

Fig. 2: Country-wise rice import to Nepal.

Note: **Bangladesh, Japan, Italy, United States, Malaysia, Thailand, Vietnam etc.*

We used milling percentages 66.2 following Panta and Aryal, (2014) for calculating rice milled equivalent. Core dataset is presented in Annex 1. Source: Department of custom, 2020

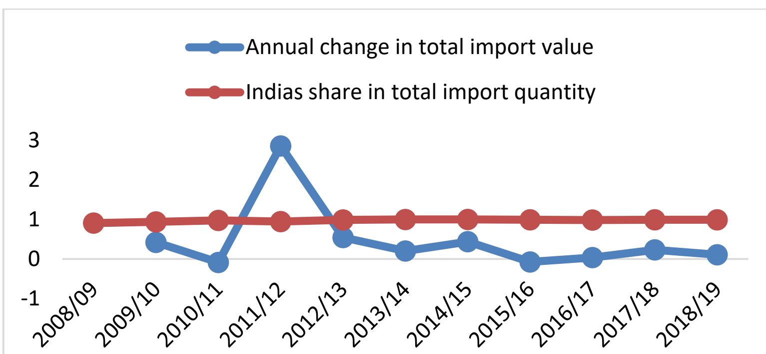

Fig. 3: Annual flow trend and India's share in rice import

Core dataset is presented in Annex 1. Source: Department of custom, 2020

Average exports over the study period are merely about 44 *Lakhs* NPR (0.01%) against 32 *arab* (99.99%) in imports which show pronounced imbalances in cereal (Table 1). Rice imports keep increasing trend in the study period. Among the cereal grains, rice imports dominate covering about 65 percent on average. Table 1 shows aggregate grain trade and corresponding rice flows over the most recent eight years.

Table 1. Share of rice import to total cereal import: 2011-2018

Year	Rice Imports in value (000NPR)	Rice export value (000NPR)	Total cereal imports value (000NPR)	Total cereal exports value (000NPR)	Share of rice imports in total cereal imports (%)
2011/12	9,288,122	47	11,972,435	8,422	77.58
2012/13	14,337,581	24,728	20,047,598	39,446	71.52
2013/14	17,254,764	8,297	28,161,992	18,373	61.27
2014/15	24,834,719	-	35,670,123	16,804	69.62

Year	Rice Imports in value (000NPR)	Rice export value (000NPR)	Total cereal imports value (000NPR)	Total cereal exports value (000NPR)	Share of rice imports in total cereal imports (%)
2015/16	23,005,541	199	39,025,913	16,303	58.95
2016/17	23,867,195	651	40,148,372	30,072	59.45
2017/18	29,409,407	309	45,414,446	16,517	64.76
2018/19	32,595,052	4,476	51,802,396	25,396	62.92

Source: Department of Custom, 2020

Import dependency ratio

One of the indicators of food security is import dependency ratio which reflects how the national supply of the commodity in question. It gives fair ideas on how a country fulfills its consumer demand both from production or imports. High dependency on a particular food item is often considered as supply vulnerable in case of any export friction of the exporting country. Exports restriction of edible food often generates price spikes in the highly import-dependent country or creates short supply pushing many people into a state of chronic food insecurity. For instance, worlds' staple food-importing countries faced big challenges of food price hikes in the year 2008-09 because of the export rigidity imposed by major exporting countries including India. This hast decision was announced to ensure its population's food requirement at affordable prices. Table 2 highlights the time series data on rice import dependency ratio over the recent decade. Rice dependency ratios over the year show visible growth over the study period indicating that rice demand is not met by national production. Shifting of people's consumption from other meals like millets and maize toward rice partly be explained by such ratios. Similarly, a change in varietal choice of Nepali consumers toward fine and aromatic rice which has little production in the country may be another reason. India, as a major rice exporter to Nepal, has leapfrogged in agriculture development popularly known as the "green revolution" that begins around 1960s. With the observed bumbler harvest, it was successful in exporting paddy to many countries including Nepal. Additionally, export enabling trade policies together with reduction in non-tariff barriers in the exporting countries may have encouraged such import growth (Hussain and Sinha, 2019). Likewise, the proximity of land border and similar languages can be regarded as a further import catalyzing factor.

Table 2. Import dependency ratio: 2009- 2018

Year	Production (Milled equivalent), mt	Import (Milled equivalent), mt	Export (Milled equivalent), mt	Import dependency ratio (%)
2009/10	2,663,771	98,377	0	4
2010/11	2,952,704	127,307	0	4
2011/12	3,357,828	325,918	338	9
2012/13	2,981,981	443,904	597,325	16
2013/14	3,341,145	445,753	123,152	12
2014/15	3,170,061	608,824	-	16
2015/16	2,845,990	511,938	650	15
2016/17	3,462,476	534,772	1,787	13
2017/18	3,410,574	667,810	1,599	16
2018/19	3,713,827	690,081	11,898	16

Note: **we used milling percentages 66.2 following Panta and Aryal, 2014 for calculating rice milled equivalent. Since the country is lacking nationally representative post-harvest loss data for rice, and therefore not postharvest loss accounted for milled rice calculation. Source: Department of Custom, 2020*

Productivity of selected countries

Rice productivity in Nepal at present and potential to grow bears special meaning for agriculture as well as trade policies. Since land under crops cannot go above some caps to maintain environmental health and sustainable agriculture and food system, the alternative is to gain on rice productivity through continuous research and extensions. Figure 5 sheds light on the most recent five-year average productivity that of Nepal and other high-yielding countries. China stands at the top rank in rice productivity with an average of 6.9 t/ha, followed by Japan and Vietnam. Nepal's five-year average productivity still lags behind most of the major producing and globally exporting countries. However, based on these FAO sources, major rice exporting country, Thailand's productivity is a bit lower than Nepal's reveals interesting curiosity. This is because Thailand produces mainly fine rice varieties for export purposes as it fetches a higher price. The productivity of fine rice varieties (traditional Thai origin) are lower yielding than hybrids and coarse high yielding varieties (HYVs). Both Asian and global productivity trend has fluctuated over recent years. Again, among Asian countries, China and India are big rice producing country in the world. They are consuming the majority of paddy produced domestically (Hedge and Hedge, 2013). However, productivity is high in Japan, Indonesia, China have higher productivity than the world average (Figure45)

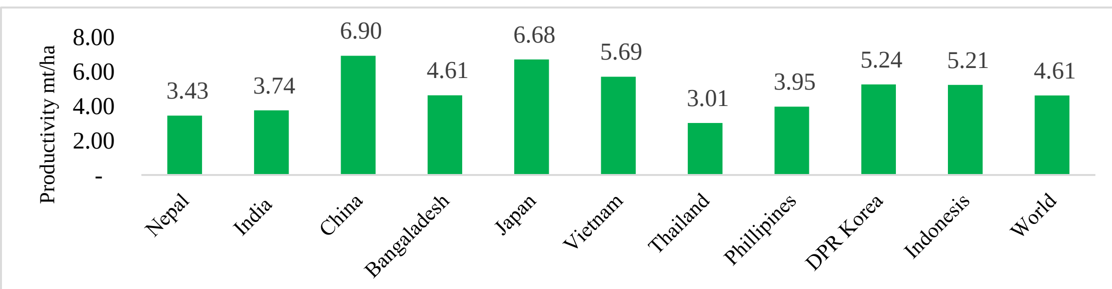

Fig. 4: Paddy average productivity comparison: Major Asian countries recent five year (2014-2018)

Source: Faostat, 2020

Given the wider rice productivity potential to achieve, there is ample opportunity for increased production by employing various policy measures. This may include but not limited to enhanced research customized to locality targeted, improvement in input supplies both in timely availability and at the recommended level, development in physical structures including agricultural roads, and quality extension services. Introducing modern post-harvest technology, strengthening market capacity at local levels, and management of year-round irrigation services are other areas on the list.

Conclusion

In spite of being an agrarian country, the continuously rising imports and sluggish or no exports affected the country's rice trade balance badly in recent years. The country was turning to importing country by following the route exporting-subsistence-importing country in rice. It is evident that Nepal exported a considerable amount of rice in 1970's and mid 1980's however, afterward, the country was importing rice and it is soaring up in recent years. The local production of rice is not enough to meet the increased requirement of the country leading dependency to India and China both for rice imports in terms of seed and grain (the negative trade balance), even though the country's edible cereal availability is sufficient. In order to ascertain food and nutrition security to its people, improved ongoing food trade deficit and increased rice production is an immediate national priority. Increased investment in agriculture, easy access of major inputs and blending of research finding with extension are some of the crucial policy areas of potential improvement.

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Effect of weed management practices on weed dynamics, yield and economics of spring maize at Dhading Besi, Nepal

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Abstract
Weeds have been a major constraint in maize cultivation resulting in huge economic loss to farmers. A field experiment was conducted at Dhading Besi, Nepal to evaluate the effect of different weed management practices on weed dynamics, yield and economics of spring maize in 2020. The experiment was laid out in Randomized Complete Block Design (RCBD) comprising of eight treatments with three replications. Rajkumar hybrid maize variety was used in the experiment. The treatments consisted of weedy check, weed free, atrazine as PE @1.0 kg a.i./ha, pendimethalin as PE @1.0 kg a.i./ha, atrazine @ 1.0 kg a.i./ha as PE followed by (*fb*) 2,4-D EE @0.5 kg a.i./ha as PoE, pendimethalin @ 1.0 kg a.i./ha as PE *fb* 2,4-D EE @ 0.5 kg a.i./ha as PoE, 2 hand weeding @ 20 and 40 DAS and Farmer's practice. The experiment result revealed that sequential application of atrazine *fb* 2,4-D EE treatment resulted in highest grain yield (11.37 t/ha) which was statistically similar with weed free (11.24 t/ha) and followed by the treatment atrazine (10.36 t/ha). 16 weed species belonging to 6 different families were identified. The broad leaf weeds and grassy weeds were more prominent than sedges. The total density and dry weight of weeds were found significantly lower in sequential application of atrazine *fb* 2,4-D EE than other treatments. Similarly, application of atrazine *fb* 2,4-D EE resulted in maximum weed control efficiency of 87.59 %, 95.91 % and 92.17% at 30, 45 and 60 DAS respectively. The lowest weed index (-1.27%) was also obtained in the application of atrazine *fb* 2,4-D EE. Yield loss due to weed in the weedy check treatment was found to be 50.99% followed by farmer's practice (43.17%). The benefit cost ratio and increment in benefit over weedy check were highest in atrazine *fb* 2,4-D EE followed by atrazine and significantly better than other weed management treatments. The sequential application of atrazine *fb* 2,4-D EE was found to be the most effective in controlling weeds, high yielding and economical among the different weed control treatments. The application of atrazine one time as PE was found to be next better option for weed control in spring maize.

Keywords: Spring maize, weed dynamics, weed management, yield

Introduction
Maize (*Zea mays* L.) also known as "Queen of Cereals" is the most important cereal crop grown in the world. Among cereals, it has the highest production volume of over 1.14 billion metric tons cultivated in 193.74 million ha area worldwide (FAO, 2018). In Nepal, maize is the second most important cereal crop after rice. It is a traditional crop cultivated as a way of life for food, feed and fodder (Paudyal *et al*., 2001). As the feed demand is increasing at the rate of 11% per annum, the demand for maize is shifting from food to feed for livestock and poultry (KC *et al*., 2015). The national production of maize in the fiscal year 2075/76 is 2713.63 thousand tons cultivated in 956.44 thousand ha (MoALD, 2018/19). The global average productivity of maize is about 5.9 t/ha with highest productivity of 11.8 t/ha in USA (FAO, 2018), whereas in Nepal the productivity of maize is only 2.8 t/ha (MoALD, 2018/19). According to MoALD (2018/19), Province no.1 and Bagmati Province have the highest share of 30.6% and 22.0% of total maize production in the country respectively with highest productivity of 3.14 t/ha in Province 2 and the lowest productivity of 2.25 t/ha in Sudurpaschim province. In Dhading district, area under maize cultivation is 20,678 ha with annual production of 58,601 Mt and productivity of 2.83 t/ha (MoALD, 2018/19). Behind this lower productivity of maize in the country, there are many production constraints.

Among them, weed infestation has been a serious problem limiting the maize production. Weeds compete with crops for nutrients, moisture, light and space and also possess allelopathic effects on crops (Walia and Walia, 2015). As farmers are practicing maize cultivation along with applying high inputs for higher production, that has enhanced the weed infestation. The extensive use of chemical fertilizers, repeated irrigation and wide spacing between maize rows provide suitable environment for weed growth and establishment enhancing the yield loss (Fanadzo *et al.*, 2007; Bajwa , *et al*.,2014).

Maize plants are more sensitive to the competition by neighboring weedy plants during critical period of weed control (CPWC) (Cerrudo *et al.*, 2012). The CPWC in maize varies from 2 to 7 weeks after sowing, with the most critical competition between 4-7 weeks after sowing (Shrestha *et al.*, 2019). As the early stages of maize are highly susceptible to weed competition, effective weed control at pre and early post emergence stages is necessary (Shrestha *et al.*, 2018). Conventional method of manual weed control requires large number of laborers (Shrestha *et al*., 2019), which are being scarce because of migration to foreign countries as well as in urban areas in non-agriculture sector and also costly because of increased wages of laborers (Jaquet *et al.,* 2019). Various chemical and mechanical methods of weed management have been used all over the world. However, the effective and economic control of weeds in maize cultivation can be achieved through the efficient and right use of pre and post emergence herbicides (Hossain *et al*., 2019). Marahatta (2018) also reported the application of suitable pre-emergence followed by post-emergence herbicides for effective control of weeds in maize, which is beneficial even than the manual weeding.

Materials and Methods

The experiment was conducted at Kudule, Dhading Besi, Nilkantha Municipality-12, Dhading, Nepal during spring season (Feb-June) of 2020. The geographical location of experimental site was 27°54’46.73’’N (latitude), 84°54’17.86’’E (longitude) and 612m (altitude). Soil of experimental plot was neutral (6.6) with sandy loam texture. The total rainfall received, average relative humidity, average maximum and minimum temperature during crop season were 727.34 mm, 61.27%, 24.82^{0}C and 15.12^{0}C respectively. The experiment was laid out in Randomized Complete Block Design (RCBD) comprising of 8 treatments and 3 replications:

1. Weed free
2. Atrazine as pre-emergence (PE) @1.0 kg a.i./ha
3. Pendimethalin as PE @1.0 kg a.i./ha
4. Atrazine @ 1.0 kg a.i./ha as PE followed by (*fb*) 2,4- D Ethyl Ester (EE) @0.5 kg a.i./ha as post-emergence (PoE)
5. Pendimethalin @ 1.0 kg a.i./ha as PE *fb* 2,4-D EE @ 0.5 kg a.i./ha as PoE
6. 2 Hand weeding @ 20 and 40 DAS
7. Farmer’s practice
8. Weedy check

Atrazine and pendimethalin were applied at 3 days after sowing (DAS) and 2,4- D EE was applied at 35 DAS. Farmer’s practice included the manual weeding at 35 DAS, hand weeding at 7 days’ interval up to 8 weeks after sowing was done in weed free plots and weedy check plot was left without weeding throughout the growing period. The individual plot size was made 3m* 2.5m (7.5 m^2) with 5 rows per plot and 10 plants per row. Seeds of Rajkumar hybrid maize were sown on 14th February 2020 at 60*25 cm spacing. The recommended dose of fertilizer N: P_2O_5:K_2O @160:60:40 kg/ha was applied in each plot in the form of urea, DAP and Muriate of Potash (MOP). Full dose of phosphorus and potassium were applied as basal dose and nitrogen was applied in three equal splits at the time of sowing, knee high stage and tasseling stage of the crop. Thinning was done at 20 DAS. Earthing up was done at 60 DAS. Weed sampling was done to identify weeds, to determine weed density and dry weight at 30, 45 and 60 DAS. Weed control Efficiency (WCE), Weed Control Index (WCI) and Weed index (WI) were calculated using the formula given by Mani *et al.*, (1973), Mishra and Tosh (1979) and, Gill and Vijay Kumar (1969) respectively. All the agronomic data and economics were taken and calculated using standard technique. The Data on weeds were transformed by square root transformation. ANOVA was computed and significant data were subjected to DMRT for mean comparison (Gomez and Gomez, 1984).

Results and Discussions

Weed flora

Sixteen different weed species belonging to 6 different families were identified in the experimental field (Table 1). *Chenopodium album*, *Oryza sativa*, *Ageratum conyzoides*, *Cynodon dactylon*, *Cyperus rotundus, Stellaria media, Digitaria* spp., *Fimbristylis* spp. were the major weed species identified in the research field. Dahal and Karki (2014) also reported 12 major species of weed including *Cynodon dactylon*, *Digitaria ciliaris, Cyperus rotundus, Ageratum conyzoides* etc. in spring maize in Rampur, Chitwan.

Table 1. Weeds observed in spring maize at Dhading Besi, Nepal in 2020

Common name	Scientific name	Family
Grasses		
Rice	*Oryza sativa* (L.) subsp. *Indica*	Poaceace
Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceace
Cogon grass	*Imperata cylindrica* (L.) P. Beauv.	Poaceace
Smooth Crab grass	*Digitaria ciliaris* (Retz.) Koeler	Poaceace
Hairy crab grass	*D. sanguinalis* (L.) Scop.	Poaceace
Sedges		
Purple nut sedge	*Cyperus rotundus* (L.)	Cyperaceae
Rice flat sedge	*Cyperus iria* (L.)	Cyperaceae
Fringe rush	*Fimbristylis* spp. (Vahl)	Cyperaceae
Broad leaf weed		
Lamb's quarters	*Chenopodium album* (L.)	Amaranthaceae
Pigweed	*Amaranthus viridis* (L.)	Amaranthaceae
Goat weed	*Ageratum conyzoides* (L.)	Asteraceae
Beggar ticks	*Bidens pilosa* (L.)	Asteraceae
Common Groundsel	*Senecio vulgaris* (L.)	Asteraceae
Heart leaf Drymarry	*Dymaria cordata* (L.)	Caryophyllaceae
Common chickweed	*Stellaria media* (L.) Vill.	Caryophyllaceae
Wood sorrel	*Oxalis* spp. (L.)	Oxalidaceae

Plant height

Significantly taller plant height was recorded in weed free plots at 30 and 60 DAS which was statistically similar with atrazine *fb* 2,4-D EE and atrazine only plots at 60 DAS (table 2). This could be due to regular removal of weeds that facilitated optimum utilization of soil nutrients and moisture by crop and hence lead to optimum growth of the plants. At 90 DAS, the maximum plant height (277.26 cm) was obtained in sequential application of atrazine *fb* 2,4-D EE. This could be due to better controlled of weeds by the application of herbicides which allow plants to grow freely without competition with weeds. As no weed control measures were applied, weedy check resulted in lower plant height at various dates of observation. The results are in accordance with Nandaji (2019) that the sequential application of atrazine *fb* 2,4- D resulted higher plant height. This was statistically at par with atrazine only and both were superior to sole application of pendimethalin.

Table 2. Plant height (cm) and leaf area index of spring maize as influenced by weed management practices at Dhading Besi, Nepal in 2020

Weed Management Practices	Plant height (cm)			Leaf area index		
	30 DAS	60 DAS	90 DAS	30 DAS	45 DAS	60 DAS
Weed free	16.57^{a}	119.1^{a}	275.93^{a}	0.14^{a}	0.86^{a}	3.80^{a}
Atrazine as PE	15.24^{ab}	113.73^{a}	272.47^{a}	0.12^{a}	0.59^{b}	3.58^{ab}
Pendimethalin as PE	14.38^{ab}	97.87^{b}	256.93^{b}	0.09^{b}	0.50^{bc}	2.50^{d}
Atrazine as PE *fb* 2,4-D EE	15.27^{ab}	118.9^{a}	277.26^{a}	0.11^{a}	0.79^{a}	3.84^{a}
Pendimethalin as PE *fb* 2,4-D EE	13.49^{ab}	107.2^{ab}	260.07^{b}	0.09^{b}	0.56^{bc}	3.16^{bc}
2 Hand weeding	13.98^{b}	110.13^{ab}	275.8^{a}	0.09^{b}	0.85^{a}	2.97^{cd}
Farmer's practice	11.52^{c}	79.93^{c}	236.87^{c}	0.06^{c}	0.43^{c}	1.59^{e}
Weedy check	11.49^{c}	68.73^{c}	222.13^{d}	0.05^{c}	0.27^{d}	0.87^{f}
F-test	*	**	**	*	**	**
LSD (P<0.05)	2.28	14.3	12.0	0.02	0.15	0.58
SEm(±)	0.75	4.70	3.94	0.01	0.05	0.19
CV %	9.32	7.99	2.63	14.21	13.69	11.79
Grand Mean	13.99	101.95	259.68	0.09	0.61	2.79

Note: *DAS = Days after sowing, Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns = Non-significant, *=significant at 5% probability level, **= significant at 1% probability level*

Leaf area index

The LAI in the experiment was significantly influenced by weed management practices at all dates of observation (Table 2). It was generally higher in weed free plots and statistically similar with atrazine *fb* 2,4-D EE applied plots and significantly lower in weedy check treatment. The lower LAI in weedy check was because of limited supply of nutrients like nitrogen to the crop due to higher crop-weed competition that reduced plant growth and chlorophyll content of plants thereby influencing leaf area and photosynthetic efficiency. Imoloame and Omolaiye (2016) also reported lower leaf area index in all plots of maize that was left weedy for 6, 9 and 12 weeks after sowing.

Weed density

The result showed significant reduction of broad leaf weed density in the application of atrazine *fb* 2,4-D EE (table 3). Similar result was reported by Gaur *et al*., (1991) that sequential application of atrazine *fb* 2,4- D significantly reduced all of the broadleaf weeds but not all of grassy weeds. The average grass and broad leaf weed density were found to be greater than that of sedge weeds. Total weed density was significantly affected by weed management practices and found significantly lower under weed free plots and higher under weedy check at all observations. After weed free, the minimum total weed density was recorded in atrazine only (44.44/m^2) at 30 DAS and in atrazine *fb* 2,4-D EE at 45 DAS (24.44/m^2) and 60 DAS (26.66/m^2). Verma and Maurya (2018) also reported low weed density in Kharif maize with the sequential application of atrazine *fb* 2,4-D.

Weed dry weight

Significantly highest and lowest grass weed dry weights were observed in weedy check and weed free respectively (Table 4). But at 45 DAS, highest grass weed dry weight (36.16 g/m^2) was recorded in pendimethalin only treated plots. Whereas the minimum broad leaf weed dry weight was recorded in atrazine *fb* 2,4- D EE at 30 and 45 DAS. The average dry weight of broad leaf weeds was greater than that of grassy and sedge weeds respectively. Total weed dry weight was significantly affected by weed management practices and recorded minimum in weed free and maximum in weedy check at all dates of observation. After weed free, the total weed dry weight was recorded minimum under application of atrazine *fb* 2,4-D EE at all dates of observation.

Weed control efficiency

Data showed that (Table 5) at all dates of observation, significantly highest and lowest WCE were observed in weed free and farmer's practice respectively. But at 45 DAS, the lowest WCE was recorded in pendimethalin only (68.43%). After weed free, the highest WCE was recorded in sequential application of atrazine *fb* 2,4-D EE at 30 DAS (87.59%), 45 DAS (95.91%) and 60 DAS (92.17%) which was statistically at par with atrazine only at 30 DAS and with 2 hand weeding at 30 and 45 DAS. Nandaji (2019) also found higher weed control efficiencies in atrazine *fb* 2,4-D treated plots than other treatments at 40, 60 and 80 DAS.

Weed control index

Weed control index (WCI) was significantly influenced by weed management practices (table 5). The highest and lowest WCI were recorded in weed free and farmer's practice treatments at all dates of observation except at 45 DAS. At 45 DAS, WCI was recorded lowest in pendimethalin only (76.21%). After weed free, the highest WCI was recorded in atrazine *fb* 2,4-D EE treatment which was statistically at par with both atrazine only and 2 hand weeding treatment at 30 and 45 DAS. The data are in accordance with the findings of Nandaji (2019).

Table 3. Weed density as influenced by weed management practices in spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Weed Density (no./m^2)											
	30 DAS				45 DAS				60 DAS			
	GW	SW	BLW	Total	GW	SW	BLW	Total	GW	SW	BLW	Total
Weed free	1.99^{a}	0.71	1.96^{ab}	2.70^{a}	1.13^{a}	0.71	2.68^{b}	2.92^{a}	1.54^{a}	0.71	1.54^{a}	2.20^{a}
	(3.44)	(0.00)	(3.33)	(6.77)	(1.11)	(0.00)	(7.77)	(8.89)	(2.22)	(0.00)	(2.22)	(4.44)
Atrazine as PE	6.43^{ab}	0.71	1.54^{ab}	6.62^{b}	5.28^{bc}	2.37	4.25^{bc}	7.24^{bc}	5.30^{bc}	2.43	2.83^{a}	6.67^{bc}
	(42.22)	(0.00)	(2.22)	(44.44)	(27.78)	(6.67)	(17.78)	(52.22)	(28.89)	(7.03)	(10.00)	(45.92)
Pendimethalin as PE	9.29^{b}	2.21	2.71^{ab}	10.06^{bc}	11.1^{bc}	1.85	7.1^{d}	13.34^{d}	7.55^{bc}	1.62	5.68^{b}	9.69^{de}
	(86.66)	(5.56)	(8.89)	(101.11)	(122.72)	(5.56)	(50.00)	(178.28)	(57.78)	(3.77)	(32.22)	(93.77)
Atrazine as PE *fb* 2,4-D EE	6.24^{ab}	1.55	0.71^{a}	6.56^{b}	4.90^{b}	0.71	0.71^{a}	4.90^{ab}	5.02^{b}	0.71	1.12^{a}	5.16^{b}
	(42.22)	(3.33)	(0.00)	(45.55)	(24.44)	(0.00)	(0.00)	(24.44)	(25.55)	(0.00)	(1.11)	(26.66)
Pendimethalin as PE *fb* 2,4-D EE	9.25^{b}	1.12	2.21^{ab}	9.71^{b}	7.63^{c}	0.71	4.01^{bc}	8.71^{c}	7.01^{bc}	0.71	2.21^{a}	7.45^{c}
	(92.22)	(1.11)	(5.56)	(98.89)	(58.89)	(0.00)	(16.67)	(75.56)	(51.11)	(0.00)	(5.56)	(56.67)
2 Hand weeding	5.26^{ab}	0.71	5.58^{b}	7.73^{b}	2.70^{bc}	0.71	4.87^{c}	5.66^{b}	4.49^{ab}	0.71	6.58^{b}	7.98^{cd}
	(27.78)	(0.00)	(32.22)	(60.00)	(8.89)	(0.00)	(23.33)	(32.22)	(21.11)	(0.00)	(44.44)	(65.56)
Farmer's practice	9.71^{b}	1.85	13.33^{c}	17.47^{c}	7.28^{d}	3.12	7.58^{d}	11.05c^{d}	7.64^{bc}	1.55	8.01^{b}	11.22^{e}
	(105.55)	(5.56)	(198.12)	(309.23)	(52.81)	(12.20)	(57.00)	(122.01)	(58.88)	(3.33)	(63.78)	(125.99)
Weedy check	8.46^{b}	1.54	16.98^{c}	19.27^{c}	11.6^{d}	2.41	20.73^{e}	24.04^{e}	8.46^{c}	1.37	15.88^{c}	18.27^{f}
	(80.00)	(2.22)	(294.45)	(376.67)	(138.89)	(11.11)	(432.22)	(582.22)	(77.78)	(2.22)	(254.44)	(334.44)
F-test	*	ns	*	**	*	ns	*	**	*	ns	*	**
LSD(0.05)	4.70	1.71	4.35	3.29	2.73	2.90	1.86	2.17	2.96	1.71	2.36	1.84
SEm(±)	1.55	0.56	1.43	1.08	0.89	0.95	0.61	0.71	0.97	0.56	0.78	0.61
CV %	37.94	75.03	44.09	18.75	24.2	105.0	16.36	13.20	28.75	79.69	24.59	12.24
Grand Mean	7.08	1.3	5.62	10.01	6.44	1.57	6.49	9.37	5.88	1.23	5.48	8.58

Note: *Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns = Non-significant, *=significant at 5% probability level, **= significant at 1% probability level, GW= grassy weeds, SW= sedge weeds, BLW= Broad leaf weeds; Data are subjected to square root transformation (*$\sqrt{(x+0.5)}$*) and data on parentheses are original values.*

Table 4. Weed density as influenced by weed management practices in spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Weed Dry Weight (g/m^2) 30 DAS				45 DAS				60 DAS			
	GW	SW	BLW	Total	GW	SW	BLW	Total	GW	SW	BLW	Total
Weed free	0.76 (0.07)	0.71 (0.00)	0.78^{a} (0.12)	0.83^{a} (0.19)	1.04^{a} (0.61)	0.71 (0.00)	0.81^{ab} (0.16)	1.11^{a} (0.77)	0.71^{a} (0.00)	0.71 (0.00)	0.78^{a} (0.11)	0.78^{a} (0.11)
Atrazine as PE	1.24 (1.09)	0.79 (0.14)	0.73^{a} (0.03)	1.31^{a} (1.25)	2.55^{bc} (6.26)	1.12 (0.84)	1.62^{b} (2.14)	3.11^{bc} (9.24)	4.81^{bc} (24.60)	2.55 (8.78)	3.33^{ab} (14.15)	6.88^{bc} (47.52)
Pendimethalin as PE	2.14 (4.72)	0.88 (0.29)	0.93^{a} (0.38)	2.33^{c} (5.38)	5.97^{e} (36.16)	0.95 (0.51)	3.03^{c} (8.77)	6.75^{e} (45.43)	6.88^{cd} (47.61)	1.20 (1.43)	8.08^{cd} (66.45)	10.67^{d} (115.50)
Atrazine as PE *fb* 2,4-D EE	1.03 (0.61)	0.82 (0.19)	0.71^{a} (0.00)	1.13^{a} (0.80)	1.93^{ab} (3.48)	0.71 (0.00)	0.71^{a} (0.00)	1.93^{ab} (3.48)	5.72^{bcd} (32.77)	0.71 (0.00)	0.79^{a} (0.14)	5.72^{b} (32.91)
Pendimethalin as PE *fb* 2,4-D EE	2.29 (4.79)	0.81 (0.18)	1.09^{a} (0.89)	2.09^{bc} (3.85)	3.76^{cd} (13.65)	0.71 (0.00)	1.02^{ab} (10.72)	3.85^{c} (14.38)	7.11^{cd} (52.01)	0.71 (0.00)	3.19^{ab} (13.26)	8.09^{c} (65.27)
2 Hand weeding	1.10 (0.77)	0.71 (0.00)	1.21^{a} (1.03)	1.50^{ab} (1.80)	1.44^{ab} (1.69)	0.71 (0.00)	1.67^{b} (2.33)	2.09^{ab} (4.02)	3.40^{b} (11.60)	0.71 (0.00)	6.06^{bc} (38.73)	6.92^{bc} (50.33)
Farmer's practice	2.42 (6.82)	0.76 (0.09)	3.69^{b} (14.11)	4.61^{d} (21.02)	3.32^{c} (11.14)	2.29 (6.13)	3.71^{c} (8.77)	5.52^{d} (30.64)	5.72^{bcd} (32.37)	1.32 (1.98)	9.82^{d} (96.04)	11.44^{d} (130.38)
Weedy check	1.81 (2.92)	0.85 (0.24)	4.66^{b} (21.72)	5.00^{d} (24.88)	4.88^{de} (23.65)	1.81 (5.22)	12.70^{d} (161.42)	13.79^{f} (190.30)	7.91^{d} (66.86)	1.39 (2.33)	16.73^{e} (282.95)	18.75^{e} (352.14)
F-test	ns	ns	*	**	*	ns	*	**	*	ns	*	**
LSD(0.05)	1.24	0.22	1.07	0.73	1.28	1.62	0.83	1.16	2.45	1.64	2.91	1.75
SEm(±)	0.41	0.07	0.35	0.24	0.42	0.53	0.27	0.38	0.81	0.54	0.96	0.58
CV %	44.36	15.69	35.31	17.70	23.57	82.04	14.92	13.89	26.49	80.58	27.27	11.57
Grand Mean	1.60	0.79	1.72	2.35	3.11	1.13	3.16	4.77	5.28	1.16	6.10	8.66

Note: *Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns = Non-significant, *=significant at 5% probability level, **= significant at 1% probability level, GW= grassy weeds, SW= sedge weeds, BLW= Broad leaf weeds; Data are subjected to square root transformation (*$\sqrt{(x+0.5)}$*) and data on parentheses are original values.*

Table 5: Weed control efficiency and weed control index as influenced by weed management practices of spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Weed Control Efficiency (WCE)			Weed Control Index (WCI)		
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
Weed free	9.93[a] (98.08)	9.94[a] (98.32)	9.96[a] (98.69)	9.97[a] (99.08)	10.01[a] (99.57)	10.02[a] (99.97)
Atrazine as PE	9.36[ab] (87.13)	9.54[bc] (90.58)	9.32[bc] (86.40)	9.76[ab] (94.70)	9.78[ab] (95.12)	9.33[b] (86.60)
Pendimethalin as PE	8.38[b] (70.25)	8.29[e] (68.43)	8.49[d] (71.74)	8.87[bc] (78.60)	8.76[d] (76.21)	8.18[c] (66.77)
Atrazine as PE *fb* 2,4-D EE	9.38[ab] (87.59)	9.82[ab] (95.91)	9.62[ab] (92.17)	9.86[ab] (96.77)	9.94[ab] (98.23)	9.56[a] (90.84)
Pendimethalin as PE *fb* 2,4-D EE	8.27[b] (69.29)	9.35[c] (86.84)	9.16[bc] (83.48)	8.61[c] (74.09)	9.63[b] (92.32)	9.05[b] (81.47)
2 Hand weeding	9.19[ab] (83.88)	9.72[ab] (94.05)	8.98[c] (80.22)	9.60[ab] (91.81)	9.92[ab] (97.93)	9.31[b] (86.20)
Farmer's practice	4.16[c] (17.47)	8.90[d] (78.70)	7.93[e] (62.35)	3.85[d] (15.25)	9.14[c] (83.15)	7.94[c] (62.63)
F-test	**	**	**	**	**	**
LSD(0.05)	1.07	0.35	0.46	0.93	0.31	0.52
SEm(±)	0.35	0.11	0.15	0.30	0.10	0.17
CV %	8.25	2.41	3.28	6.91	2.06	3.69
Grand Mean	7.42	8.28	8.02	7.65	8.49	8.01

Note: *Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns= Non-significant, *=significant at 5% probability level, **= significant at 1% probability level; Data are subjected to square root transformation* ($\sqrt{(x+0.5)}$) *and data on parentheses are original values*

Yield attributing characters

Yield attributing characters of maize were significantly influenced by weed management practices (table 6). Plants per square meter (6.51), number of cobs harvested per m^2 (6.89), number of grains per cob (630.93) and thousand grain weight (331.71g) were found significantly higher in sequential application of atrazine *fb* 2,4-D EE. This could be due to the application of treatment which reduced the weed competition enhancing utilization of growth resources for better crop performance accompanied with better photosynthetic efficiency. Whereas, the lowest values of these yield attributing characters were recorded in weedy check plots.

Table 5. Yield attributing characters of spring maize as influenced by weed management practices at Dhading Besi, Nepal in 2020

Weed Management Practices	No. of Plants/m^2	No. of cobs harvested/m^2	No. of kernels per cob	Thousand Grain Weight (g)
Weed free	6.51^{a}	6.59^{b}	599.33^{ab}	318.05^{a}
Atrazine as PE	6.22^{b}	6.52^{b}	581.20^{ab}	325.59^{a}
Pendimethalin as PE	5.48^{c}	5.48^{d}	491.20^{cd}	292.49^{b}
Atrazine as PE *fb* 2,4-D EE	6.51^{a}	6.89^{a}	630.93^{a}	331.71^{a}
Pendimethalin as PE *fb* 2,4-D EE	6.07^{b}	6.15^{c}	502.67^{c}	290.92^{b}
2 Hand weeding	6.22^{b}	6.22^{c}	548.67^{bc}	297.87^{b}
Farmer's practice	5.33^{c}	5.33^{d}	444.40^{de}	276.72^{c}
Weedy check	4.89^{d}	4.89^{e}	397.20^{e}	268.31^{c}
F-test	**	**	**	**
LSD(0.05)	0.26	0.29	54.9	13.5
SEm(±)	0.08	0.09	18.11	4.46
CV %	2.54	2.72	5.98	2.57
Grand Mean	5.91	6.01	524.45	300.21

Note: *Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns= Non-significant, *=significant at 5% probability level, **= significant at 1% probability level*

Grain yield

Statistical analysis of data (Table 7) showed that the highest grain yield of 11.37 t/ha was obtained in atrazine *fb* 2,4-D EE which was statistically similar with weed free and followed by atrazine as PE (10.36 t/ha). Sharma *et al.*, (2018) also reported higher grain yield in application of atrazine *fb* 2,4-D among different herbicide treatments. The lowest grain yield (5.50 t/ha) was obtained in weedy check. The higher grain yield in atrazine *fb* 2,4-D EE could be due to its ability to reduce crop-weed competition resulting lower weed density and lower weed dry weight that provided better amounts of growth sources for increased plant height, LAI, number of cobs, number of grains per cob, thousand grain weight and in combined increased the grain yield.

Weed index

The data regarding weed index (Table 7) revealed that sequential application of atrazine *fb* 2,4-D EE resulted in significantly minimum value of weed index (-1.27%). Where, the negative sign indicated higher grain yield than in weed free plots. Similar result was reported by Shrestha *et al.*, (2018). Whereas, the weedy check plots recorded maximum yield loss of 50.99% which was followed by farmer's practice (43.17%). Gurung *et al.*, (2019) also reported highest weed index of 61.5 % in weedy check plots of winter maize.

Table 6. Grain yield, weed index and harvest index as influenced by weed management practices in spring maize at Dhading Besi, Nepal in 2020

Weed Management Practices	Grain yield (kg/ha)	Weed index (%)	Harvest index(HI)
Weed free	11247.76[a]	0.00[a]	0.49[a]
Atrazine as PE	10369.80[b]	7.74[b]	0.48[ab]
Pendimethalin as PE	8060.22[d]	28.18[d]	0.46[b]
Atrazine as PE *fb* 2,4-D EE	11372.46[a]	-1.27[a]	0.48[ab]
Pendimethalin as PE *fb* 2,4-D EE	9282.52[c]	17.36[c]	0.48[ab]
2 Hand weeding	9756.81[bc]	13.30[bc]	0.48[ab]
Farmer's practice	6379.99[e]	43.17[e]	0.43[c]
Weedy check	5507.33[f]	50.99[f]	0.42[c]
F-test	**	**	**
LSD (P<0.05)	730.00	6.35	0.02
SEm(±)	240.72	2.09	0.01
CV %	4.63	18.20	2.84
Grand Mean	8997.11	19.93	0.47

Note: *Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns= Non-significant, *=significant at 5% probability level, **= significant at 1% probability level*

Economic analysis

The economic analysis of the data (Table 8) revealed that sequential application of atrazine *fb* 2,4-D EE resulted in the highest net return of 162.35 thousands/ha and B:C ratio of 2.70. Whereas atrazine only remained at second with net return of 144.15 thousands/ha and B:C ratio of 2.58. Similarly, weedy check plot resulted the lowest net return (42.42 thousands/ha) and B:C ratio (1.49) which were statistically similar with farmer's practice. Patel *et al*., (2018) also reported higher B:C ratio (2.98) for application of atrazine + pendimethalin as PE *fb* 2,4- D. The analyzed data also revealed that the application of atrazine *fb* 2,4-D EE resulted highest (73.83%) increment in benefit over weedy check which was statistically similar with atrazine only (70.57%).

Table 7. Economics of spring maize as influenced by weed management practices at Dhading Besi, Nepal in 2020

Weed Management Practices	Total Cost of Cultivation (NRS)	Gross Return (NRS)	Net Return (NRS)	B:C Ratio	Increment in benefit over weedy check (%)
Weed free	142500	254313.0[a]	111813.03[c]	1.79[d]	61.89[b]
Atrazine as PE	91320	235472.9[b]	144152.90[b]	2.58[a]	70.57[a]
Pendimethalin as PE	94050	184559.0[d]	90508.96[d]	1.96[c]	52.81[c]
Atrazine as PE *fb* 2,4-D EE	95345	257702.0[a]	162357.04[a]	2.70[a]	73.83[a]
Pendimethalin as PE *fb* 2,4-D EE	98075	210492.5[c]	112417.48[c]	2.15[b]	62.12[b]
2 Hand weeding	114500	221712.3[bc]	107212.26[c]	1.94[c]	60.02[bc]
Farmer's practice	98000	148855.3[e]	50855.28[e]	1.52[e]	15.85[d]
Weedy check	86500	128927.4[f]	42427.43[e]	1.49[e]	-
F-test	-	**	**	**	**
LSD(0.05)	-	14627	14627	0.14	7.91

Weed Management Practices	Total Cost of Cultivation (NRS)	Gross Return (NRS)	Net Return (NRS)	B:C Ratio	Increment in benefit over weedy check (%)
SEm(±)	-	4822.42	4822.42	0.04	2.61
CV %	-	4.07	8.13	3.89	9.10
Grand Mean	102536.2	205254.3	102718	2.01	49.64

Note: *Means followed by the same letter(s) in a column are not significantly different by DMRT at 5% level of significance. ns= Non-significant, *=significant at 5% probability level, **= significant at 1% probability level, NRS = Nepali Rupees The local market price of maize grain was NRS 20 per kg and market price of maize stover was assumed as NRS 2.5 per kg.*

Conclusion

The sequential application of herbicide atrazine @ 1.0 a.i. kg/ha as pre-emergence followed by 2,4-D EE @0.5 a.i. kg/ha as post-emergence herbicide was the most effective weed management treatment in Spring maize under Dhading Besi conditions of Nepal in controlling weeds, which also resulted in higher yield and economics. The next better option was pre emergence application of atrazine @ 1.0 a.i. kg/ha.

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Authors' Contributions

B. Shrestha, S.K. Sah and D. Marasini together planned and designed the experiment. B. Shrestha performed the experiment and analysis while S.K. Sah supervised throughout the experiment, result interpretation and manuscript development. KR Kafle and HB Bista contributed in facilitating and supervising the experiment.

Conflict of Interest

The authors declare no conflict of interest regarding publication of this manuscript.

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Managing weeds in dry direct seeded rice: A profound challenge

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Abstract
Dry Direct Seeded Rice (DDSR) is a promising technology to address environmental, water, labor and profitability issue that is constantly threatening the rice farming community around the world. Rice yield under DDSR is primarily limited due to weeds. There are instances of complete crop failure in DDSR owing to poorly managed weeds. More than 50 weeds species infest DDSR crop due to aerobic nature of soil confronting a major challenge in the wide spread adoption of dry direct seeding. Direct-seeded rice faces a potential threat from changes in the competing weed flora, with an increase in those species that are difficult to control. This review article presents the prospects of DDSR along with the available weed management strategies such as preventive, physical, chemical, cultural and biological methods and their judicious use. Over reliance on only one approach of managing weeds may be back firing as well. The use of chemical means are getting popular in an alarming rate for being cost effective, without calculating the environmental concerns which might lead to herbicidal resistance and negative consequences to environment and human health. Therefore, it is necessary to understand the environment while shifting from transplanted rice to dry direct seeding, identifying weeds flora and choosing or integrating the best weed management practices foreseeing the future consequences. The logical integration of available weed management options that is ecologically sound, economic and effective for season long weed control is the main essence that ensures the sustainability of rice production.

Keywords: Dry direct seeded rice, herbicides, integrated weed management

Introduction

Basically, there are two methods of rice establishment viz. tsransplanting and direct seeding. Transplanting of 20-30 days old nursery raised seedlings in the puddled soil is the most common method of establishment of rice in Asia as well as in Nepal (Kumar and Ladha, 2011, Shah and Bhurer, 2005), whereas direct seeding refers to direct planting of rice seeds in the main field without puddling (Farooq *et al.*, 2011) and it covers 26% of the total rice area in the world (Rao *et al.*, 2007) and 10% in Nepal (NARC, 2007). Transplanted rice (TPR) faces severe threat due to increasing shortages of water and labor, therefore the incentive to develop and adopt dry direct seeded rice (DDSR) has increased. Kumar and Ladha (2011) reported that DDSR saves up to 60% of labor, 35% water with reduction in methane emission and cost of cultivation by 92% and 32% respectively saving about $50 per hectare, also DSR crop matures 7-14 days earlier ensuring timely planting of succeeding crop. Although DDSR has evolved as a promising technology to minimize cost of production by drastically reducing labor and water requirement, several challenges confront the wide-scale adoption of DDSR by farmers. Weed infestation, stagnant yield, unavailability of purposely developed varieties, panicle sterility, nutrient availability, pests, diseases and water management are the challenges (Nguyen and Ferrero, 2006), among which high weed infestation is the major bottleneck in DSR especially in dry fields (Rao *et al.*, 2007). In absence of effective weed control measure the yield penalty in DDSR was found very high often leading to drastic reduction in yield or no yield at all (Kim and Ha, 2005; Rashid *et al.*, 2012, Busi *et al.*, 2017). Due to aerobic nature of soil in direct seeding establishment, the weed pressure is more and difficult to control compared to transplanting establishment. Managing weeds effectively is purely technical and very tedious in fact, in DDSR. Reliance on only one strategy may not achieve the satisfactory level of weed control. Therefore, the use of available weed management strategies in conjunction rather than in isolation with proper judgement is essential for sustainable weed management in DDSR.

Materials and Methods

This manuscript is purely a review article. The information presented here is the result of rigorous review on the past research/review works carried out by various Scientists on dry direct seeded rice at different times. After the extensive review of the available and accessible reading materials related to dry direct seeded rice, the relatable information are summarized under various headings.

Results and Discussion

Challenges of dry direct seeded rice

Direct-seeding of rice has the potential to provide several benefits to farmers and the environment over TPR. However, Kumar and Ladha (2011) stated that in majority of the cases (16 out of 25) the yields of DDSR were found lower than CT-TPR. According to Kumar and Ladha (2011), the possible risks associated with dry direct seeding are:

- Sudden rain immediately after seeding can adversely affect crop establishment.
- Reduces availability of soil nutrients such as N, Fe, and Zn especially in Dry-DSR
- Appearance of new weeds such as weedy or red rice.
- Increases dependence on herbicides.
- Increases incidence of new soil-borne pests and diseases such as nematodes.
- Enhances nitrous oxide emissions from soil.
- Relatively more soil C loss due to frequent wetting and drying.

Weed flora

The composition of weed communities in rice fields is continuously changing and is influenced by cultural, mechanical, chemical, and environmental factors (Bhandari and Moody, 1981). In DSR the weed communities are floristically diverse and more in abundance than TPR (Tomita *et al.,* 2003; Rao *et al.*, 2007). Vongsaroj (1997) reported that the broad leaves dominated weed communities in TPR subsequently shift towards grasses and sedges dominated with DSR. It was found that the weeds like as *Echinochloa crus-galli, Ischaemum rugosum* and *Leptochloa chinensis*, which were not common to rice fields became widespread and dominant in Malaysia after the introduction of DSR in the 1970s (Azmi *et al.,* 2005). Direct-seeded rice faces a potential threat from changes in the competing weed flora, with an increase in those species that are difficult to control (Johnson *et al.*, 2003). These include *I. rugosum, E. crus-galli*, *E. colona, L. chinensis,* and *Cyperus* spp. According to Singh (2013), major weeds infesting DSR field at 40 days after seeding (DAS) were: *Cynodon dactylon* (6.2%), *Dactyloctenum aegypticum* (2.2%), *Echinochloa colona* (20.3%), *Echinochloa crusgalli* (5.9%), *Leptochloa chinenis* (1.7%) among grasses; *Ammannia baccifera* (1.9%), *Caesulia axillaries* (4.5%), *Commelina benghalensis* (6.1%), *Physalis minima* (6.3%), *Eclipt aalba* (3.3%), *Euphorbia hirta* (5.1%), *Phyllanthus niruri* (12.6%), *Ludwigia* spp. (1.3%), *Trianthema monogyna* (3.8%) among broad-leaved weeds and *Cyperus difformis* (5.4%) among Sedges.

Sharma (2013) during 2011 and 2012 in Chitwan, Nepal, recorded from DDSR field that among broad leaf weeds *Amiscophacelus axillaris, Ageratum conizoides* and *Melochia corchorifolia* were dominant at 20DAS whereas *Aeschynomene indica, Alternenthera sessilis, Commelina diffusa*, *Cleome viscosa*, *Euphorbia hirta*, *Monochoria vaginalis* and *Sphenoclea zeylanica* dominated during 40 and 60 DAS. The grasses like *Echinocloa colona, Cynodon dactylon* and Digitaria ciliaris were dominant at 20 DAS and infested the field till harvest. During later stage of crop growth *Digitaria setigera, Eleusine indica, Iscchaemum rugosum, Paspalum scrobiculatum* and *Setaria glauca* emerged dominantly. In the same way, *Cyperus difformis, C. iria* and *Fimbristylis miliacea* were consistently dominant sedges at 20 DAS and thereafter. *Cyperus compresus* was observed during 40 and 60 DAS while *Scirpus juncoides* infested the field from 60 DAS till harvest.

Weeds: The major biological constraint

Weeds are serious concern while shifting from CT-TPR to DSR and more specifically to DDSR (Rao *et al.,* 2007; Farooq *et al.,* 2011). In TPR, puddling creates anaerobic condition and hinder weed seed germination, transplanted seedlings has size advantage to suppress weeds however, in DDSR rice seeds are planted in dry fields and there is no water layer to suppress weeds initially (Kumar *et al.*, 2008; Rao *et al.,* 2007). As a result rice seedlings are prone to weed competition from the early stage of crop emergence. In aerobic soil weeds emerge more rapidly than the crop and proliferate by using the fertilizers and nutrient applied rendering the crop with very less productivity. In early growth stage weeds makes 20 -30% of growth whereas crop makes only 2-3% of its growth (Moody, 1990). Weeds compete with the crop for various factors such as moisture, nutrient, light and space resulting in yield loss in the range 30 to 90% (Singh *et al.,* 2007). In addition, weeds are difficult to identify from crop during early stage of growth in broadcasted DDSR where manual or mechanical weeding becomes ineffective. More than 50 weed species infest direct-seeded rice, causing major losses to rice production worldwide where the new weed species that were no longer seen in transplanted rice start to emerge with greater diversity (Rao *et al.*, 2007; Tomita *et al.*, 2003). Evolution of weedy rice (*Oryza sativa f. spontanea*) also known as red rice is another threat to adoption of DDSR, especially in Asian countries. Weedy rice is difficult to control because of its genetic, morphological, and phenological similarities with rice and matures early with high shattering ability (Ferrero, 2003). Weedy rice is highly competitive and causes severe rice yield losses ranging from 15% to 100% (Kumar and Ladha, 2011). Weed management become increasingly difficult with DDSR as various cases of herbicide resistance has been reported from countries like Philippines, Malaysia, Vietnam, Thailand and Korea. So far, no cases of herbicide resistant has been reported in South Asia but preventive measures should be considered instantly (Kumar and Ladha, 2011).

Critical period of weed competition (CPWC)

A major threat to yields of direct-seeded rice crops is weed competition and high costs of weed control (or unavailability of efficient weed control methods), which will be a major factor constraining the widespread adoption of direct seeding (Singh *et al.,* 2008). In DDSR weeds and crop emerge simultaneously and there is serious competition among them for space, water, nutrients and sunlight which may lead to yield reduction of crop. The optimum time, at which crop must be free of the adverse effect of weeds, is referred to as the critical period of weed competition. In other words it is the time frame during which the yield is reduced by weed crop competition or the minimum duration for crop to be weed free to prevent any compromise in the yield. Knowledge of CPWC helps scheduling weed management interventions such as weeding and herbicide applications (Matloob *et al.,* 2014) which reduce the cost and hazards associated with indiscriminate herbicide use. CPWC limits the weed management practices within the certain time frame to make weed management more easy, effective and economical. The start and end of CPWC is exclusively dependent on choice of cultural practices, crop and weed characteristics and agro climatic conditions (Knezevic *et al.,* 2002).

The effective period of weed-crop competition in DSR occurs in two phases; i.e. between 15-30 days, and 45-60 days after seeding. The competition beyond 15 days after seeding may cause significant reduction in the grain yield however, competition for the first 15 days only may not have much adverse effect on crop. Chauhan and Johnson (2011) reported that critical periods for weed control, to obtain 95% of a weed free yield, was estimated between 17 to 56 days after sowing of the DSR crops at 15-cm row spacing. The critical period of weed infestation determined from the field experiment was similar for the three New Rice for Africa (NERICA) varieties and the O. sativa parent (WAB 56-104), and was between 14 and 42 days DAS. Weed competition either before or after these critical periods had negligible effects on crop yield (Toure *et al.,* 2013). In dry direct drill-seeded rice, the “critical period” of weed competition has been reported to be 15–45 days after seeding (Rao and Nagamani, 2007; Singh *et al.,* 1999; Yaduraju and Mishra, 2004). Weed infestation up to 15 DAS or weed-free for 60 or 75 DAS produced grain yields similar to those of plots kept weed-free throughout the growing season (Singh, 2008). Under saturated conditions, the CPWC was found between 2 and 71 DAS, while in flooded conditions, it was found between 15 and 73 DAS (Juraimi *et al.,* 2009).

Weed management in dry direct seeded rice

Weed management refers controlling weeds below the level that case any kind of harm or losses to crop or human and prevent any kind of prospect that cause managing weeds a problem in future. There are various methods of managing weeds in DDSR and judicious (economic, effective and sustainable) application of weed management methods require the knowledge about weed flora and the critical period to control them.

a) Preventive measures

Preventing weeds from entering an area may be easier than trying to control them once they have established. Prevention of weed introduction and spread is the most important strategy in managing weeds, establishment method, and ecosystem. Use of clean seeds, machineries, making irrigation channels, bunds, levees free from weeds will reduce the weeds infestation to considerable extent (Mahajan *et al.*, 2012).

b) Mechanical and manual weeding

Rice being monocot, it permits fair amount of disturbance of manual and mechanical weeding so it is more common and effective way (Singh *et al.*, 1999) of controlling weeds. However, labor requirement for manual weeding in DDSR is 150 to 200-labor-day/ha (Trung *et al.*, 1995; Roder, 2001). Manual weeding alone proves to be very expensive and depends on availability of labour (Ruthenberg, 1980) and climatic condition. Moreover, it is difficult to identify some mimic weeds during early stage of crops which interfere with yield ultimately. Mechanical weeding is removal of weeds by use of tools and implements like khurpi, hoe, cultivator, rotary and cono weeders etc. But it is limited to row seeded crops and dependent on soil moisture. Subudhi, (2004) reported that a dry land weeder (with a straight-line peg arrangement) has shown excellent performance in different soil types and with varying soil moisture levels and weed intensity, providing a labor savings of approximately 57% compared with hand weeding. Mechanical weeding could be more effective in situations in which continuous rains or dry spells may reduce the effectiveness of post emergence herbicides. It can also help to reduce overall herbicide use but the cost and labor involved is questionable.

c) Cultural methods

Weeds and crops compete with each other and weeds persist as a result of adaptation to agronomic or cultural management applied in field. Cultural practices significantly influence crop weed competition resulting into complex interactions. Grichar *et al.*, (2004) has opined that cultural approaches determine the competitiveness of crop against weed for underground and above ground resources which might influence the weed management. Tillage and land preparation method greatly affect the weed by reducing weeds seeds germination. Tillage practices determines the vertical distribution of weed seeds in soil profile and in turn affects crop establishment and weed emergence (Chauhan *et al.*, 2006). Weeds managed effectively for 2-3 years in zero tillage can reduce weed problems and make management easier. Precise land levelling improves seed germination, good stand establishment and crop ability to suppress weeds. Similarly, stale seedbed technique can also be incorporated in cultural practice. In this practice a light irrigation is provided in the land before final land preparation to allow the weeds to germinate followed by killing the weeds using shallow tillage or non-selective herbicide (Chauhan and Johnson, 2011). The success of stale seedbeds depends on several factors such as method of seedbed preparation, method of killing emerged weeds, weed species, duration of the stale seedbed and environmental conditions (Kumar and Ladha, 2011). Gopal *et al.*, (2010) reported 53% lower weed density in DDSR after a stale seedbed than without this practice. Bhurer *et al.*, (2013) found that stale seed bed followed by Pendimethalin 30 EC (stomp) @ 1 a.i. kg/ha followed by Bispyribac (nominee gold) @ 25 a.i. g/ha 10 % @ 200 ml/ha at 20 days gave economic and effective weed control with similar yields compared to hand weeding. Sowing of primed seeds enhance crop emergence and establishment is achieved easily. Hardening and priming seeds with growth promoters like growth regulators and vitamins have been successfully employed in rice to hasten and synchronize emergence, achieve uniform stands, and improve yield and quality (Basra *et al.,* 2006). Similarly, use of high seed rates as much as 200 kg/ha has been found in broadcasted DDSR with aim to suppress weeds (Moody, 1977). Also weed competitive rice varieties that make up vigorous early growth (leaf area and dry matter) accounted for 87% variation in grain yield between varieties in competition for weeds (Zhao *et al.,* 2006). Precise water management is essential as high soil moisture during or before crop emergence is detrimental for crop and soon after that maintaining some level of water depth is crucial for suppressing weeds (Moody, 1977). Most weeds have an optimum soil moisture level below or above which growth is suppressed; hence, time, duration, and depth of flooding can be managed to suppress weed growth.

Use of crop residue as mulch can suppress weeds through allelopathy and creating physical barrier for weed emergence. Singh *et al.,* (2007) found that wheat residue mulch of 4 t/ha reduced the emergence of grass weeds by 44–47% and of broadleaf weeds by 56–72% in dry drill-seeded rice. Timing and method of fertilizer application need due consideration to derive maximum benefits. Rice yield was found lower with surface broadcast of fertilizer than with subsurface fertilizer treatments as surface broadcasted fertilizer benefit weeds more (Chauhan and Abugho, 2013). Basal application of fertilizer should be delayed till weeds are removed and nitrogen should be applied only after use of pre emergence herbicide application. To increase fertilizer use efficiency top dressing of nitrogen should be done after weeding (De Datta, 1981). Sesbania co-culture is a practice in which rice and sesbania seeds are seeded simultaneously followed by knocking of sesbania at 25-30 DAS with the help of 2,4-D Ethyl ester (selective dicot herbicide). Sesbania being fast growing in nature, covers up the field in very few days thus offering smothering effect to suppress the weeds. Sesbania co-culture in addition with weed suppression fix atmospheric nitrogen, add biomass to soil and facilitate crop emergence in areas where soil crust formation is a problem (Gopal *et al.,* 2010).

d) Chemical methods

With the availability of different herbicides, it has been possible to manage weeds in DSR in an effective and more economical ways. Herbicides are different in their mode of action and hence control specific groups of weed flora. They are used effectively as pre-plant/burn down, pre emergence, and post emergence weed control in DSR. Pendimethalin, oxadiargyl, and pyrazosulfuron are widely used as pre emergence herbicide and common post emergence herbicides are bispyribac sodium, penoxsulam, pyrazosulfuron, bentazone, bensulfuron, carfentrazone, clomazone, cyhalofop, molinate, propanil, and fenoxaprop. Glyphosate and paraquat are recommended pre plant herbicides (Kumar and Ladha, 2011).

There are various considerations for use of herbicides. It is crucial to select the right herbicide depending upon the weed flora present in a given field. In addition, the correct rate, timing, and application techniques should be used. Continuous use of single herbicide may lead to shift in weed flora and herbicide resistant biotype may develop. Therefore, a careful choice of herbicides must be made to control different flushes of weeds that arise in DDSR and use them in sequence and rotational manner to control weeds effectively. Tank mixtures of herbicides can be used when two or more herbicides are compatible to broaden the spectrum of weed control in such a way that each herbicide controls the weeds missed by the other one. Kelly and Coats (1999) has mentioned that the use of two or more herbicides sequentially or in combination to broaden the spectrum of chemical weed control, reduce production costs, and/or prevent the development of weeds resistant to certain herbicides.

Effect of Pendimethalin on weeds and yield of DDSR

It acts as mitotic poison and inhibits root growth by disrupting cell division and cell elongation killing germinating seeds rather than seedlings. It is used as a selective herbicide in both pre and early post emergence to control most of grasses and certain broadleaf weeds (Valverde *et al.,* 2001). Weeds seeds are small and with less energy compared to rice which are susceptible to network of herbicide upon germination. Pendimethalin is effective when there is sufficient soil moisture in the field and @ 2-3 DAS when rice seeds have imbibed water in order to avoid injury. Mishra and Singh (2008) reported that pre-emergence application of pendimethalin 1.0 kg/ha followed by one hand weeding or harrowing at 30 DAS significantly reduced the population of *Echinocloa colona* compared with weedy check in DDSR. The sequential applications of pre-emergence herbicides such as pendimethalin at 1,000 g/ha followed by 2,4-D at 500 g/ha was found to be effective in controlling mixed weed flora and resulted in higher grain yields and gross returns of DDSR (Singh *et al.,* 2006).

Effect of Bispyribac sodium on weeds and yield of DDSR

It acts as branched chain amino acid i.e. aceto lactate synthesis (ALS) inhibitor and is effective as foliar spray in post emergence application. It is a selective herbicide which works based on absorption, translocation and differential metabolism. In rice it is absorbed and rapidly metabolized into non herbicidal products. It is a selective herbicide effective to control grasses, sedges and broad leaf weeds in rice (Schmidt *et al.,* 1999) but poor on grasses other than *Echinochloa* species, including *Leptocloa chinensis, Dactyloctenium aegyptium, Eleusine indica, Ergrostis* species and has no residual control. Ranjit and Suwanketnikom (2005) observed that post emergence application of bispyribac sodium (bispyribac Na) @ 50 g/ha gave number of tillers per m^2 ranged from 205 in weedy check plots to 335 in straw mulch + bispyribac sodium along with higher yield which was at par with the yield recorded in hand weeding twice. Bispyribac sodium provided excellent control of grass (*Echinochloa* spp.) and sedge weeds (*Cyperus* spp.) which was particularly effective when applied at higher rates (25-30 g/ha) and early application timings (15-20 DAS) (Gill *et al.,* 2006). It was also observed that sole application of bispyribac sodium caused more than 80% reduction in total weed density and about 78% reduction in weed dry weight (Khaliq *et al.,* 2011). Sharma (2013) from her experiment concluded that sole as well as sequential application of bispyribac sodium with pendimethalin as pre emergence was effective in controlling weeds in DDSR producing higher grain yields and economic return.

Effect of 2,4-D on weeds, growth and yield of DDSR

It is a selective herbicide used as post emergence and is effective for the control of broad leaf weeds and some annual sedges in rice. 2, 4-D at 500 g/ha at 30-35 DAS provided effective control of non-grasses and sedges in wet and dry seeded rice (Bindra *et al.,* 2002). It is a synthetic auxin that regulate abnormal metabolism in dicots resulting in uncontrolled growth and later inhibition of these processes leading to death of plant and has no residual control. Sequential applications of residual pre emergence herbicides followed by 2, 4-D performs better than do residual herbicides alone (Nyarko and De Datta, 1991). The use of 2,4-D at 500 g/ha at 30–35 DAS provides effective control of non-grasses and sedges in wet and dry-seeded rice (Bindra *et al.,* 2002; Moorthy and Saha 2002; Saha *et al.,* 2003). Singh *et al.,* (2006) recorded higher net returns from 2, 4-D ethyl ester when applied @ 500 g a.i./ha than weed free treatment and also reported the control of broadleaf weeds in DSR. Bhurer et al, (2013) stated that application of pendimethalin 1 a.i. kg/ha followed by 2,4-D 1 a.i kg /ha at 25 DAS followed by hand weeding 45 DAS is the best way obtaining higher yield and controlling weeds effectively in dry direct seeded rice.

e) Integrated weed management (IWM)

DDSR is thought to be an alternative to TPR and the area under DDSR is expected to increase in future owing to water and labor crisis. However, weeds continue to be serious threat that can undermine DDSR performance. The use of any single approach would not provide season-long and sustainable weed control because of the variation in dormancy and growth habits of weeds (Chauhan, 2012). Swanton and Weise (1991) stated that none of the control measures in single can provide acceptable levels of weed control, and therefore, if various components are integrated in a logical sequence, considerable advances in weed management can be accomplished. Chauhan (2012) has devised various components of integrated weed management in DDSR.

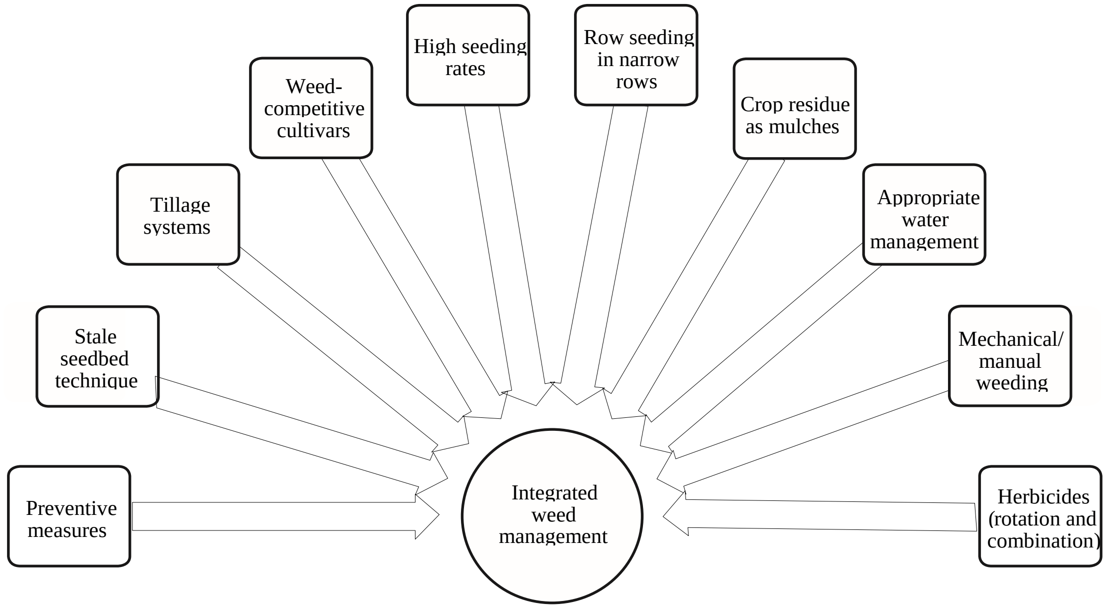

Fig.1 Different weed management strategies for direct-seeded rice systems (Chauhan, 2012)

Use of herbicide will inevitably increase in future due to increasing labor scarcity and wage rates (Kumar and Ladha, 2011). Herbicides are a possible solution to manage weeds in DSR, but the sole use of herbicides cannot provide effective and season long weed control and depending entirely on herbicides is no longer ecologically sound, economically feasible, and effective against the diverse weed flora in DSR (Matloob *et al.*, 2014). Similarly, excessive herbicides lead to environmental pollution (Spliid and Koeppen, 1998) and impoverishment of the natural flora and fauna and shift in weed species dominance (Azmi and Baki, 2002). Reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as five years. In order to achieve sustainable, economic and effective weed management, various weed management strategies such as preventive, physical, cultural and chemical must be integrated in a logical sequence. IWM is particularly desired for the DDS rice due to hardy weeds, shifts in weed flora and the appearance of repeated flushes of weed flora. Integration of diverse technologies is essential for weed management because weed communities are highly responsive to management practices and environmental conditions (Buhler *et al.*, 1997).

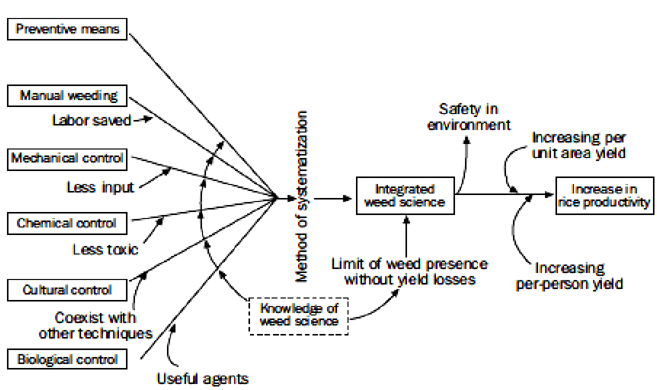

Fig. 2: A conceptual model of integrated weed management (IWM) (Singh *et al.*, 2005)

Buchanan (1976) defined IWM as "the application of many kinds of technology in a mutually supportive manner". Integrated weed management better utilizes resources and offers a wider range of management options (Buhler *et al.*, 2000). Out of various options available for weed management selection, integration, and implementation of effective weed control means with due consideration of economics, environmental, and sociological consequences is the concept of integrated weed management. Juraimi *et al.*, (2013) suggest integrated approaches for sustainable weed control in direct seeded rice, such as the use of clean certified seeds, higher seeding densities, cultivation of competitive variety, seed invigoration, stale seed bed preparation, crop rotation, water and fertilizer management along with rotation of herbicides with different mode of actions followed by manual weeding and rouging after mid stage of rice growth. For sustainability of direct seeded rice culture, long term changes in weed flora, herbicide efficacy, resistance, residual toxicity and environmental implications of continuous use of herbicides should be properly addressed.

Selection of weed control measures based on the weed flora in dry seeded rice would enable farmers to control weeds with lower cost. Matloob *et al.*, (2014) has reported that the combined use of narrow row spacing (e.g., 15 cm) and a high seeding rate (e.g., 80-100 kg/ha) along with the application of an effective pre emergence herbicide (e.g., oxadiazon) can help to suppress weeds more effectively than using a single weed management approach. A combined use of high seeding rate and the application of oxyfluorfen at 0.25 kg/ha increased the competitiveness of rice against weeds (Angiras and Sharma, 1998). Similarly, Maity and Mukharjee (2008) revealed that among the herbicides and cultural methods combined, butachlor and sesbania brown manuring followed by 2,4-D at 40 DAS recorded the lowest dry weight of weeds at all the growth stages, leading to highest weed control efficiency of 80.8% and 86% in 2006 and 84.7 and 88.1 % in 2007 at 30 and 60 DAS respectively. Bhurer *et al* (2013) found that the use of Pendimethalin followed by 2,4-D followed by one hand weeding produced higher and statistically similar yields with weed free treatment with highest net return and benefit cost ratio among other treatments in both years 2010 and 2011. Weed dry weight was significantly reduced due to the treatment as a result highest yield and yield attributing traits were observed. They suggest that amid increasing wage rate and labor scarcity integrated weed management through Pendimethalin 30 EC (stomp) @ 1 a.i. kg/ha as pre emergence herbicide application followed by 2,4-D sodium salt 80 WP @ 0.5 a.i. kg/ha followed by one hand weeding or stale seed bed followed by Pendimethalin 30 EC @ 1 a.i. kg/ha followed by Bispyribac (nominee gold) @ 25 a.i. g/ha 10 % SC @ 200 ml/ha at 20 days of seeding resulted best alternative for manual hand weeding practices giving higher net return per unit investment.

Conclusion

Being said that DDSR is a promising technology that stands out in the shortcomings of TPR in the context of water and labor scarcity, but the success of DDSR crop looms uncertain amidst the serious challenge to manage weeds effectively. However, availability of various herbicides has made weed management easier and economical. Under this scenario, we cannot undermine the consequences of haphazard use of herbicides to rice production system and ultimately to environmental and human health. Careful rotation and choice of herbicides to prevent herbicidal resistance is must and at the same time proper timing of herbicide application taking critical period of weed control, level of weed infestation, weed flora and weather conditions into consideration. Sole reliance on herbicides is not sustainable approach for DDSR system as herbicides may be regarded as best alternative until other ecofriendly solutions are developed. Rationalizing use of herbicide integrating with preventive, cultural, mechanical and biological strategies to manage weeds is the dire need for sustainability of DDSR.

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Optimum sowing date and fertilizer management for durum wheat genotype DWK 38 in mid-hills condition

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Abstract
Durum wheat is relatively new crop for Nepal and research on durum wheat were carried out only by Agriculture Botany Division of Nepal Agricultural Research Council (NARC). To find the optimum sowing time and fertilizer dose for mid-hills conditions of Nepal, an experiment was carried out in 2017/18 and 2018/19 at Agronomy Division Experimental farm in Khumlatar at an altitude of 1360 masl. The experimental design was factorial randomised complete block design. There were 3 fertilizer level and 4 sowing date constituting 12 treatment combinations. From the combined analysis over years, we found that plant height, days to heading, days to maturity, thousand grain weight and grain yield were found significnat in sowing date whereas number of tillers per square meter, straw yield and harvest index were significant in fertilizer doses**.** Combined analysis of both years yielded mean grain yield of 5.2 t/ha and thousand grain weight of 48.6 gm respectively. Precipitation during reproductive period (March-April) in 2017/18 contributed in higher grain yield than 2018/19. Optimum sowing date of durum wheat for khumaltar condition is no later than 26 November and optimum dose of fertilizer is 125:75:50 $N:P_2O_5:K_2O$ kg/ha.

Keywords: Durum, fertilizer, optimum, sowing date, yield

Introduction
Bread wheat (*Triticum aestivum* L.), commonly wheat, is widely grown throughout the world (Slafer, *et al.,* 1994). The global wheat production was 734045174 tons from harvested area of 214991888 ha (FAOSTAT, 2018).Wheat occupies 3rd position in terms of area and production in Nepal after paddy and maize. In 2018/19, area occupied by wheat was 703,992 ha and production was 2005665 mt (MoALD 2020). Grain yield of wheat was significantly influenced by sowing dates and cultivars (Fazal *et al.*, 2015). Wheat is sown in winter as it has its own definite requirement for temperature and light for emergence, growth and heading (Dabre *et al*., 1993). Too early sowing produces weak plants with poor root system as the temperature is above optimum. Temperature above optimum leads to irregular germination and the embryo frequently dies. Late sowing results in poor tillering and crop grow generally slow which get short growth period in the field (Sattar *et al.*, 2010). Timely sowing is important for obtaining high yield. Delay in sowing from 15 November to 15 December decreased grain yield by 32.6 % to 27.4 % (Virendar *et al.,* 2002).

Durum wheat (*Triticum turgidum* sp. *durum*) growing regions are the middle East, Southern Europe, North Africa, the former Soviet Union, North America and India. Worldwide, durum is grown in approximately in 13 million hectares (Boyacioglu, 2017) and with production of 30 million tonnes. The major durum producing countries in the world are Canada (>2 million ha), USA (>1 million ha), Mediterranean (particularly in Italy with >1 million ha), France, Spain and Greece each with > 500000 ha (Miedaner and Longin, 2012). Durum wheat has tremendous scope of production in plain areas of mid and far western regions of Nepal (ABD, 2014). Nepal has imported 417571 kg of durum wheat worth Rs 1,066,258,000 during 2018/19 (MOALD, 2020). Researches on durum wheat were carried outby National Plant Breeding and Genetics Research Centre (then Agriculture Botany Division) of NARC in coordination with Agriculture Research Directorate, Lumbini Province (then RARS Khajura) at Khajura, Banke for durum wheat improvement for mid and far western terai (ABD, 2014).The general recommended fertilizer dose for durum wheat is 120:60:60 $N:P_2O_5:K_2O$ kg/ha (ABD, 2015), wherever this is not site and variety specific. The research work on date of sowing and dose of fertilizer on promising durum wheat genotypes is very limited. Therefore, this experiment was designed and conducted at National Agronomy Research Centre, Khumaltar to find out the optimum date of planting and optimum fertilizer dose for durum wheat genotype DWK 38.

Materials and Methods

The field experiments were conducted in the winter season of 2017 and 2018 in the experimental field of Agronomy division, Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal. The site was geographically located at 85°10'E Longitude 27°39'N latitude and at 1360 masl altitude and the experiments were laid out in factorial randomized complete block design (RCBD) in three replications. The field was prepared using Mould Board plough and soil clods were broken with disc harrow. The plot size was 4m x 3m and row spacing was 25 cm. The three different fertilizer doses comprised as factor A (125:75:50, 150:75:50 and 175:75:50 N:P_2O_5:K_2O kg/ha) and four sowing dates as Factor B (6th Nov, 16th Nov, 26th Nov and 6th Dec).The durum wheat genotype used was DWK 38 and seeds were manually sown in line at the rate of 120 kg per hectare. Half dose of nitrogen and full dose of phosphorus and potash was applied as basal dose and remaining nitrogen was top dressed at tillering and heading stage. Nitrogen was applied through urea, phosphorus through Di-ammonium phosphate (DAP), and potash through Muriate of Potash (MOP). All the recommended agronomic practices including irrigation, weeding and hoeing were carried out for all the treatments. Ten random plants from each plot were selected for recording plant height and spike length. 1m^2 quadrate was used to estimate tillers/m^2, 10 randomly selected spikes were taken to estimate number of grains/spike and 1000 grain weight. In case of grain yield and straw yield estimation, net harvested area of 8 m^2 was used. The data obtained were analyzed using the software STAR and grand mean, coefficient of variation (CV %) and least significant difference of mean (LSD) were calculated.

Meteorological data

The meteorological data were obtained from the meteorological station at Agronomy division. The mean maximum and minimum temperature in 2017/18 were 23.2 °C and 8.40 °C respectively in crop growing period. Total rainfall recorded was 181.6 mm and numbers of rainy days was 40 days. In 2017/18, April received highest volume of rainfall which helps in reproductive growth of crop. Similarly, the mean maximum and minimum temperature in 2018/19 were 22.2 °C and 8.0 °C respectively. Total rainfall recorded was 310.3 mm and number of rainy days was 41. May received highest volume of rainfall of 120.9 mm in 5 days which adversely affects in yield and yield parameters.

Results and Discussion

The result of the experiments shows that data on plant height ranged from 94.8 to 98.9 cm among different fertilizer doses and 94.3 to 100.8 cm among different sowing dates with mean plant height 97.2 cm in 2017. It shows that fertilizer and even sowing date does not impact on plant height in 2017, however, plant height decreased after 16 November (table 2). Similarly, plant height ranged from 97.5 to 101.9 cm among different fertilizer doses and 94.9 to 104.0 cm among different sowing dates in 2018. Plant height was significantly different among different sowing dates with maximum plant height in 26 Nov (104.0 cm) and minimum in 6 Dec (94.9 cm) and mean plant height 100.3 cm in 2018 (table 3). Spike length ranged from 7.6 to 7.8 cm among different fertilizer doses and 7.2 to 8.0 cm among different sowing dates in 2017 which are not significantly different within the groups. The mean spike length in 2017 was 7.7 cm. In 2018, spike length ranged from 10.5 to 12.1 cm among fertilizer doses and 10.3 cm to 12.3 cm among different sowing dates which are not significantly different within the groups. The mean spike length in 2018 was11.0 cm. Days to 50 % heading in durum wheat ranged from 115.9 to 117.1 days among different fertilizer doses which was not significantly different within the group. Days to 50% heading ranged from 111.5 to 123.3 days with thelowest for late sown wheat and the highest value for early sown wheat. Days to 50% heading in sowing date was significantly different within the group where mean days to 50% heading was116.4 days in 2017. Similarly in 2018, days to heading ranged from 126 to 126.5 days among different fertilizer doses which was not significantly different within the group while days to heading ranged from 116.4 to 134.6 days among different sowing dates which was significant among sowing dates. The mean 50% days to heading in 2018 was 126.2 days.

No. of grains per spike, grain yield and straw yield were found non-significant both in fertilizer doses and date of sowing while days to 90% maturity, tillers per m^2 and thousand grain weight in date of sowing and harvest index in fertilizer doses were found significantly different (however tillers per m^2 and thousand grain weight in fertilizer doses and harvest index in date of sowing were found non-significant) in 2017. Days to 90 % maturity ranged from 165.3 to 171.5 days in fertilizer level and 159.3 to 183.6 days in sowing days with mean maturity of 169.2 days. Number of tillers per m^2 ranged from 374.1 to 455.5 in fertilizer doses and 334.1 to 514.1 in sowing dates. Highest no. of tillers both in fertilizer doses and sowing dates contributed in straw yield rather than grain yield. The mean value for tillers was 427.7 in 2017. No. of grains per spike ranged from 48.4 to 49.9 in fertilizer dose and 45.3 to 53.5 with mean value of 49.2 in 2017. Thousand grain weight ranged from 50.1 to 51.4 g in fertilizer doses and 46.3 to 55.7 gm with mean test weight 50.9 g in 2017. Grain yield in fertilizer doses ranged from 5.67 to 6.43 t/ha and 5.82 to 6.06 t/ha in sowing dates in 2017 with mean grain yield of 5.98 t/ha. Straw yield ranged from 8.1 to 11.15 t/ha in fertilizer level and 8.3 to 10.7 t/ha in sowing dates with mean straw yield of 9.4 t/ha in 2017. Harvest index ranged from 0.35 to 0.46 in fertilizer level and 0.35 to 0.44 in sowing dates with mean harvest index of 0.40 in 2017.

Table 1. Yield and yield attributing traits of durum wheat trial in 2017/18

Treatments	PH	SL	DH	DM	Tillers	Grains	TGW	GY	SY	HI
Fertilizer dose (A) ($N:P_2O_5:K_2O$ kg/ha)										
125:75:50	97.9	7.6	116.1	170.7	374.1	49.9	51.4	6.4	8.1	0.46
150:75:50	94.8	7.6	115.9	170.3	453.6	49.4	51.2	5.8	9.0	0.40
175:75:50	98.9	7.8	117.1	171.5	455.5	48.4	50.1	5.7	11.1	0.35
LSD (P<0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.07
Sowing date (B)										
6Nov	98.9	7.9	123.3	183.6	334.1	53.5	55.7	6.1	9.4	0.44
16 Nov	100.8	8.0	115.4	174.7	399.6	52.2	54.2	6.0	8.3	0.43
26 Nov	95.0	7.6	115.1	165.9	463.1	45.7	47.5	6.0	9.3	0.40
6 Dec	94.3	7.2	111.6	159.3	514.1	45.3	46.3	5.8	10.7	0.35
LSD (P<0.05)	ns	ns	2.5	2.3	97.4	ns	3.4	ns	ns	ns
A*B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	5.7	8.8	2.2	1.4	23.3	18.8	6.8	18.1	34.8	21.4
Grand Mean	97.2	7.7	116.4	170.9	427.7	49.2	50.9	6.0	9.4	0.40

Note: *PH: Plant height (cm), SL: spike length (cm), DH: days to 50% heading, DM: days to 90% maturity, tillers: No. of tillers per m^2, Grains: No. of grains per spike, TGW: thousand grain weight (g), GY: grain yield (t/ha), SY: Straw yield (t/ha), HI: harvest index*

In winter season 2018, plant height of durum wheat ranged from 97.5 to 101.9 cm in fertilizer doses and 94.9 to 104.0 cm in sowing dates. Plant height was significantly different in different sowing dates. The mean plant height was 100.3 cm. Spike length ranged from 10.5 to 12.1cm in different fertilizer doses and 10.3 to 12.3cm in different sowing dates. The values were not significantly different in both fertilizer dose and sowing date. The mean spike length was 11.02 cm. Similarly, days to 50% heading ranged from 126 to 126.5 days in fertilizer doses and 116.4 to 134.6 days in sowing days which was significantly different. Early sown durum wheat takes longer period for heading while late sown wheat are earlier in heading. Day to 50% heading mean was 126.22 days. Days to 90% maturity ranged from 168.92 to 170 days in fertilizer doses while it ranged from 156.2 to 179.8 days in sowing dates which were significantly different. Like heading, early sown wheat matured late and late sown wheat matured early. The mean days to 90% maturity was 169.3 days. Number of tillers per m^2 ranged from 306.1 to 370.5 in fertilizer doses which were significantly different with maximum number of tillers (370.5) in highest fertilizer dose (175:75:50 N:P_2O_5:K_2O kg/ha). The tillers numbers ranged from 245.4 to 377.4 in sowing date which was significantly different among different sowing dates. Minimum tillers were found in late sown wheat. The mean tillersnumber per m^2 was 335.2. No. of grains per spike ranged from 42.5 to 45.1 in fertilizer doses while it ranged from 40.1 to 50.4 in sowing date which was significantly different among sowing dates. Grains per spike was found maximum (50.4) in late sown wheat. The mean no. of grains per spike was 43.7. Thousand grain weight (test weight) ranged from 44.8 to 47.7 g in fertilizer doses which was significantly different while test weight ranged from 43.9 to 47.9 g in different sowing dates which was also significantly different. The mean test weight was 46.3 cm.

Grain yield ranged from 4.09 to 4.85 t/ha in difzferent fertilizer doses which was significantly different. Highest fertilizer dose (175:75:50N:P_2O_5:K_2O kg/ha) gave highest grain yield of 4.85 t/ha.Timely precipitation during growing season could have contributed in optimization of fertilizer which ultimately foster grain yield. Similarly, grain yield ranged from 3.37 to 5.28 t/ha in sowing date which was also significantly different. Maximum grain yield was obtained from 26 Nov (early planting) and minimum from 6 Dec (late planting). The mean grain yield was 4.49 t/ha. Similarly, straw yield ranged from 6.1 to 7.4 t/ha in fertilizer doses while it ranged from 4.1 to 7.7 t/ha in sowing dates. The yield is significantly different in sowing dates with minimum yield in 6th Dec and maximum yield in 6th Nov. The mean straw yield was 6.68 t/ha. The harvest index value in different fertilizer doses ranged from 0.40 to 0.42 while the value ranged from 0.38 to 0.44 in sowing dates (Table 2). The index was neither significant in fertilizer dose nor in sowing date. The mean harvest index value was 0.41.

Table 2. Yield and yield attributing traits of durum wheat trial in 2018/19

Treatments	PH	SL	DH	DM	Tillers	Grains	TGW	GY	SY	HI
Fertilizer dose (A) (N:P_2O_5:K_2O kg/ha)										
125:75:50	97.5	10.5	126.2	168.9	328.9	42.5	47.7	4.1	6.1	0.41
150:75:50	101.5	10.5	126.0	170.0	306.1	43.5	44.8	4.5	6.5	0.42
175:75:50	102.0	10.4	126.5	169.0	370.5	45.1	46.3	4.9	7.4	0.40
LSD (P<0.05)	ns	ns	ns	ns	47.0	ns	3.3	0.6	ns	ns
Sowing date (B)										
6Nov	100.5	10.3	134.6	179.8	358.1	40.9	47.8	4.5	7.7	0.38
16 Nov	102.0	10.1	128.9	175.0	359.7	40.1	47.9	4.8	7.2	0.40
26 Nov	104.0	10.5	125.0	166.2	377.4	43.4	45.5	5.3	7.6	0.41
6 Dec	94.9	11.0	116.4	156.2	245.4	50.4	43.9	3.4	4.1	0.44
LSD (P<0.05)	4.9	0.6	2.9	3.9	54.2	6.2	3.3	0.7	1.5	ns
A*B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	5.0	5.8	2.4	2.3	16.6	14.6	4.2	14.9	22.8	13.3
Grand Mean	100.3	10.5	126.2	169.3	335.2	43.7	46.3	4.5	6.7	0.4

Note: *PH: Plant height (cm), SL: spike length (cm), DH: days to 50% heading, DM: days to 90% maturity, tillers: No. of tillers per m^2, Grains: No. of grains per spike, TGW: thousand grain weight (g), GY: grain yield (t/ha), SY: Straw yield (t/ha), HI: harvest index*

Plant height of durum wheat has exhibited significant difference in different sowing dates in 2018 while there was no significant difference in 2017 in sowing dates. Plant height was not significant in both years over fertilizer doses. Similarly, spike length was not significant for fertilizer doses and sowing dates in both years. Days to heading and days to maturity were higher in early sown wheat as compared to late sown wheat in both years. In 2017, days to heading were earlier than 2018 but maturity date was later than 2018 in every date. Effect of fertilizer doses was not found significant in both years. Tillers number was found significant for both fertilizer doses and sowing dates in 2018 and only for sowing date in 2017. Although tillers number was more in 2017 for fertilizer dose and sowing date, the result was not significant within sowing date and fertilizer dose. Number of grains per spike was found significant for sowing date in 2018 which may be due to less plant population. Thousand grain weight was found significant for different sowing dates in both years and fertilizer doses in 2018 however mean thousand grain weight was higher in 2017 (50.9 g) compared to 2018 (46.3 g). Grain yield was found non-significant in 2017 and significant in 2018 for both factors, however, mean grain yield was higher in 2017 (5.98 t/ha) than 2018 (4.49 t/ha).Straw yield was only significant in sowing date in 2018. Like grain yield, mean straw yield was also higher in 2017 (9.39 t/ha) than 2018 (6.68 t/ha). Although, mean harvest index was higher in 2018 compared to 2017, there was no significant difference in 2018. Harvest index was significant difference in fertilizer doses in 2017. Fertilizer dose 125:75:50 N: P_2O_5:K_2O kg/ha yielded highest HI (0.46) and lowest by 175:75:50 N: P_2O_5:K_2O kg/ha (0.35). Fertilizer dose was found non-significant for almost all traits in both years.

Table 3. Combined analysis of yield and yield attributing traits of durum wheat trial over 2017/18 and 2018/19

Treatments	PH	SL	DH	DM	Tillers	Grains	TGW	GY	SY	HI
Fertilizer dose (A) (N:P_2O_5:K_2O kg/ha)										
125:75:50	97.7	9.1	121.1	169.8	351.5	47.8	49.6	5.3	7.1	0.43
150:75:50	98.2	9.0	121.0	167.6	379.8	47.2	48.0	5.2	7.8	0.41
175:75:50	100.5	9.1	121.8	170.3	413.0	47.0	48.2	5.3	9.2	0.38
LSD (P<0.05)	ns	ns	ns	ns	46.9	ns	ns	ns	1.5	0.04
Sowing date (B)										
6 Nov	99.7	9.1	128.9	181.7	346.1	50.1	51.8	5.3	8.6	0.41
16 Nov	101.4	9.1	122.2	174.8	379.6	48.2	51.1	5.4	7.7	0.41
26 Nov	99.5	9.0	120.1	166.1	420.3	45.5	46.5	5.6	8.4	0.40
6 Dec	94.6	9.1	114.0	157.8	379.8	45.6	45.1	4.6	7.0	0.40
LSD (P<0.05)	3.5	ns	2.6	2.2	ns	ns	4.6	0.8	ns	ns
A*B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	5.3	7.1	2.3	1.9	21.1	17.1	5.7	17.2	31.	17.8
Grand Mean	98.8	9.1	121.3	170.1	381.4	46.5	48.6	5.2	8.0	0.41

Note: *PH: Plant height (cm), SL: spike length (cm), DH: days to 50% heading, DM: days to 90% maturity, tillers: No. of tillers per m^2, Grains: No. of grains per spike, TGW: thousand grain weight (g), GY: grain yield (t/ha), SY: Straw yield (t/ha), HI: harvest index*

After combined analysis of data over two years, results for different parameters were obtained. Plant height was found non significant for fertilizer dose however it was significant for date of sowing with mean plant height 98.8 cm. Late sown wheat had shorter plant height than earlier dates. Late sown wheat had shorter height due to shorter growing period. Early sown crop had enjoyed longer growing period with plenty of temperature and solar radiation which resulted in taller plants. Similar results were also reported by Shahzad *et al.*, (2002) and Anwar *et al.*, (2015). On other side spike length was found non-significant for both fertilizer and sowing date with mean spike length 9.1cm. Days to heading and days to maturity were significant for date only and mean were 121.3 days and 170.1 days respectively. Early sowing took longer period for heading and maturity. Numbers of tillers per m^2 were found significant in fertilizer doses and mean value was 381.4. Highest fertilizer dose contributed highest tillers. Number of grains per spike were non-significant in both fertilizer dose and date where mean number of grains per spike was 46.5. Highest thousand grain weight was recorded in early planting. Early sowing resulted in better development of seeds due to longer growing periods whereas decreased in thousand grain weight in delayed sowing was also reported by Spink *et al.*, (2000) and Anwar *et al.*, (2015). Early sowing date at Nov 26 gave highest grain yield (5.6 t/ha) while late sowing at 6 Dec yielded lowest yield (4.6 t/ha) where mean value of thousand grain weight and grain yield were 48.6 g and 5.2 t/ha respectively. Highest fertilizer dose (175:75:50 N: P_2O_5:K_2O kg/ha) gave highest straw yield (9.2 t/ha) and lowest harvest index (0.38) which may be due to highest number of tillers per m^2 (413). Harvest index had inverse relationship with straw yield. The highest harvest index (0.43) was recorded in the lowest fertilizer dose (125:75:50 N: P_2O_5:K_2O kg/ha). Mean straw yield and mean harvest index were 8.0 t/ha and 0.41 respectively.

Conclusion

From the two years experiment data, durum wheat sown by 26th November gave maximum grain yield and later from this date, grain yield decreases by 100 kg/ha/day in Khumaltar condition .Sowing date had significant result on growth and yield attributing traits like plant height, days to heading, days to maturity, thousand grain weight and grain yield whilefertilizer dose had significant result in number of tillers per m^2, straw yield and harvest index**.** Fertilizer dose was found significant for number of tillers per m^2 but not for yield. This may be due to less source sink conversion because of which straw yield was highest in highest fertilizer level. From this experiment, we conclude that fertilizer dose of 125:75:50 N:P_2O_5:K_2O kg/ha is optimum for growth and yield of durum wheat in Khumaltar condition.

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Performance of rice varieties and nitrogen levels under aerobic condition in Eastern Terai

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Abstract
An experiment was conducted for two years (2016 – 2017) to evaluate the performance of rice varieties and nitrogen level under aerobic conditions in the Regional Agriculture Research Station, Tarahara, Sunsari Nepal. The treatments were two varieties of rice (Sukhkhadhan 3 and Sukhkhadhan 6) and five levels of Nitrogen (0, 30, 60, 90 and 120 kg/ha) which was assigned in a split-plot design with three replications. The varieties were treated as the main factor and nitrogen levels were assigned as a sub-plot factor. In both years, the plant height, number of tillers per meter square, panicle number per meter square, panicle length, filled grains, thousand grain weights were recorded. All the recorded values of these paremeters were remarkably same with the application of 120:30:30 $N:P_2O_5:K_2O$ kg/ha and application of 90:30:30 $N:P_2O_5:K_2O$ kg/ha. The grain yields of 3.47 t/ha (2016) and 4.77 t/ha (2017) and straw yields of 7.65 t/ha (2016) and 7.44 t/ha (2017) were recorded with the application of 120:30:30 $N:P_2O_5:K_2O$ kg/ha which found statistically at par with the application of 90:30:30 $N:P_2O_5:K_2O$ kg/ha in both years. Furthermore, grain yield of Sukhkhadhan 3 (3.46 t/ha) remained statistically similar with that of Sukhkhadhan 6 (3.38 t/ha).

Keywords: Direct seeded rice, nitrogen level, varieties

Introduction
Rice (*Oryza sativa* L.) is one of the most important cereals in the world. The rice growing area and production in Nepal are 1.5 million hectares and 5.6 million tons respectively (MOALD, 2018). The population of the country is increasing day by day and horizontal expansion of rice area is not possible due to high population pressure, especially in rice production (Poudel, 2016). Hence, special attention should be given to increase the yield by applying nutrient conserving practice in the soil, use of an optimum dose of nitrogen fertilizer; proper seed rate, high yielding varieties and hybrid varieties (Singh and Singh, 2017). Nutrient management plays an important role whereas nitrogen is the key input for production especially in rice-growing countries including Nepal (Thapa, 2010). According to Tadesse *et al.,* (2020), the 70-80 percent increase in grain yield of rice may be obtained by proper application of nitrogen fertilizer. It is the main nutrient associated with yield in the rice crop, but N rates respond differently to rice type, cultivar, geographic zone and other practices (Bouman *et al.,* 2007). Both lower and higher nitrogen rates are detrimental to crop growth and development. The appropriate nitrogen dose gives a higher yield of the crop and reduced fertilizer cost (Hossain and Islam, 1986). But the dose of nitrogen fertilizer is inappropriate in most cases due to lack of information and over 97 percent of farmers do not follow the recommended dose in developing countries (Hossain *et al.,* 2014). Unfortunately, nitrogen management in direct-seeded rice has received very little attention and management is usually similar to the transplanted method (Chen *et al.,* 2018). Direct-seeded rice is becoming more popular as an alternative to transplanted rice, as it is more profitable when the crop is managed properly. Direct seeding of rice avoids the need for nursery preparation, uprooting of seedlings and transplanting. There has been a rapid shift to the direct seeding method of rice establishment in Asia with 21-22% of the total rice area being dry direct-seeded rice (Gathala *et al.,* 2011). Although a large number of experiments have been carried out to find out the optimum doses of nitrogen in transplanted rice in many places of the world including Nepal, a sufficient number of experiments have not yet been done in direct-seeded rice. Therefore, the experiment was conducted with the objectives to identify the optimum level of nitrogen for obtaining a higher yield from direct-seeded rice.

Materials and Methods

Study site
The study was conducted during two rainy seasons of 2016-2017 A.D at Regional Agriculture Research Station (RARS), Tarahara, Sunsari, Nepal. The climate of the station is sub-tropical and clay loam soil type. It is geographically located at 26º42'16.85" North latitude and 87º16'38.43" East longitude with an elevation of 136 m above mean sea level.

Experimental design
The experimental plot was designed in a split-plot with three replications. The main plot included two drought-tolerant varieties (Sukhkhadhan-3 and Sukhkhadhan-6) with 5 fertilizer levels as sub-plot (0:30:30 $N:P_2O_5:K_2O$ kg/ha, 30:30:30 $N:P_2O_5:K_2O$ kg/ha, 60:30:30 $N:P_2O_5:K_2O$ kg/ha, 90:30:30 $N:P_2O_5:K_2O$ kg/ha and 120:30:30 $N:P_2O_5:K_2O$ kg/ha). Nitrogen was provided through urea and DAP, Phosphorus was applied through DAP and the source of potassium as MOP. The full dose of phosphorus and potassium and half dose of N was applied at the time of land preparation. The remaining half dose of N was applied in two splits.

Seed preparation and sowing
The seed was pre-soaked for 24 hours and incubated for 36 hours before seeding. The same pre-germinated seeds were sown in continuous lines with the row spacing of 25cm on the first week of July 2016 and 2017 respectively. The land was well prepared by 2-3 tillage and well leveled. The treatments sub-plot size was 10 m^2 and seed rate of 40 kg seed/ha was used.

Weed control
All intercultural operations such as weed control and irrigation were applied as needed. Pendimethalin @ 1000 ml a.i /ha was applied to control grasses and sedges in the initial stages of crop followed by one hand weeding and bispyribac sodium salt 20 a.i. g/ha were applied after one month of planting in all the treatments.

Data recording
During the experimentation, the data were recorded in such a way as average plant height was measured from the base of the stem up to the longest panicle tip in randomly selected 10 hills in each plot. To determine the effective tillers/m^2, only the panicle bearing tillers were counted from the 4th sample hills and its average was expressed in tillers or panicle m^{-2}. Days to flowering were determined when 50% of the hills in each plot had reached anthesis. Days to maturity were determined when 80% of the hills in each treatment were matured. Panicles after maturity were hand-threshed and the filled and unfilled grains were separated. Total numbers of filled grains and empty grains per panicle were counted and expressed in grain filling %. Grain and straw yields were determined from the harvested area of 1 m^2 marked in the middle of each sub-plot to avoid the border effect in each plot. Grain samples were harvested, dried and adjusted to a moisture content of 14% for determining thousand grain weight (TGW) and yield. The straw was sun dried, weighed and expressed in t/ha.

Data analysis
The data collected were analyzed using STAR software and compared among the different treatments. Treatment means were compared using the least significant difference (LSD) tests and compared at $p \leq 0.05$ level of significance.

Results and Discussions

Climatic condition during experimentation
In two consecutive years, the monsoon started from May to September, but the rainfall pattern was unevenly distributed in 2017 with lower rainfall (1899.2 mm) as compared to 2016 (2262.40 mm) within

the entire experimentation (from May to October). The rainfall highly fluctuated in August and September in both years but in 2016, the highest rainfall recorded was 590.5 mm which was quite similar to June (589 mm). In the case of 2017, the highest rainfall was recorded as 918.2 mm in August, which was higher than in other months. This intense rainfall did not damage the crop because it already attained panicle initial stage (90 days after sowing) that favored growth and development of the crop. However, late rainfall in 2016 did not favor the proper germination of the crop so the optimum population wasn't obtained. Similarly, the maximum temperature ranged from 31.03 to 33.59 °C and minimum temperature from 21.32 to 25.75°C during the crop growing season in the year 2016 (Figure 1 and 2) but the maximum temperature ranged slightly higher (32.8 to 34.3°C) in 2017. In both years, the maximum temperature reached above 34°C in August or September and the minimum was recorded below 22°C in October.

Table 1. Growth parameters influenced due to different dose of fertilizer and varieties for DSR at Regional Agricultural Research Station Tarahara, Sunsari, Nepal during wet season 2016 and 2017

Treatments	Plant height (cm)		Panicle length (cm)		Panicle no. /m^2	
	2016	2017	2016	2017	2016	2017
Variety						
Sukhkhadhan 3	103.61^{b}	100.9	22.27	22.8	205.46	257.7
Sukhkhadhan 6	115.00^{a}	110.8	23.05	23.0	208.66	234.7
LSD (P<0.05)	6.12	ns	ns	ns	ns	ns
Fertilizer ($N:P_2O_5:K_2O$ kg/ha)						
0:30:30	105.26^{b}	98.0^{c}	21.99^{b}	21.1^{c}	202.16	214.2^{b}
30:30:30	105.26^{b}	105.0^{b}	22.31^{ab}	22.3^{bc}	210.50	238.0^{ab}
60:30:30	107.96^{ab}	106.2^{ab}	22.39^{ab}	22.9^{abc}	220.83	245.8^{ab}
90:30:30	110.03^{ab}	108.7^{ab}	22.82^{ab}	23.6^{ab}	200.83	261.5^{a}
120:30:30	117.76^{a}	111.2^{a}	23.79^{a}	24.6^{a}	201.00	271.7^{a}
LSD (P<0.05)	9.68	5.54	1.41	1.9	ns	31.9
CV, %	0.85	4.28	5.07	6.89	22.26	10.59

Note: *Treatment means followed by same letter(s) in the column are not significantly different among each other based on DMRT at 0.05. ns= non-significant*

Table 1 showed that the plant height and number of panicle length were significantly higher with the increasing dose of fertilizers in both consecutive years. The plant height was highest (117.8 cm) with the application of 120:30:30 $N:P_2O_5:K_2O$ kg/ha which was at par with 90:30:30 and 60:30:30 $N:P_2O_5:K_2O$ kg/ha on both consecutive years. Likewise, the panicle number per meter square and panicle length were recorded as 271.7 and 24.6 with the application of 120:30:30 $N:P_2O_5:K_2O$ kg/ha which was statistically at par with the application of 90:30:30 $N:P_2O_5:K_2O$ kg/ha. Similar results were also obtained by Singh *et al.*, (2014); Mahajan and Timsina (2011); Gala *et al.*, (2011) and Dongarwar *et al.*, (2015) who reported that the increasing amount of nitrogen considerably improves the vegetative growth of rice. Furthermore, the panicle per meter square was non-significant with the increasing dose of nitrogen fertilizer. It might be due to the lodging of the crop at a later stage. Similar findings reported by Lacerda *et al.*, (2016) because nitrogen can make plants more susceptible to lodging. Likewise, the plant height, panicle per meter square and panicle length were non-significant among the varieties but the plant height of Sukhkhadhan-6 was around 12 cm higher than Sukhkhadhan-3 in both years.

Table 2. Growth parameters influenced due to different dose of fertilizer and varieties for DSR at Regional Agricultural Research Station Tarahara, Sunsari, Nepal during wet season 2016 and 2017

Treatments	Filled grains panicle		Grain filling %		TGW (g)	
	2016	2017	2016	2017	2016	2017
Variety						
Sukhkhadhan 3	87.42^{a}	77.7	89.99^{a}	87.9	21.76	21.9^{b}
Sukhkhadhan 6	75.98^{b}	82.9	77.57^{b}	84.7	24.24	24.1^{a}
LSD (P<0.05)	9.925	ns	3.885	ns	ns	0.96
Fertilizer ($N:P_2O_5:K_2O$ kg/ha)						
0:30:30	70.80^{c}	69.6	83.83	85.5	22.61	22.4
30:30:30	77.96^{bc}	78.4	84.14	85.8	22.73	22.8
60:30:30	79.63^{b}	79.9	82.51	85.9	22.97	23.2
90:30:30	81.36^{b}	86.6	82.35	86.5	22.29	23.2
120:30:30	98.76^{a}	86.9	86.08	87.7	24.40	23.4
LSD (P<0.05)	15.69	ns	ns	ns	ns	ns
CV, %	15.74	16.24	5.99	3.29	26.78	2.57

Note: *Treatment means followed by same letter(s) in the column are not significantly different among each other based on DMRT at 0.05. ns= non-significant*

Grain filling percentage and thousand grain weights were non-significantly differed among the doses of fertilizers; however, all these were significant among the varieties. The filled grain was significantly higher by 15.5 and 16.0 % in Sukhkhadhan 3 in the first year but non-significant in the second year. Likewise, the thousand grain weight was significantly higher by 10.0 % in Sukhkhadhan 6 for the second year but non-significant in the first year.

Table 3. Growth parameters influenced due to different doses of fertilizer and varieties for DSR at Regional Agricultural Research Station Tarahara, Sunsari, Nepal during wet season 2016 and 2017

	Straw yield (t/ha)		Harvest index (HI)		Grain yield (t/ha)		
Variety	2016	2017	2016	2017	2016	2017	Pooled
Sukhkhadhan	4.92^{b}	5.87	0.385	0.41 ^{a}	2.96	3.96	3.46
Sukhkhadhan	7.84^{a}	7.57	0.291	0.33 ^{b}	3.14	3.61	3.38
LSD (P<0.05)	1.09	ns	0.042	0.07	ns	ns	ns
Fertilizer ($N:P_2O_5:K_2O$ kg/ha)							
0:30:30	5.64^{b}	5.71 ^{c}	0.330	0.34	2.57^{d}	2.76 ^{d}	2.66^{d}
30:30:30	5.77^{b}	6.45 ^{b}	0.336	0.36	2.59^{c}	3.47 ^{c}	3.03^{cd}
60:30:30	6.06^{ab}	6.74 ^{ab}	0.363	0.36	3.24^{b}	3.65 ^{bc}	3.44^{bc}
90:30:30	6.79^{ab}	7.24 ^{a}	0.343	0.38	3.37^{ab}	4.29 ^{ab}	3.83^{ab}
120:30:30	7.65^{a}	7.44 ^{a}	0.321	0.40	3.47^{a}	4.77 ^{a}	4.12^{a}
LSD (P<0.05)	1.72	0.63	ns	ns	0.691	0.70	0.47
CV,%	22.01	8.43	15.10	12.85	18.50	15.07	16.58

Note: *Treatment means followed by same letter(s) in the column are not significantly different among each other based on DMRT at 0.05. ns= non-significant*

The grain yield and straw yield significantly differed due to the nitrogen level but the harvest index was non-significant among the treatments on both consecutive years. The pooled data analysis showed that the higher grain yield (4.12 t/ha) was recorded by the application of 120:30:30 N:P_2O_5:K_2O kg/ha which was statistically at par with the application of 90:30:30 N:P_2O_5:K_2O kg/ha (3.83 t/ha). Similarly, the straw yield was also recorded higher (7.65 and 7.44 t/ha) by the application of 120:30:30 N: P_2O_5:K_2O kg/ha which was statistically at par with the application of 90:30:30 N: P_2O_5:K_2O kg/ha (6.79 &7.24 t/ha) respectively. Similar results were also obtained by Sharma *et al.* (2007) who reported that application of 120 N kg/ha gave significantly higher grain and straw yields over 40 N kg/ha. Similarly, the application of 120 N kg/ha significantly increased the grain yield of rice as compared to the lower (60 N kg/ha) and higher doses (180 N kg/ha) (Xiang-long *et al.*, 2007 and Huang *et al.*, 2008). However, the grain yield and straw yield were non-significant among the varieties in both consecutive years. But the harvest index was significantly higher by 21.2 % in Sukhkhadhan-3 over the Sukhkhadhan-6 during 2017.

Conclusion

The application of 120:30:30 and 90:30:30 N:P_2O_5:K_2O kg/ha performed similarly but comparatively 120:30:30 N:P_2O_5:K_2O kg/ha had higher plant height, more effective tillers per meter square, thousand grains weight, panicle weight, panicle length and grain yield under the direct-seeded condition in both years.

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Response of rapeseed (*Brassica campestris* var *toria*) varieties to sowing dates in middle Terai

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Abstract
A field experiment was conducted during the winter season at Tamsariya-7, Nawalparasi, Nepal to determine the effect of sowing dates on growth and yield of rapeseed varieties. Four varieties of rapeseed (Unnati, Preeti, Pragati and Local) were planted in four sowing dates; October 13th, October 28th, November 12th and November 27th. The experiment was laid out in split-plot design with sowing date in the main plot and varieties in the sub-plot. Significant variations due to sowing dates and varieties were observed in plant height, leaf area index, dry matter accumulation, branches per plant, number of siliqua per plant, siliqua length, number of seeds per siliqua, abortion percentage, test weight and the grain yield. Results showed that the highest grain yield (1.278 t/ha) was obtained from the October 28th sowing date and it was statistically different from the yield of all other dates of sowing. There were 17.05%, 40% and 62.18% reduction in grain yield for October 13th, November 12th and November 27th sowing dates compared to October 28th sowing date. Variety Preeti was the highest yielding variety for October sowing while variety Unnati was the highest yielding variety for November sowing. So, variety Preeti sown on October 28th is recommended to the farmers of the area and similar locations for obtaining optimum yield but under late sown condition, variety Unnati is preferred to Preeti for obtaining the optimum yield.

Key words**:** Grain yield, rapeseed, sowing date, variety

Introduction
Oil seed crops are the third important crops of Nepal after cereals and legumes both in area and production. Oil seeds occupy about 5.867% of the total cultivated land (30,91,000 ha) of the country with a total production of 1,35,494 mt and their average productivity is about 0.747 t/ha (MoAC, 2009). The average productivity of oilseed crops in Nepal is very low as compared to that of the world average of 1.28 t/ha (NORP, 2007/08). There are many crops being cultivated for oil seed purpose in Nepal, among them tori (*Brassica campestris* var. *toria*) is particularly important and cultivated from Terai (60 masl) to high hill (2500 masl). Agro-ecologically, Terai and inner Terai occupy 77% area of the total oil crops followed by hills with 20.6% (NORP, 2007/08). Among *Brassica* oil seed crops, rapeseed (*Brassica campestris* var. *toria*) occupies 80% of the total area under oilseed crops. Nepal was a rapeseed exporting country during 1970's, but at present the country is spending a huge amount of precious foreign exchange by importing it to bridge the wide gap between production and consumption (Ghimire, 2001). The import of rapeseed oil from the overseas countries was NRs. 26,536,637 (MoAC, 2009). The productivity of rapeseed has been declining for last many years as reported from various parts of the country (Chaudhary *et al.,* 1993). The growing condition changed due to climate change, nominal or no use of fertilizers, micronutrient deficiency, little attention in terms of maintaining the plant population, crop management with proper protection measures could be the major factors associated with the yield decline of rapeseed (Ghimire and Awasthi, 2000).

There is a great scope of increasing yield of rapeseed by selecting high yielding varieties and improving management practices. Time of sowing is very important for rapeseed production (Mondal and Islam, 1993). Sowing at proper time allows sufficient growth and development of a crop to obtain a satisfactory yield. The grain yield and maturity of rapeseed are greatly influenced by environmental conditions regardless of genotypes. Different sowing times provide variable environmental conditions within the same location for growth and development of crop and yield stability (Pandey *et al*., 1981). Decreasing crop yield in delayed sowing date has been reported by many workers (Degenhardt and Kandra, 1981; McDonald *et al*., 1983). National Seed Boardof Nepal has recommended a few high yield potential varieties of rapeseed. These varieties may differ in their response to sowing dates for yield and yield components. Therefore, the present study was undertaken to find out the response of different varieties of rapeseed on different sowing in the middle Terai condition of Nepal.

Materials and Methods

A field experiment was conducted at Tamsariya-7, Nawalparasi, Nepal during October 2009 to February 2010. The soil analysis of the experimental field at a depth of 0-20 cm was sandy loam in texture with strongly acidic in reaction (pH 4.6) and medium in total nitrogen (0.19%), available phosphorus (50.4 kg/ha) and available potassium (259 kg/ha). Four varieties (Unnati, Preeti, Pragati and Local) were used to assess their performance on four sowing dates (October 13th, October 28th, November 12th and November 27th). The experimental design was split-plot design with three replications assigning sowing dates as main-plot factor and varieties as sub-plot factor. The unit plot size was 2.5 x 2.4 m^2 and the crop was planted in the rows spaced 25cm with 5cm plant to plant distance. FYM (farm yard manure) was applied at the rate of 6 t/ha two weeks before sowing. The chemical fertilizer dose used for the experiment was 60, 40, 20, 25, 5 and 1 kg/ha of N, $P_2 O_{5,}$ K_2O, S, Zn and B in the form of urea, DAP, murate of potash, gypsum, $ZnSO_4$ and boric acid, respectively. Half of the urea and whole amount of other chemical fertilizers were applied as a basal dose in all the treatments and were applied in the furrows opened at a depth of 8-10 cm at the time sowing. The remaining 50% of the total dose of nitrogen was splitted in two equal halves and first halve was applied before first irrigation at initiation of flowering stage and the second halve applied before second irrigation stage at grain filling stage. Bevisteen (Carbendazim 50% WP) at the rate of 2 g/litre of water and Roger (Dimethoate) at the rate of 2 ml/litre of water were sprayed at an interval of 10 days starting from 25 DAS-70 DAS to control alternaria blight and aphid of rapeseed. All other recommended practices were followed and kept uniform for all treatments. Plant height was measured at 15 days interval from 25 to 70 DAS of crop as an average of 10 randomly selected plants per plot from the ground level to the top of the plant.

Plant height and dry matter were measured at 15 days interval from 25 to 70 DAS. For plant height, an average of 10 randomly selected plants per plot was measured from the ground level to the top of the plant. For dry matter accumulation, five plants from four destructive rows were continuously uprooted and all leaves was detached from the main stem and packed in the envelope and placed in the electronic oven. Similarly, the shoot of the rapeseed plant of each plot after detaching the whole leaves was put in an envelope separately and placed in the oven for complete drying. Temperature was maintained at 70 ^{o}C for 72 hours for complete drying of leaves and stems. After complete drying, dry weight of the leaves and stem was taken and calculated for the individual plants.

Number of primary branches, number of siliqua per plant, number of grains per siliqua, siliqua length, abortion percentage, thousand grain weight and grain yield were calculated at physiological maturity of the crop as an average of 10 randomly selected plants from net harvested rows per plot. Data collected were statistically analysed by M-STATC 1997 computer program. All the analysed data were subjected to DMRT for mean comparison at 5% level of significance.

Results and Discussions

Physiological attributes

Plant height

The highest plant height was observed on October 28th sowing date at 70 DAS and it was at par with October 13th sowing date. Significantly the lowest plant height was observed on November 27th sowing followed by November 12th sowing (Table 1). Murdock *et al.*, (2007) reported that the best growth of canola takes place when minimum temperature is higher than 12.22 ^{o}C and maximum temperature is below 30 °C. The maximum and minimum temperature for October 13th, October 28th, November 12th and November 27th were (31.25 and 19.08 °C); (28.33 and 16.46 °C); (25.89 and 12.61°C) and (24.5 and 17.74 °C) respectively for the first 25 days after sowing. Thus, the temperature range suitable for the best growth of rapeseed crop was observed on October 28th sowing date. Therefore, at the optimum temperature, high growth rate of the plant is accompanied by the high activity of auxins, gibberellins and cytokinins and lower activity of abscissic acid but reverse occurs at low temperature (Reddy and Reddi, 2005). So, plants of October 28th sowing date were taller than those of October 13th sowing date. This finding was fully supported by Mondal *et al.*, (1999) who found significantly the highest plant height (124.1 cm) on November 1st sowing date when the rapeseed crop was sown from October 1st to December 1st at 15 days' interval in Bangaladesh. Decrease in plant height in late sowing was mainly attributed to the decreasing minimum temperature. Plant height was significantly influenced by varietal characteristics at 70 DAS. Variety Preeti had the highest plant height compared to other three varieties and it was followed by variety Unnati and Pragati. Variety Local had the lowest plant height compared to other three varieties (Table 1).

Leaf area index

LAI decreased significantly with delay in sowing from October 28th to November 27th at 70 DAS (Table 1). The LAI recorded on October 28th sowing date was higher than October 13th sowing date. This might be one of the reason for getting significantly higher yield attributes and final grain yield (Table 2) on October 28th sowing date as compared to October 13th sowing date. Singh *et al.*, (2002) reported higher LAI on October 30th (1.34) and October 10th (1.28) sowing dates as compared to November 20th and December 10th sowing dates. Variety Preeti had significantly higher LAI at 70 DAS compared to variety Pragati and Local. Variety Preeti and Unnati were at par for LAI at 70 DAS. Similarly, LAI for variety Pragati and Local were also at par at 70 DAS (Table 2).

Table 1. Physiological attributes as influenced by different date of sowing and varieties

Treatments	Plant height (cm) 70 DAS	Leaf area index 70 DAS	Dry matter (g/plant) 70 DAS	Braches/plant
Sowing dates				
October 13th	72.23[a]	0.33[a]	10.51[b]	2.80[b]
October 28th	73.68[a]	0.37[a]	12.75[a]	3.58[a]
November 12th	51.37[b]	0.24[b]	8.11[c]	2.13[c]
November 27th	47.84[c]	0.21[b]	5.76[d]	1.4[d]
LSD(<0.05)	1.56*	0.05**	2.23**	0.65*
SEm±	0.45	0.01	0.64	0.18
Varieties				
Unnati	64.60[b]	0.33[a]	7.77[b]	2.63[b]
Preeti	71.86[a]	0.34[a]	8.75[a]	3.01[a]
Pragati	57.30[c]	0.26[b]	6.80[c]	2.27[c]
Local	50.00[d]	0.23[b]	5.81[d]	2.00[d]
LSD(<0.05)	7.21**	0.02**	0.96**	0.25**
SEm±	2.47	0.009	0.33	0.08
CV%	14.04	9.63	15.76	12.19

Note: *DAS= Days after sowing. Treatments means followed by the common letter (s) within a column are non-significantly different based on DMRT at 5% level of significance.*

Dry matter accumulation

Total dry matter production per plant was significantly higher on October 28th sowing date compared to other sowing dates at 70 DAS. CCC (2011) reported that at full flower in canola, stems become the major photosynthetic structure although leaves are still important. At the beginning of ripening, pod walls and stems account for the majority of photosynthesis while leaves make only a small contribution. Higher dry matter production at 70 DAS on October 28th sowing date compared to other dates of sowing may be due to the higher plant height and more number of siliqua per plant (Table 1). Total dry matter production was significantly affected by varieties at 70 DAS of rapeseed. Variety Preeti produced significantly higher dry matter compared to other three varieties. The lowest dry matter per plant was produced by variety Local (Table 1). Higher plant height, LAI and higher number of branches per plant, might be the reasons for attaining higher total dry matter of variety Preeti compared to other varieties.

Number of branches per plant

Number of branches per plant was significantly influenced by sowing dates (Table 2). The highest number of branches per plant was produced on October 28th sowing date and the lowest number on November 27th sowing date. This finding was in conformity with the findings of Shahidullah *et al.*, (1997) who stated that crop sown on October 27th recorded higher number of primary and secondary branches per plant as compared to November 6th and November 16th sowing dates. Varieties were characteristically different in producing branches per plant. Variety Preeti produced significantly the highest number of branches per plant which was followed by variety Unnati and Pragati. Similarly, variety Local produced significantly the lowest number of branches compared to other varieties.

Yield attributing characters

Siliqua per plant

Sowing date had a great influence on the number of siliqua per plant, which may have apparent impact on seed yield (Table 2). The highest number of siliqua per plant was attained on October 28th sowing date. A serious reduction of siliqua per plant was noted with earlier as well as later sowing dates viz. October 13th, November 12th, and November 27th. This finding was in conformity with the findings of Bhuiyan *et al.*, (2008) who stated that the highest number of siliqua per plant was obtained in October 30th sowing date and the lowest on November 30th sowing date. Siliqua per plant was significantly influenced by varietal characteristics. Variety Preeti produced the highest number of siliqua per plant followed by Unnati and Pragati. Similarly, variety Local produced the lowest number of siliqua per plant.

Siliqua length

Siliqua length was significantly influenced by sowing dates (Table 2). The highest length of siliqua was obtained on October 28th sowing date followed by October 13th and November 12th sowing dates. The lowest length of siliqua was obtained on November 27th sowing date. Afroz *et al.*, (2011) found the highest siliqua length from November 10th sown crop and the lowest siliqua length from the plants of November 30th sowing date when the mustard crop was sown at 10 days interval from November 10th to November 30th. Variety Preeti had significantly the highest length of siliqua followed by Unnati and Pragati . The lowest length of siliqua was observed in variety Local.

Number of seed per siliqua

Number of seeds per siliqua was significantly influenced by sowing dates. The highest number of seeds per siliqua was obtained on October 28th sowing date and the lowest seeds per siliqua were found on November 27th sowing date (Table 2). The result of the present investigation with respect to seed per siliqua fairly agreed with the findings of Ghose and Chatterjee (1998). They reported that delay in sowing resulted decrease in the number of seeds per siliqua in rapeseed and mustard. Seeds per siliqua were significantly influenced by varietal characteristics. Variety Preeti produced the highest number of seed per siliqua followed by Unnati and Pragati. Similarly, variety Local gave the lowest seeds per siliqua compared to other varieties. Highest number of seeds per siliqua with variety Preeti might be attributed to the higher number of branches per plant, higher number of siliqua per plant and higher length of siliqua compared to other three varieties.

Table 2. Yield attributing characters as influenced by different date of sowing and varieties

Treatments	SPP[1]	SL[2]	SPS[3]	Abortion[4]%	TW[5]	Yield (t/ha)
Sowing dates						
October 13th	54.79[b]	5.57[b]	10.08[b]	21.34[bc]	2.60[b]	1.06[b]
October 28th	59.64[a]	6.09[a]	14.89[a]	19.18[c]	2.83[a]	1.27[a]
November 12th	50.14[c]	5.26[c]	8.26[c]	23.52[ab]	2.16[c]	0.76[c]
November 27th	45.49[d]	4.19[d]	6.12[d]	26.85[a]	1.91[d]	0.48[d]
LSD(<0.05)	4.64**	0.27**	1.01**	3.50**	0.044**	0.12**
SEm±	1.59	0.08	0.29	1.01	0.012	0.03
Varieties						
Unnati	54.95[b]	5.69[b]	5.69[b]	24.45[a]	2.68[b]	1.01[b]
Preeti	72.38[a]	6.2[a]	6.21[a]	21.55[b]	2.9[a]	1.16[a]
Pragati	47.56[c]	4.99[c]	4.99[c]	25.71[a]	2.12[c]	0.76[c]
Local	35.16[d]	4.21[d]	4.21[d]	19.19[b]	1.76[d]	0.64[d]
LSD(<0.05)	4.64**	0.50**	0.50**	2.66**	0.23**	0.07**
SEm±	1.59	0.17	0.17	0.91	0.08	0.027
CV%	10.49	11.37	10.79	13.91	11.75	10.81

Note: *1. Siliqua/plant 2. Siliqua length 3. Seeds/siliqua 4. Abortion 5. Test weight; Treatments means followed by the common letter (s) within a column are non-significantly different based on DMRT at 5% level of significance.*

Thousand grain weight

Thousand grain weight was significantly influenced by sowing dates. The highest thousand grain weight was obtained on October 28th sowing date and the lowest thousand grain weight was obtained on November 27th sowing date which was statistically lower than other dates of sowings indicating that thousand grain weight reduced with delay in sowing (Table 4). Bhuiyan *et al.,* (2008) recorded that the highest thousand grain weight in rapeseed was recorded on October 30th compared to October 20th and November 10th sowings. Thousand grain weight was significantly influenced by varietal characteristics. Preeti had the highest thousand grain weight which was followed by Unnati and Pragati. The lowest thousand grain weight was observed on Local.

Grain yield

Grain yield in rapeseed and mustard is a function of number of siliqua per plant, number of seeds per siliqua and seed size. Grain yield was significantly influenced by sowing dates. The highest grain yield was obtained on October 28th sowing date (Table 2). This might be due to higher number of branches per plant, higher number of siliqua per plant, higher number of seeds per siliqua and higher thousand grain weights of the crop sown on October 28th sowing date. There were 17.05%, 40% and 62.18% reduction in grain yield for October 13th, November 12th and November 28th sowing dates compared to October 28th sowing date. Accumulation of higher dry matter per plant might have attributed to higher yield of October 28th sowing date compared to October 13th sowing date. Yield depression recorded from October 28th sowing date to November 27th sowing date may be due to the dominance of vegetative growth over the reproductive one as described by Mendham *et al.,* (1990). This finding was supported by Bhuiyan *et al.,* (2008) who noted significantly higher yield on October 30th sowing date compared to October 20th, November 10th and November 30th sowing dates. Grain yield was also significantly influenced by varietal characteristics. Variety Preeti produced significantly the highest grain yield followed by Unnati and

Pragati. Variety Local produced the lowest grain yield. The yield difference of variety Unnati, Pragati and Local compared to Preeti were 12.63%, 34.14% and 44.78%, respectively (Table 2).

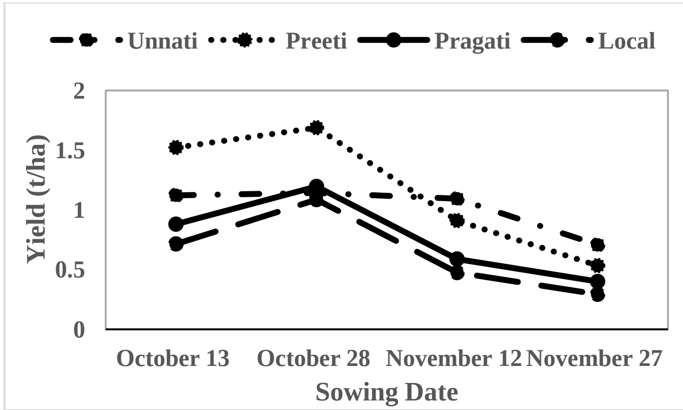

Fig. 1: Interaction effect as influenced by different date of sowing date and varieties on grain yield per hectare

The interaction effect of sowing time and variety on grain yield per hectare was found significant (Figure 1). The highest grain yield of each of the variety was obtained on October 28th compared to other dates of sowing. Sowing of Preeti on October 28th produced significantly the highest seed yield. This yield was significantly higher than those obtained from Unnati, Pragati and Local. But one important aspect was noted that in November sowing dates, grain yield was significantly higher for variety Unnati compared to variety Preeti. Thus, variety Preeti was the best yielding variety for October sowing dates while variety Unnati was the best suitable for November sowing dates. The higher yield with variety Unnati with latter sowing might be attributed to higher number of branches per plant compared to other varieties. Variety Local produced the lowest seed yield in all the dates of sowing followed by the variety Pragati. Though the grain yield of each variety was declined either before or after sowing of October 28th, the rate of grain yield decline was higher from October 28th sowing date onwards to November 27th sowing date.

Conclusion

It is concluded from this study that October 28th sowing date was the best sowing date of rapeseed for obtaining maximum yield. The late planting of rapeseed adversely affected the yield and yield components. Among varieties Preeti appeared to the high yielding variety for October sowing whereas variety Unnati was the best yielding variety for November sowing. So, it is suggested to the farmers of the area and locations with similar climatic conditions that they should plant variety Preeti on October 28th sowing for obtaining maximum yield but under late sown condition they should give preference to variety Unnati to Preeti for producing maximum yield.

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Effect of innovative nutrient management practices on performance of maize and wheat under different tillage methods in rice-based cropping system

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Abstract
A field experiment was conducted to evaluate the effect of tillage and nutrient management practices on the performance of subsequent wheat and maize in the rice-based cropping system at Agriculture and Forestry University (AFU), Rampur, Chitwan, Nepal during November 2018-May 2019. The experiment was executed in a split-plot for evaluating two establishment methods viz. (i) zero tillage followed after (*fa*) conventionally tilled dry direct seeded rice (ZT *fa* CT-DDSR) (ii) conventional tillage followed after puddled transplanted rice (CT *fa* Pu-TPR) and four nutrient management practices, i.e. (i) recommended dose (100% RDF; 80:60:40 and 180:90:60 $N:P_2O_5:K_2O$ kg/ha for wheat and maize respectively), (ii) Residue retention of rice crop @ 5 t/ha + 75% RDF (RR +75% RDF), (iii) Nutrient expert (NE) dose (140:60:45; 150:50:90 $N:P_2O_5:K_2O$ kg/ha for wheat and maize respectively), (iv) Rice residue @ 3.5 t/ha +75% RDF of each crop followed after brown/green manuring of *Sesbania* in rice (R+75% RDF *fa* BM/GM) and the treatments were replicated thrice. The data on yield (rice equivalent yield), yield attributes, and economics were recorded and analyzed by R studio. The study revealed that none of the yield attributes and rice equivalent yield of wheat were significantly influenced by the tillage methods but maize had significantly higher number of grains per cob under CT *fa* Pu-TPR and significantly higher (8.9%) yield under ZT *fa* CT-DDSR. NE assisted nutrient management practice produced significantly a greater number of spike (281.9 per m^2) and grains per spike (44.5 and higher straw yield (5.9 t/ha) for wheat crop and also showed better performance for maize as well. Maize had yield advantage of 21% and 14% when planted after BM/GM practices in rice and residue mulched condition respectively. The rice equivalent yield of wheat was 21% and 16% more under NE dose and R+75% RDF *fa* BM/GM respectively compared to 100% RDF. NE dose was the most profitable in terms of B:C ratio for both the wheat (1.9) and maize (3.0). Hence, tillage methods were indifferent for wheat but ZT *fa* CT-DDSR was significantly productive for maize and NE dose was the best nutrient management practice for better productivity and profitability for the wheat and maize in the rice-based cropping system in inner Terai of Nepal.

Keywords: Nutrient Expert, residue, rice-based system, zero tillage

Introduction
Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are the dominant crop of the cereal based cropping systems of Asian region which alone contributes 43.5% and 29% to global wheat and maize production respectively (FAOSAT, 2017). These cereals occupy 91% of total cultivated land of Nepal (MoALD, 2018). Despite the higher potential yield (Amgain and Timsina, 2004) (4.4 t/ha) of wheat and >8 t/ha (Devkota *et al.,* 2016) of maize in Nepal, the national average yield has been confined to 2.8 and 3.5 t/ha respectively (MoF, 2018) which created a huge yield gap in the nation and increment in the import of agri-products. In the Nepalese rice-wheat cropping system, the popular rice establishment method includes the transplantation of 20-25 days old rice seedlings in the puddled field while wheat and maize are established (in rice residue removed fields) by broadcasting/drilling seed after conventional tillage and planking operations (Bhatt *et al.,* 2016). The continuous practice of conventional tillage in most areas has led to degradation in soil properties (Zamir *et al.*, 2013), (Moraru and Rusu, 2013) and (Thomas *et al*, 2007) and increment in the nutrient loss leaving the soil infertile in long run. The conventional wheat planting system involves repeated dry tillage and long turn around period which delays wheat planting (Kumar *et al*., 2014). Rice-maize system has now emerged as the best alternative to

rice-wheat system in some niches of IGP because of better suitability of maize after harvest of long-duration rice cultivars, increasing demand of maize in feed industry, higher productivity and profitability of maize compared to the other crops (Timsina *et al*., 2010). The yield stability of wheat grown after rice have been a popular issue and the appropriate agronomic management practices rice-based system has always been the focal area of the global research but a solid conclusion is yet to be derived. Hence, the current study was carried out with the objectives of evaluating the effect of different tillage methods and nutrient management practices and the residual effect of crop management practices of rice on performance and profitability of wheat and maize crops grown as sequence crops.

Materials and Methods

Site description

The experiment was conducted at the research block of Agronomy Farm of Agriculture and Forestry University (AFU), Rampur, Chitwan district of Bagamati Province of Nepal (27˚40ˈ N and 84˚23ˈ E and 256 masl) from June 2018 to May 2019. The soil in the experimental field was sandy loam with slightly acidic to neutral pH, medium to low OM and nitrogen content, high phosphorus and medium potassium content according to the standard rating of Government of Nepal, Kathmandu.

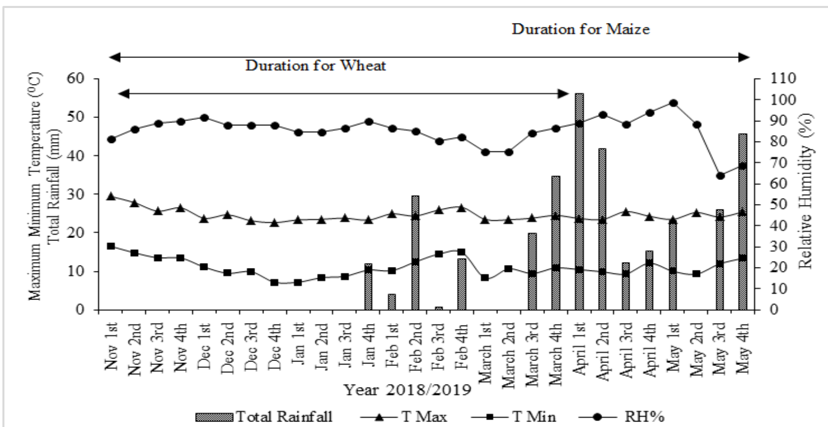

Fig. 1: Minimum and maximum daily temperature (°C), daily rainfall (mm) and daily relative humidity during the experimental period at Rampur, Chitwan, Nepal, 2019 (Source: NMRP, 2019)

The experimental site lies in the subtropical humid climate belt of Nepal. The area has sub-humid type of weather condition with cool winter, hot summer, and distinct rainy season with annual rainfall of about 2000 mm. The weather data during the cropping seasons was recorded from the metrological station of the National Maize Research Program (NMRP), Rampur, Chitwan (Figure 1).

Experimental design and treatments

The experiment was conducted in a split-plot design, with two factors i.e. two establishment methods as main plot and four nutrient management practices as sub plot factors for both crops. The two establishment methods comprised of (i) zero tillage followed after conventionally tilled dry direct seeded rice (ZT *fa* CT-DDSR) (ii) conventional tillage followed after puddled transplanted rice (CT *fa* Pu-TPR). The four nutrient management practices included: (i) 100% recommended dose (100% RDF; 80:60:40 and 180:90:60 N:P_2O_5:K_2O kg/ha respectively for wheat and maize), (ii) Residue retention of previous crop @ 5 t/ha + 75% RDF of each crop (RR +75% RDF), (iii) Nutrient expert (NE) dose (140:60:45; 150:50:90 N:P_2O_5:K_2O kg/ha for rice and wheat respectively), (iv) Rice residue @ 3.5 t/ha +75% RDF of each crop followed after Brown/green manuring of *Sesbania* in rice (R+75% RDF *fa* BM/GM) and the treatments were replicated thrice. The variety 'Bijay' of wheat was sown @120 kg/ha with spacing 20 cm × continuous in the experimental units of size 14.4 m^2 (4.8m×3 m) whereas the maize variety 'Rampur hybrid-6' was used and sown at spacing of 60 cm × 25 cm. Two seeds per hill was sown and maintained as one plant after thinning at 20 days after sowing.

Crop management

Conventional tillage dry direct seeded rice (CT-DDSR) and puddled transplanted (Pu-TPR) field were managed as the zero tillage (ZT) wheat/maize and convention tillage wheat and maize, respectively. The wheat and maize residues @ 5 t/ha were applied on rice crop as mulch in DDSR and incorporated in soil for Pu-TPR. ZT plots were prepared by spraying the glyphosate-47SL @ 5 ml/L a week prior to sowing and wheat and maize seeds were directly sown in lines. For CT, after Pu-TPR, the field was ploughed twice, pulverized and leveled and wheat and maize were sown. For both establishment methods, seed was sown on 5^{th} November 2018. The RDF used for the crops was determined from the economic maximum dose obtained from various previous researches and the nutrient expert doses for all the crops were calculated using Nutrient Expert Model of each crops developed by International Plant Nutrient Institute (IPNI). The residue amount varied with treatments and was used as surface mulch for wheat and maize. Full dose of K_2O and P_2O_5 was applied through muriate of potash (MOP) and di-ammonium phosphate (DAP) as basal dose whereas N in each treatment was divided three equal splits and each split was applied as basal dose, and at 30 days after sowing (DAS) for both crops whereas the third split was applied at 60 DAS for wheat and at 90 DAS for maize synchronizing the critical stages. For maize, tank mixture of Atrazine and Pendimethalin (each @ 0.75 a.i kg/ha), was sprayed followed by one hand pulling of weeds at 50 DAS for both ZT and conventional tillage treatments. No weeding operation was conducted for wheat.

Sampling and measurements

For the wheat crop, the effective tillers at harvest were counted from an entire row in the net plot area and expressed in per square meter. For the computation of sterility, 20 spikes from each treatment were randomly selected, the unfertilized and fertilized florets were counted and sterility was computed and expressed in percentage using the formula:

$$\text{Sterility (\%)} = \frac{\text{unfertilized florets}}{\text{total floret}} \times 100$$

The average grain per spike was also calculated from the same 20 selected spikes. The crop was harvested at physiological maturity stage from the net plot area of 9.6 m^2 for determination of yield. For maize crop, the final plants were counted form net plot area and converted to plants per ha. The number of cobs harvested from the net plot area was converted into cobs per plant by dividing the number of harvested cobs with the final plant count. The 10 average cobs were selected randomly and the number of rows, grains per cobs of each individual cob was counted and finally converted into grains per cob. From the same cobs, the total length of the cob and the sterile length of the cob was measured using measuring scale and then sterility percentage was calculated for individual cob and was averaged to determine the sterility percentage was calculated for each treatment.

$$\text{Sterility (\%)} = \frac{\text{Sterile length}}{\text{total cob length}} \times 100$$

The thousand grain weight (TGW) was also calculated from the grain lot by counting 1000 grains. The harvest index (HI) was determined by calculating the ratio of grain yield and biological yield and expressed in percentage. The B:C ratio was calculated by dividing the gross returns (based on the local market price of Chitwan) by total cost of cultivation and converted into USD based on the exchange rate of the Nepal Rastra Bank.

Statistical analysis

The data were subjected to analysis of variance, and Duncan's multiple range test at α level 0.05 (DMRT) for mean separations (Gomez and Gomez, 1984). Dependent variables were subjected to analysis of variance using the R Studio for split plot design. Sigma Plot v. 12 was used for the graphical representation. The rice equivalent yield of wheat and maize were compared using paired t-test.

Result and Discussions

Yield attributing characters of wheat

The yield of wheat was assessed through the various attributes like number of effective tillers per square meter, number of grains per spike, thousand grains weight (TGW) and sterility percentage. The average number of effective tillers per square meter at the time of harvest was 234.1. In response to establishment methods, CT *fa* Pu-TPR showed higher number of effective tillers per square meter than ZT *fa* CT-DDSR. Regarding the nutrient management practices, NE dose showed significantly higher number of effective tillers (281.9/m^2) (Table 1).

Table 1. Number of effective tillers per square meter, number of grains per spike, thousand grain weight (g), sterility (%) of wheat as influenced by the establishment methods and nutrient management practices at Rampur, Chitwan, 2018-2019

Treatments	Number of effective tillers per square meter	Number of grains per spike	Thousand grain weight (g)	Sterility (%)
Establishment methods				
ZT *fa* CT-DDSR	233.3	41.4	66.4	46.9
CT *fa* Pu-TPR	234.9	38.3	67.6	47.2
SEm (±)	6.8	0.8	0.2	0.3
LSD (P<0.05)	ns	ns	ns	ns
CV, %	10.0	6.8	1.4	1.8
Nutrient management practices				
100% RDF	219.4^b	38.6^b	67	47.9
RR+75% RDF	214.7^b	38.8^b	66.7	47.3
NE dose	281.9^a	44.5^a	67.6	45.5
R+75% RDF *fa* BM/GM	220.3^b	37.5^b	66.7	47.5
SEm (±)	4.2	1.1	0.7	0.9
LSD (P<0.05)	12.9	3.4	ns	ns
CV, %	4.4	6.7	3.2	3.8
Grand mean	234.1	39.8	67	47.1

Note: *CT-DDSR, conventional tillage dry direct seeded rice; Pu-TPR, puddled transplanted rice; fa, followed after; CT, conventional tillage; ZT, zero tillage; RR, Residue retention (5 t/ha); BM, brown manuring; GM, green manuring, R, residue retention (@3.5 t/ha); RDF, recommended dose of fertilizer (80:60:40 N:P_2O_5: K_2O kg/ha); NE, nutrient expert (140:60:45 N:P_2O_5:K_2O kg/ha); DAS, days after sowing.* ***.*** *Same letter(s) represent non-significant difference at 0.05 level of significance based on Duncan multiple range test.*

The average number of grains per spike was about 8% higher for ZT *fa* CT-DDSR than that for CT *fa* Pu-TPR and regarding the nutrient management practices. NE assisted nutrient management had significantly higher grains per spike. The average thousand grain weight (TGW) was 67.1g and sterility was 47.1% but none of them were significantly differed among the nutrient management practices and crop establishment methods. However, ZT *fa* CT-DDSR had relatively lesser TGW and sterility. Among the nutrient management practices, NE dose had relatively higher TGW and lesser sterility. A better yield attributing parameters under nutrient expert model dose might be due to higher doses of fertilizer i.e. 75% more N and 12.25% more K_2O than for 100% RDF which had resulted in significant increase in number of grains per spike, number of spikes per square meter and hence had lowered sterility (Woyema, 2012); Abedi *et al.*, 2011); Maqsood *et al.*, 2002) and Ali *et al*. (2002)).

Significant interaction was seen between establishment methods and nutrient management practices for number of effective tillers per square meter of wheat as shown in Figure 2.

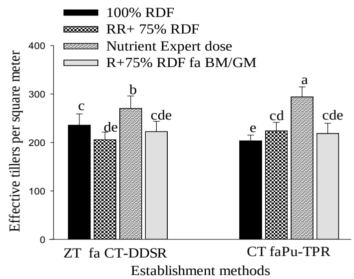

Fig. 2: Number of effective tillers per m^2 at the time harvest of wheat as influenced by the interaction of establishment methods and nutrient management at Rampur, Chitwan, 2018-19.

Note: *CT-DDSR, conventional tillage dry direct seeded rice; Pu-TPR, puddled transplanted rice; fa, followed after; CT, conventional tillage; ZT, zero tillage; RR, Residue retention (5 t/ha); BM, brown manuring; GM, green manuring, R, residue retention (@3.5 t/ha); RDF, recommended dose of fertilizer (80:60:40 N: P_2O_5: K_2O kg/ha); NE, nutrient expert (140:60:45 N:P_2O_5: K_2O kg/ha); DAS, days after sowing. Same letter(s) represent non-significant difference at 0.05 level of significance based on Duncan multiple range test.*

The interaction showed that, under both establishment methods, the number of effective tillers per square meter was statistically higher for NE dose treated plots for CT *fa* Pu-TPR than ZT *fa* CT-DDSR which might be due to the better soil moisture conservation (Moraru and Rusu, 2013); better nutrient mobility and higher N availability due to lesser loss due to rapid mineralization (Thomas *et al*., 2007) than the conventional tillage and favorable environment created due to absence of puddling in DDSR. The residue applied treatments were similar in terms of effective tillers per square meter but superior to 100% RDF under CT *fa* Pu-TPR. The reason behind this might be the hastened decomposition and mineralization process thereby increasing the nutrient availability in residue applied treatments (Halvorson *et al*., 2002) In contrast to which, 100% RDF under ZT *fa* CT-DDSR had higher effective tillers than residue applied treatments which might be due to the increment in nutrient availability and uptake by plants, and better nutrient use efficiency resulting from moisture conservation (Hulugalle and Lal, 1986; Halvorson *et al*., 2002).

Yield attributing characters of maize

The average plants per ha, number. of cobs per plant, grains per cob, sterility percentage and TGW (g) of maize were 59861/ha, 1.1, 306.9, 7.6 and 340.3 respectively but, except the number of grains per cob, all the other yield attributing characters were not significantly different under different tillage methods. The number of grains per cob was significantly higher (7.6%) under CT *fa* Pu-TPR but the number of plants per ha was 7.5% more for the case of ZT *fa* CT-DDSR but was not significant.

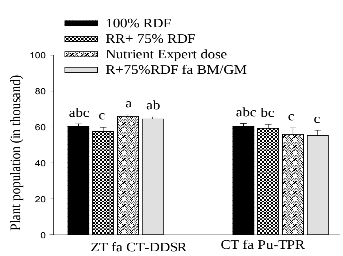

Fig. 3: Final plant population of maize as influenced by the interaction of establishment methods and nutrient management at Rampur, Chitwan, 2018-19

Note: *CT-DDSR, conventional tillage dry direct seeded rice; Pu-TPR, puddled transplanted rice; fa, followed after; CT, conventional tillage; ZT, zero tillage RR, Residue retention (5 t/ha); R, Residue retention (3.5 t/ha); RDF, recommended dose of fertilizer (120:80:60 N: $P_2O_{5:}$ K_2O kg/ha); Nutrient expert dose, nutrient expert model dose (150:50:90 N: $P_2O_{5:}$ K_2O kg/ha); Same letter(s) represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. The nutrient expert dose used was (150:50:90 N: $P_2O_{5:}$ K_2O kg/ha).*

Significant interaction of establishment methods and nutrient management practices for plant population is presented in Figure 3. The plant population was recorded highest for NE dose treated plot under ZT *fa* CT-DDSR which as statistically at par with 100% RDF and R+75% RDF *fa* BM/GM but lowest in RR +75% RDF. Under CT *fa* Pu-TPR, plant population was highest for 100% RDF which was statistically similar to other nutrient management practices. Regarding the nutrient management practices, none of the yield attributing characters was significantly influenced by the various practices (Table 3). However, 100% RDF had higher number of plants per ha, and grains per cob and sterility percentage which might be due to higher phosphorus application (90 P_2O_5 kg/ha) as phosphorus had direct effect on the formation of grain (Masood *et al*., 2011). NE fertilizer management had relatively lower sterility percentage and higher number of plants per ha compared to residue applied plots. RR+ 75% RDF had the highest TGW (7.1% more than 100% RDF) and the highest cob per plant among the various nutrient management practices which might be due to increased soil moisture content, organic matter content, better partial factor productivity, and minimizing weed growth as also explained by Upadhyay *et al*., (2016), Sime *et al*., (2015), Bastola *et al*., (2020), and Singh *et al*., (2016). Khurshid *et al*., (2006), were not statistically significant as indicated in Table 3.

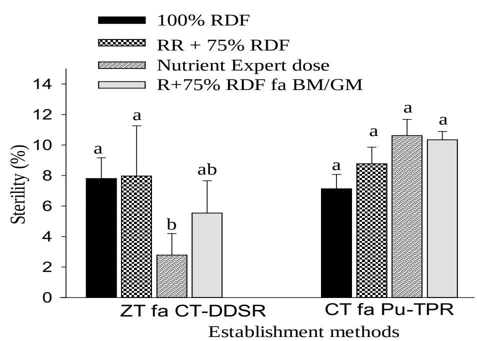

Fig. 4: Sterility of maize as influenced by the interaction of establishment methods and nutrient management at Rampur, Chitwan, 2018-19

Note: *CT-DDSR, conventional tillage dry direct seeded rice; Pu-TPR, puddled transplanted rice; fa, followed after; CT, conventional tillage; ZT, zero tillage; Residue [#], Residue retention (5 t/ha); Residue [@,] Residue retention (3.5 t/ha); RDF, recommended dose of fertilizer (120:80:60 N: $P_2O_{5:}$ K_2O kg/ha); Nutrient expert dose, nutrient expert model dose (150:50:90 N: $P_2O_{5:}$ K_2O kg/ha); Same letter(s) represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. The nutrient expert dose used was (150:50:90 N: $P_2O_{5:}$ K_2O kg/ha).*

Significant interaction of establishment methods and nutrient management practices for sterility percentage as presented in Figure 4 shows that the highest sterility was recorded for RR + 75% RDF which was significantly higher than NE dose but at par with 100% RDF and R + 75% RDF *fa* BM/GM under zero tillage. In contrast to this, all the nutrient management practices resulted in statistically similar sterility under conventional tillage.

Table 2. Plant population, cobs per plant, grains per cob, sterility (%) and thousand grain weight (g) of maize as influenced by the establishment methods and nutrient management practices at Rampur, Chitwan, 2018-2019

Treatments	Plant Per ha	Cobs per plant	Grains per Cob	Sterility (%)	Thousand grain weight (g)
Establishment methods					
ZT *fa* CT-DDSR	62037	1.1	295.7[b]	0.77 (6)	345.2
CT *fa* Pu-TPR	57685	1.1	318.2[a]	1.00 (9.2)	335.4
SEm (±)	2123	0.04	2.7	0.08	6
LSD (P<0.05)	ns	ns	16.5	ns	ns
CV, %	12.3	11.00	3.1	30	6.1
Nutrient management practices					
100% RDF	62037	1.1	317.3	0.92 (7.5)	330.1
RR+75% RDF	58333	1.2	299.1	0.92 (8.4)	356.7
NE dose	60926	1.1	301.8	0.79 (6.7)	341.3
R+75% RDF *fa* BM/GM	59815	1.1	309.7	0.91 (7.9)	333
SEm (±)	1271.8	0.03	7.4	0.06	7.2
LSD (P<0.05)	ns	ns	ns	ns	ns
CV, %	5.2	6.9	5.9	16.7	5.20
Grand mean	59861	1.1	307	0.9 (7.6)	340.3

Note: *CT-DDSR, conventional tillage dry direct seeded rice; Pu-TPR, puddled transplanted rice; fa, followed after; CT, conventional tillage; ZT, zero tillage; RR, Residue retention (5 t/ha); BM, brown manuring; GM, green manuring, R, residue retention (@3.5 t/ha); RDF, recommended dose of fertilizer (120:80:60 N: P_2O_5: K_2O kg/ha); NE, nutrient expert (150:50:90 N: P_2O_5: K_2O kg/ha); DAS, days after sowing. Same letter(s) within the column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. The figures in parenthesis represent the original values of the log transformed data*.

Rice equivalent grain, straw yield and harvest index of wheat and maize

The average rice equivalent grain yield (REY), straw yield and harvest index (HI) of wheat and maize were 3.8 t/ha and 7.3 t/ha, 4.41 t/ha and 4.4 t/ha, 38.4% and 54.4% respectively (Table 4). All these parameters were not significantly different among the establishment methods and nutrient management practices except that the REY of maize was significantly higher under zero tillage and straw yield of wheat was significantly higher under NE fertilizer management. The highest REY was seen in NE nutrient management for wheat (4.1 t/ha) and maize (7.7 t/ha) which were 20% and 18% more than the yield obtained with the application of 100% RDF for respective crops. The harvest index was found highest (56%) for maize but lowest (33.6%) for wheat under NE dose. The amount of fertilizers used under NE dose (150:60:90 N, P_2O_5, K_2O kg/ha) was 16.66% less N, 44.44% less P_2O_5 and 50% more K_2O than 100% RDF (180:90:60 N, P_2O_5, K_2O kg/ha) (Table 7) which also ensured timely and crop demand oriented nutrient supply to the crop and resulted in yield increment under NE dose as also supported by Singh *et al*., (2019), Banerjee *et al*., (2014), Pooniya *et al*., (2015), and Dahal *et al*., (2018). The yield advantage of 15.5% under R+75% RDF *fa* BM/GM (Table 2) might be consequence of the favorable soil environment created from the addition of OM and conservation of beneficial microbes due to the green and brown manuring practices in rice field which might be responsible for the improved yield (Hoque *et al.,* 2017). The yield of maize under Residue[@] + 75% RDF despite having 1.5 t/ha less residue might be due to *Sesbania* incorporation in the previous rice crop as compared to Residue[#] + 75% RDF. Salahin *et al.*, 2013 also reported that 21% yield advantage on maize crop when planted on same plot on which green manuring treatment on rice crop was applied.

Table 3. Rice equivalent grain yield (t/ha), straw yield (t/ha) and harvest index (%) of maize as influenced by the establishment methods and nutrient management practices at Rampur, Chitwan, 2018-2019

Treatments	Rice equivalent grain yield (t/ha)		Straw yield (t/ha)		Harvest Index (%)	
	Wheat	Maize	Wheat	Maize	Wheat	Maize
Establishment methods						
Zero tillage	3.6	7.6[a]	4.7	4.6	36.2	54.3
Conventional tillage	4.0	7.0[b]	4.2	4.3	40.6	54.6
SEm (±)	0.1	0.1	0.3	0.4	2.5	2.0
LSD (P<0.05)	ns	0.5	ns	ns	ns	ns
CV, %	12.4	4.4	25.6	30.0	22.3	12.8
Nutrient management practices						
100% RDF	3.4	6.6	3.8[b]	4.0	40.0	55.0
RR+75% RDF	3.6	7.5	4.4[b]	4.7	37.2	53.2
NE dose	4.1	7.7	6.0[a]	4.4	33.6	56.0
R+75% RDF *fa* BM/GM	3.9	7.5	3.8[b]	4.7	42.8	53.7
SEm (±)	0.2	0.4	0.4	0.3	2.4	2.0
LSD (P<0.05)	ns	ns	1.1	ns	ns	ns
CV, %	15.2	15.1	20.2	17.8	15.5	9.0
Grand mean	3.8	7.3	4.4	4.4	38.4	54.4

Note: *CT-DDSR, conventional tillage dry direct seeded rice; Pu-TPR, puddled transplanted rice; fa, followed after; CT, conventional tillage; ZT, zero tillage; RR, Residue retention (5 t/ha); BM, brown manuring; GM, green manuring , R, residue retention (@3.5 t/ha); RDF, recommended dose of fertilizer (80:60:40 and 120:80:60 $N:P_2O_5:K_2O$ kg/ha respectively for wheat and maize); NE, nutrient expert (140:60:45 and 150:50:90 $N:P_2O_5:K_2O$ kg/ha respectively for wheat and maize); DAS, days after sowing*. *Same letter(s) within the column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test.*

The rice equivalent yield of wheat and maize under similar nutrient management practices were subjected to paired t-test and the test revealed that the REY of the wheat and maize under similar establishment methods were significantly different as shown in Table 5.

Table 4. Rice equivalent grain yield of wheat and maize under different establishment methods at Rampur, Chitwan during 2018-19

Establishment methods	Rice equivalent yield (t/ha)		t-value
	Wheat	Maize	
Conventional tillage	3.98	7.00[b]	-8.124***(12)
Zero tillage	3.56	7.63[a]	-12.964***(12)

Note: **** indicate 0.01 level of significance and the figures in parenthesis indicate the pairs used for comparison.*

Economic analysis of wheat and maize

The average total cost of production, gross return and net return of wheat were USD 545.23, USD 885.391 and USD 340.16/ha respectively (Figures 5 and 6) and were not significantly different among the establishment methods. The net return under NE dose was 49% more than 100% RDF and hence significantly higher B:C ratio was obtained. Similarly, the average total cost of production, gross return and net return of maize were USD 679.08, USD 1682.11 and USD 1027 /ha respectively (Figures 5 and 6) and were not significantly influenced by establishment methods. The net return from ZT *fa* CT-DDSR was significantly higher than CT *fa* Pu-TPR and similar was the case for B:C ratio (Figure 7). The net return from NE dose was more (USD 286.8/ha) compared to 100% RDF and hence had significantly the highest B:C ratio than other nutrient management practices (Figure 7).

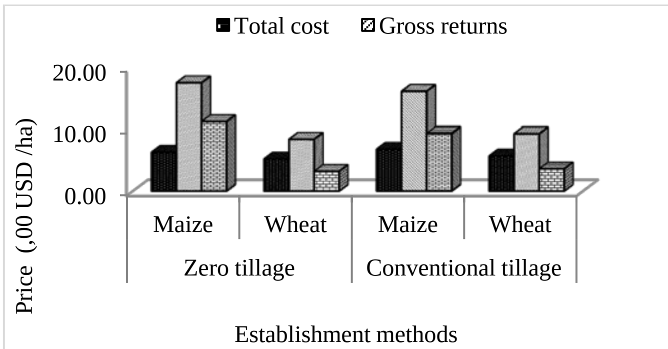

Fig. 5: total cost, gross and net returns of wheat and maize under different establishment methods

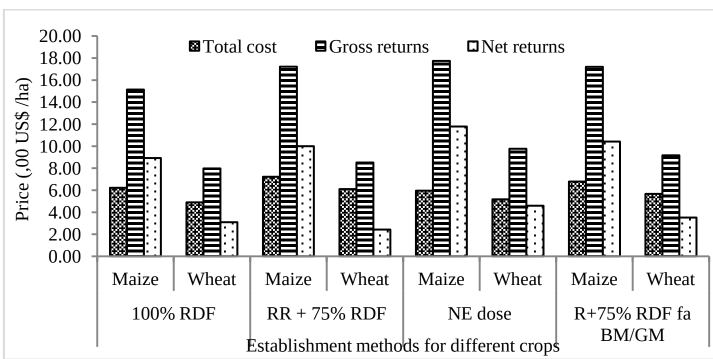

Fig. 6: Total cost, gross and net returns (,00 USD /ha) of wheat and maize under different nutrient management practices.

For both wheat and maize, the highest cost was incurred under RR + 75% RDF followed by R + 75% RDF *fa* BM/GM which was due to the higher cost of rice residue (a valuable livestock feed) applied/left under the treatment which constitutes 26.7% and 18.7% of average cost of wheat production and 22.3% and 15.6% of average cost of maize production under the respective treatments. Wheat was more profitable under CT *fa* Pu-TPR than ZT *fa* CT-DDSR in terms of net return and B:C ratio. Wheat cultivation was the most profitable having highest B:C ratio (Figure 7) when fertilizer was managed with NE model. Despite having US$ 27.75/ha more cost of fertilizers than 100% RDF, the higher net return was attributed to the higher yield (Table 4 and Figure 6) as also explained by Khurana *et al*., (2005), Majumdar *et al*., (2015) and Shahi *et al.,* (2018). But maize was the most profitable under ZT *fa* CT-DDSR (Figure 6 and 7) due to lower cost of production and higher yield (Table 4 and Figure 6). Similar to wheat, maize cultivation was the most profitable under NE nutrient management, which had the lowest cost of production and the maximum net return (Figure 6) and was in accordance with findings of Khurana *et al*., (2008), Pant *et al*., (2020), and Pasuquin *et al*., (2014).

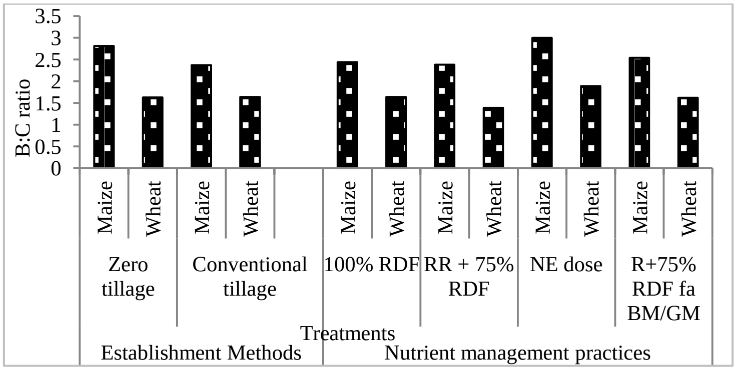

Fig. 7: Total cost, gross and net returns (,00 USD /ha) of wheat and maize under different nutrient management practices

Conclusions

Zero tillage followed after CT-DDSR was productive for maize but less productive for wheat compared to conventional tillage. Maize was more productive and profitable as compared to wheat in rice-based cropping system. The nutrient expert fertilizer management was the best nutrient management practice for both crops. The yield advantage in subsequent wheat and maize could be obtained from the residue retention and green/brown manuring practices in rice along with the enhancing the soil qualities.

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Weed dynamics in no-till maize system and its management: A review

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Abstract

Among different factors, tillage and weed management are two important factors that influence remarkably the growth and yield of maize. The present review reveals that *Echinochloa colona* L. is the most dominant weed species with an importance value index (IVI) of 41 followed by *Papaver rhoeas* L. (32.6), *Descurainia Sophia* L. (22.27) and *Polygonum aviculare* L (16.16) in no-till maize. Wider spacing and initial slow growth of maize during the first 3-4 weeks provides enough opportunity for weeds to invade and offer severe competition, resulting in 60-81% in maize yield losses. The shift of the weed population towards perennial was observed under NT. Species like *Xanthium strumarium, Solanum nigrum, Euphorbia helioscopia, Convolvulus arvensis, Sorghum halepense, Digitaria sanguinalis, Sonchus oleraceus* and *Euphorbia vermiculata* were associated with no-till *Zea mays*. The highest weed seed density was found in conservation agriculture practices (no-tillage, no-fertilizer and no-herbicide use) with the highest seed distributed in 0-1 cm depth followed by 1-3 cm depth. Weed control efficiency of Nicosulfuron @0.90 kg/ha was found the highest (98.8%) followed by Atrazine + Tembotrione + Atrazine (@1 kg/ha + 120 g/ha + 0.5 kg/ha) (98.7%) and Tembotrione + atrazine (@ 120 g/ha + 0.5 kg/ha) (96.5%), therefore were very effective in controlling weed in no-till *Zea mays*.

Keywords: Maize, management, no-till, weeds

Introduction

Maize (*Zea mays* L.), is one of the most important cereal crops belonging to the family Poaceae. It ranks third in the world production after wheat and rice but it surpasses all cereals in productivity (Deshmukh *et al.,* 2009). The productivity of maize in Nepal is 2.83 (AITC, 2020). Yield losses in maize of 60-81% occur due to weed infestation (Lagoke *et al.,* 1998). The ear number per plant and 1000-seed weight of grains decreased linearly with increasing duration of weed interference and seed number per ear was the most sensitive yield component to weed interference (Evans *et al.*, 2003). Imoloame and Omolaiye (2017) reported that the weed interference in maize for 6 weeks after sowing and beyond significantly depressed growth parameters and grain yield. Plots left weedy for only 3 weeks after sowing produced significantly higher yield which was comparable to the maximum.

Appropriate tillage operations are desired for better crop yields and as a result of which the total production increases (Memon *et al.,* 2012). In recent years, the traditional deep tillage is gradually replaced by the no-tillage system because it reduces soil erosion, increases soil organic carbon, improves water quality, reduced soil compaction, optimizes soil moisture, increases yield and reduces fuel consumption (Oerke, 2005). Changes from traditional tillage to a conservation tillage system can lead to shifts in weed species composition (Ball and Miller, 1993). Some species display a greater capacity of infestation when the intensity of tillage is reduced (Buhler *et al.,* 1994). Several researchers have observed that changes in weed species composition could occur by the adoption of the conservation tillage system (Ball and Miller, 1993). There were more kinds and quantities of weeds in no-tillage farmland, so its consumption of herbicides was much higher (Bo *et al.,* 2013). Reducing herbicide consumption and avoiding weed resistance in the conservation tillage system has become the key issues of modern sustainable agriculture (Brainard and Mirsky, 2013). Careful monitoring and management of the weed flora during the initial period of transition from conventional tillage to conservation tillage are stressed (Santin Montany *et al.,* 2004). Soil disturbance is considered an important factor in breaking dormancy and might explain lower weed densities under no-tillage compared to the other tillage systems (Blackshaw *et al.,* 2002). Studies have compared weed growth parameters as influenced by tillage (Cardina *et al.,* 2002; Davis *et al.*, 2005).

Methodology

An extensive review was done to collect pertinent data going through several proceedings, annual reports, pamphlets, and booklets, thesis works and so on from different national, public and private organizations. Similarly, the findings are mainly based on the secondary information of the thesis available in the Central Library of Agriculture and Forestry University, Rampur, Chitwan in the respective field.

Discussions

Weed dynamics under different tillage systems

Tillage affects weeds by uprooting, dismembering, and burying them deep enough to prevent emergence, by moving their seeds both vertically and horizontally, and by changing the soil environment and so promoting or inhibiting weed seed germination and emergence. Any reduction in tillage intensity or frequency may, therefore, influence the weed infestation. The composition of weed species and their relative time of emergence differ between conservation tillage systems and soil-inverting conventional tillage systems. Their germination and emergence may be accelerated by the type of equipment used in soil-inverting tillage systems than by CT machinery. Shifts in weed populations from annuals to perennials have been observed in conservation tillage systems. Weeds cause enormous damage (30 to 50 %) to the maize crop depending upon the growth and persistence of the weed population in standing crop (Rout and Satyapathy, 1996). Weeds reduce crop yield by competing for light, water, nutrients and carbon dioxide, interfere with harvesting and increase the cost involved in crop production depending on the type of weed flora, intensity and duration of crop weed competition (Oerke, 2005). The effect of tillage on the weed community dynamics was greater when the cereal crop was present (Alarcóna *et al.*, 2018).

Critical period of crop-weed competition

The critical crop growth stages consider as the most vulnerable period for crop-weed competition, during which crop must be weed free to prevent yield losses. In the no-tillage system, a critical time of weed removal (CTWR) of 33 and 31 DAE (Helvig *et al.*, 2020). Wider spacing and the slow-growing nature of the crop during the first 3-4 weeks provide enough opportunity for weeds to invade and offer severe competition resulting in 30-100% yield reduction (Sandhu *et al.*, 1999). Yield losses of 60-81% in maize due to weed infestation (Lagoke *et al.*, 1998). Due to infestation of grasses, non-grassy weeds and sedges in maize yield losses of 77.4%, 44.2% and 38.4% were observed respectively (Pandey *et al.*, 2002).

Effect of tillage on weed species composition

The nature and growth of weed species are greatly influenced by tillage. Various types of tillage practices are adopted worldwide, out of which conventional and conservation are most predominant. Certain weed species germinate and grow more profusely than others under the continuous ZT system. The shift in weed population towards perennials have also been observed in conservation tillage systems simply because of less or no disturbance of the root system of perennial weeds and no or less effect of the herbicides which are mainly used to control annual weeds under ZT systems. However, differential responses of weed species are found to varying tillage practices, irrespective of dicot or monocot. Species like *Ageratum conyzoides, Digitaria ciliaris, Echinochloa colona, Eclipta prostrata, Eleusine indica, Amaranthus* species *(A. retroflexus* and *A. powelli), Echinochloa crusgalli, Sida rhombifolia, Sonchus oleraceus* and *Portulaca oleracea* have been reported to be greater in no-till system than in conventional tillage system (Chauhan and Johnson, 2009). *Cynodon dactylon, Convolvulus arvensis* and *Cirsium arvense, Conyza canadensis, Tribulus terrestris, Convolvulus arvensis* and *Cyperus rotundus* are easily controlled under conservation tillage systems (Demjanová *et al.*, 2009) whereas weeds like *Dinebra* sp. and *Digitaria* sp. and dicot weeds such as *Euphorbia, Eclipta* sp., *Alternanthera philoxeroides* were found more under conventional tillage (Blaise *et al.*, 2015). *Saccharum spontaneum* is generally observed only in the reduced tillage and no-tillage systems. Eliçin *et al.*, (2018) reported dominant weed species *Xanthium strumarium, Solanum nigrum, Euphorbia helioscopia, Convolvulus arvensis* and *Sorghum halepense* than other weeds species in NT. Similarly, *Chenopodium album, Euphorbia heterophylla,* *Molluga verticillata* and *A. retroflexus* were associated with Conventional tillage (Helvig *et al.,* 2020). *Digitaria sanguinalis, Sonchus oleraceus* and *Euphorbia vermiculata* were associated with NT (Swanton *et al.,* 1999). Zero tillage significantly delayed the emergence of *Commelina benghalensis* by 2-3 days over other tillage methods because of deep placement (35.4 mm) of its seeds/rhizomes in zero tillage plots as compared to plots with other tillage methods (29-32 mm) (Chopra *et al.,* 2014).

Table 1. Dominant weed flora found in no-till condition

Weed species	Family	Importance value index (%)	References
Echinochloa colona	Grasses	41	Rao *et al.,* (2009)
Papaver rhoeas	Broadleaf	32.6	Alarcóna *et al*., (2018)
Descurainia Sophia	Broadleaf	22.27	Alarcóna *et al*., (2018)
Polygonum aviculare	Grasses	16.16	Alarcóna *et al*., (2018)
Chrozophora rottleri	Broadleaf	15	Rao *et al.,* (2009)
Trianthema portulacastrum	Broadleaf	13	Rao *et al.,* (2009)
Merremia emerginata	Broadleaf	12	Reddy *et al*. (2012)
Dinebra. retroflexa	Grasses	11	Reddy *et al*. (2012)
Chenopodium album	Broadleaf	10.91	Alarcóna *et al*., (2018)
Digeria arvensis	Broadleaf	9	Reddy *et al*. (2012)
Euphorbia hirta	Broadleaf	9	Reddy *et al*. (2012)
Cyperus rotundus	Sedges	8	Reddy *et al*. (2012)
Panicum repens	Grasses	8	Reddy *et al*. (2012)
Leptochloa chinensis	Grasses	7	Reddy *et al*. (2012)
Galium tricornutum	Broadleaf	4.08	Alarcóna *et al*., (2018)
Veronica hederifolia	Broadleaf	3.77	Alarcóna, *et al*., (2018)
Anacyclus clavatus	Broadleaf	3.42	Alarcóna, *et al*., (2018)
Phyllanthus niruri	Broadleaf	3	Rao *et al.,* (2009)
Avena sterilis	Grasses	2.7	Alarcóna *et al*., (2018)
Cynodon dactylon	Sedges	2	Rao *et al.,* (2009)
Amaranthus blitoides	Broadleaf	1.36	Alarcóna *et al*., (2018)
Papaver hybridum	Broadleaf	1.36	Alarcóna *et al*., (2018)
Lactuca serriola	Broadleaf	0.92	Alarcóna *et al*., (2018)

Effect of tillage practices on the weed seedbank

The natural storage of various weed seeds at different depths in the soil is referred to as weed seed bank. The seed bank in the soil builds up through seed production and dispersal, while it depletes through germination, predation and decay. The distribution of weed seeds within the soil profile is mainly influenced by different types of tillage practices. Repeated tillage reduces the number of weed propagules in the plough layer. Weed seed burial by tillage is difficult or negligible in case of no-tillage due to the absence of soil inversion process. The no-tillage system leaves most of the weed seeds in the top one cm of the soil profile, whereas conventional tillage tends to uniformly distribute seeds throughout the profile. Redistribution of seeds in the soil profile is stimulated by tillage practices that favour germination. In the NT system, the weed seed bank remains on or close to the soil surface after crop planting (Chauhan *et al.,* 2006). Better tilth and exposure of the weed seeds to upper soil may be responsible for higher weed infestation under conventional tillage than NT. Seeds of some species like *R. dentatus* are sensitive to burial depth, which could not emerge at a burial depth of 4 cm (Dhawan, 2005). Most of the weed seedlings emerge from the top 0.5 to 2 cm depth of soil layer but some weeds species like *Mimosa invisa* and *E. crusgalli* can emerge from 8 cm depth (Chauhan *et al.,* 2010). As seeds in NT are on the soil surface and are prone to rapid desiccation result in lower emergence of seedlings of some weed species.

Differential vertical distribution of seeds in soil differs in the availability of moisture, diurnal temperature fluctuation, light exposure and activity of predators that affect seedling emergence and weed population dynamics. In conservation tillage, as minimum soil disturbance occurs, most of the weed seeds remain on the soil surface after crop planting. Such conditions may also be more favourable for grain feeding fauna such as ants and other insects. Thus, under conservation tillage, weed seeds remaining on the soil surface are most vulnerable to surface-dwelling seed predators. Under a no-tillage system, seed predation could be important where newly produced seeds remain on the soil surface. On the other hand, tillage can damage the nests of harvester ants and redistribute the weed seeds stored in superficial chambers. Thus, seed predation can substantially reduce the size of the weed seed bank (Chauhan *et al.,* 2010). Crop residue should be retained in the field rather than removing or burning, and this may provide forage to seed predators. A similar result was reported by Yenish *et al.*, (2015) (Table 2). Beneficial soil-dwelling Arthropods (spider, centipede, flies, ant etc) consumed more weed seeds in the NT treatment and preferred broad-leaf weed seeds (*C. album* and *K. scoparia*) as compared with grassy weed seeds (E. *crusgalli* and *S. pumila*) (Pretorius *et al*., 2018). Fertilization increases the weed seed density in soil under deep tillage and no herbicide management, but reduced that under no tillage and no herbicide management (Ge *et al.,* 2018). The highest weed seed density was found in conservation agriculture management (no-tillage, no-fertilizer and no-herbicide use) (Ge *et al.*, 2018).

Table 2. Distribution of weed seed by depth in soil as affected by tillage and weed management at Arlington, West Indies

Tillage	Weed management	Weed seed as affected by depth (cm)					
		0-1	1-3	3-6	6-9	9-14	14-19
		no./m^3 soil x 10^{-4}					
Mouldboard plough	Untreated	74	53	53	59	120	113
	Herbicide	49	30	33	41	48	40
	Weed free	45	42	33	47	45	50
Chisel plough	Untreated	411	281	240	206	59	20
	Herbicide	209	157	121	105	34	15
	Weed free	203	139	112	79	36	17
No-tillage	Untreated	1803	311	94	47	20	14
	Herbicide	542	190	65	46	16	10
	Weed free	328	97	44	28	12	8

Source: Yenish *et al., (2015)*

Effect of tillage on weed density and dry weight

The highest forb covers and grass cover was under NT and amounted to 276 weeds/m^2 and 185 weeds/m^2 followed by Conventional tillage (Odhiambo *et al.*, 2015). However, in the second year, NT demonstrated a 61.4% decline in grass cover and 72.3% decline in forb cover with no change in the third year. The lowest abundance of *Cyperus rotundu*s (9 weeds/m^2) (grass) and *Commelina benghalensis* (7 weeds/m^2) and *Richardia brasiliensis* (6 weeds/m^2) was observed in NT (Odhiambo *et al.*, 2015). Among different forms of tillage, no-tillage increases the density as well as dry weight of certain annual and perennial weeds. Increasing density leads to the flourish of the weeds vigorously, causing significant yield losses in different field crops. The density and dry weight of weed species like *R. dentatus* have been reported to be significantly higher under NT compared to conventional tillage (Eliçin *et al.,* 2018). The greater density of dicot weeds was observed under reduced tillage compared to conventional tillage systems. However, significantly lower density and dry biomass of monocot and dicot weeds under reduced tillage than conventional tillage have also been reported (Shrivastav *et al.*, 2015). As a result, weeds under reduced tillage accumulate less dry matter. In general, the density and dry weight of weeds is the lowest under conventional tillage and the highest in conservation tillage (NT) practices. Conventional tillage which places the seeds closest to the soil surface results in the highest weed density. Also, for the species with heavy seeds, densities generally increase with ploughing (Blaise *et al.*, 2015). Rotational tillage systems result in the reduction of seed density of *A. ludoviciana, Amaranthus powellii, C. iria, Medicago hispida,* and *Solanum sarrachoides* compared to continuous NT and conservation tillage (Peachey *et al.*, 2006). Maize yields were found to be highest in maize monoculture with fertilizer under conventional tillage compared to zero tillage or flat till practice due to more weed infestation in the latter (Mafongoya *et al.*, 2016).

Table 3. Effect of tillage system and sweet corn cultivar on weed dynamics, corn plant height, and canopy cover

Tillage	Texas weed *Panicum* (weeds/ha (x 10^5)	*Amaranthus spp*.(weeds/ha (x 10^5)	*Purslane*(weeds / ha (x 10^5)	All weeds(weeds/ ha (x 10^5)	Total dry wt. (t/ha)	Plant height (cm)
Conventional	0.65^b	0.80^b	3.95	5.65	2.74^b	159
No tillage	3.10^a	1.35^{ab}	3.10	7.55	8.28^a	164

Source: (Makus, *2000*)

Table 4. Weed density (per m^2) and diversity as affected by tillage systems in maize

Tillage systems	Annual	Weeds		Perennial	weeds	All weeds
	Chenopodium album	*Echinochloa colonum*	*Cucumis prophetarum*	*Cynadon dactylon*	*Cyperus rotundus*	
No-till (NT)	17	62	18	86	117	300
Reduced tillage (RT)	17	83	9	33	69	211
Deep tillage (DT)	20	44	6	35	101	206

Source: Arif *et al., (2007)*

Weed management

Several non-chemical methods and chemical method are used to keep the weeds below the threshold level, out of which crop residue or mulching, time of sowing and herbicidal methods play an important role. Herbicide combination must be blended for each specific condition because the wide variations in weed infestations may cause a combination that is excellent in one situation to be poor in another (PANS, 1971).

Crop residue or mulching

Crop residues, when uniformly and densely present, under conservation tillage, can suppress and smother weed seedling emergence, delay the time of emergence, and allow the crop to gain an initial advantage in terms of early vigour over weeds. No-tillage and residue retained level had a significantly lower number of grasses as compared to conventional tillage (Dahal and Karki, 2014). Due to the sufficient moisture in long term no-tillage treatment; there is sufficient growth of maize (Dahal, 2014), which creates the shedding effect of maize for weed growth and germination. Long term use of rice straw on maize converts to mineralized nutrient which causes sufficient growth of maize, may be the probable reason for the suppression of weeds by the shedding effect (Dahal, 2014). Combining good agronomic practices including depth and timeliness of tillage operation with retaining crop residues on the soil surface can effectively improve weed control efficiency (Chauhan *et al.*, 2012) . Finger millet as a cover crop can effectively manage weed biomass under minimum tillage to a level as achieved under conventional tillage without a cover crop at an early stage of growth of Maize (Samarajeewa *et al.*, 2006). Crop residue controls the germination of weeds. Six ton per ha of live mulch can reduce significantly the weed population (Eliçin *et al.,* 2018). But, Black plastic mulch was found much effective as compared to live mulch, weed mulch and white plastic mulch for reducing the weed biomass (Gul *et al.,* 2011).

Herbicide application

Tillage practices also need to be coupled with an appropriate choice of herbicides and their timely application towards achieving better efficacy in weed management. Weed management using herbicides is becoming popular because of a handful of advantages in terms of cost, efficacy and efficiency in weed management. The introduction of herbicides has proved ZT and other conservation tillage effective by managing weeds in different cropping systems. Weeds that are present at the time of planting of crops in NT may need to be controlled with a non-selective herbicide like glyphosate during the turnaround period. Spraying of broad-spectrum herbicide glyphosate at the rate of 2 litres/ha by mixing with 200L of water at 15-18 days before planting and supplementing with one-time hand weeding at 40 days after sowing (40DAS) is found to be an effective weed control option in maize during turnaround period (Kebede *et al.,* 2018). Application of pre-emergence herbicide like pendimethalin in NT was found to be effective to control grassy weeds (Blaise *et al.,* 2015). Poor control of *D. aegyptium, E. colona* and a few other weeds by the herbicides in NT system had also been reported (Chauhan *et al*., 2006; Chauhan and Johnson, 2009). On the other hand, conventional tillage combined with pre-emergence herbicide pendimethalin at 1.0 a.i. kg/ha followed by hand weeding at 40 days after sowing (DAS) recorded lower weed density and biomass (Baskaran and Kavimani, 2014). Crop residue can intercept 15-80% of the applied herbicides (Chauhan *et al.,* 2006). The recent development of post-emergence broad-spectrum herbicides provides an opportunity to control weeds in conservation tillage systems. Normally herbicides applied as granule formulated to provide better weed control in a no-till system because granules are supposed to move through the stubble more effectively than its liquid formulation. On the other hand, under intensive tillage with high soil disturbance, the herbicide loss is minimized because of better incorporation in the soil (Duary *et al.,* 2016). As the farm size decreases, conservation tillage adoption has been decreased resulting in increased adoption rates of no-till and reduced-till systems and ultimately increases Glyphosate-Resistant crop cultivation (GR corn) in their cropping sequence (Givens *et al.,* 2009). Wide herbicide band (38 cm) treatment was found to be effective in controlling the weed and maintaining the maize yield than the narrow band (19 cm) treatment (Hanna *et al.,* 2000). Atrazine @ 1.25 kg/ha followed by 2,4-D @ 2.0 kg/ha recorded significantly higher plant height (183.7 cm) and LAI at 60 DAS (4.29) as compared to unweeded check and was on a par with an application of atrazine @ 1.25 kg/ha (Kumar and Angadi, 2014).

Table 5. Different herbicides, doses, time of application and their weed control efficiency

Herbicides	Doses	Time of application	Weed control efficiency	References
Nicosulfuron	0.90kg/ha	Post-emergence	98.8%	Amare *et al.,* 2015
Metolachor	1.5 kg/ha	Pre-emergence	87.1%	Amare *et al.,* 2015
Atrazine	3 kg/ha	Pre-emergence	83.9%	Amare *et al.,* 2015
Atrazine + glyphosate	0.75kg a.i./ha + 2.5 mL/ L	Pre-emergence	42.67%	Shrivastav *et al.,* 2015
Atrazine + pendimethalin	0.75kg a.i./ha + 2.0 mL/ L	Pre-emergence	24.66%	Shrivastav *et al.,* 2015
Tembotrione	120g/ha	Post-emergence	89.6%	Mitra *et al*., (2018)
Tembotrione + atrazine	120g/ha + 0.5 kg/ha	Post-emergence	96.5%	Mitra *et al*., (2018)
Halosulfuron +	90 g/ha + 0.5	Post-emergence	80.6%	Mitra *et al*., (2018)

Herbicides	Doses	Time of application	Weed control efficiency	References
Atrazine	kg/ha			
Atrazine + Tembotrione	1 kg/ha + 120g/ha	Pre-emergence+ post emergence	96.1%	Mitra *et al.*, (2018)
Atrazine + Tembotrione + Atrazine	1 kg/ha + 120g/ha + 0.5 kg/ha	Pre-emergence+ post-emergence + postemergence	98.7%	Mitra *et al.*, (2018)

Conclusion

The findings of the various studies indicated the weed stress on the productivity of maize (*Zea mays* L.) under no-till condition. Weed management practices should be mainly based on the critical period of weed competition (CPWC). Similarly, by understanding the nature of weed seed bank, various methods of integrated weed control should be formulated. Concerning weed control, no-till maize should never be implemented in monoculture systems but can be done with a proper cropping system. The adoption of recommended agronomic practices, understanding the nature of the weeds and conservation agriculture can help the farmers to obtain the maximum productivity of maize under no-till condition.

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Productivity of the rice-wheat cropping system as influenced by nutrient management under conservation and conventional agriculture practices

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Abstract
A field experiment was conducted to evaluate the productivity of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) through nitrogen management practices under conservation and conventional agriculture practices during 2012-2013 at Chitwan, Nepal. The experiment on rice was conducted in strip-split plot design with two establishment methods (conservation agriculture and conventional practices), two rice varieties (improved variety Sabitri and hybrid Gorakhnath 509), and four nitrogen levels (0, 60, 120, and 180 kg/ha). The experiment on wheat was conducted in a split-plot design with two establishment methods and four nitrogen levels as in rice with Gautam variety. The research result revealed that the grain yield of the rice-wheat system was higher in conservation agriculture (6.6 t/ha). Gorakhnath 509 of rice followed by Gautam variety of wheat had a higher system grain yield (6.8 t/ha) than Sabitri followed by Gautam (6.5 t/ha). The highest system grain yield was obtained from 180 N kg/ha (8.1 t/ha) which was significantly higher than 0 and 60 N kg/ha but was statistically similar to 120 N kg/ha. Thus, in Chitwan and similar niches, the rice-wheat system either Sabitri followed by Gautam or Gorakhnath 509 followed by Gautam variety under conservation agriculture practices by applying 120 N kg/ha can be successfully grown by the farmers.

Keywords: Conservation agriculture, conventional agriculture, yield, nitrogen, varieties

Introduction
Rice (*Oryza sativa* L.) is the first and wheat (*Triticum aestivum* L.) is the third leading cereal crop of Nepal cultivated in 44.0% and 21.9% of the total cultivated area with a national average grain yield of 3.3 t/ha and 2.4 t/ha respectively (MoAD, 2012). Rice-wheat (RW) is one of the most prominent cropping systems in Nepal and accounts for 0.56 million hectares area (Khanal *et al*., 2008). Rice alone contributes about 20% and wheat contributes 4.5% in AGDP (MoAC, 2012). Cereals production in Nepal is constrained by factors such as limited irrigation potential, low fertilizer availability, unavailability of quality seeds, inadequate weed management practices, and weather stress (Marahatta, 2008). The rice-wheat system of terai and inner terai showed yield stagnation in the last two decades (Pathak *et al*., 2003). Due to which there is a huge yield gap between potential and farmers' management (rice 2.8 t/ha and wheat 3.2 t/ha) (Amgain and Timsina, 2005). Rice is grown during the monsoon season and wheat during the cold and dry winter season. There is a transition period of variable length between the harvest of wheat and the transplanting of rice, during which the land typically lies fallow. CA-based practices like zero or minimum tillage with residue retention and proper N management has been an alternative option for sustainable crop production systems under rainfed as well as irrigated conditions (Sayre and Hobbs, 2004; Govaerts *et al*., 2005).

Nitrogen is normally a key factor in achieving optimum rice grain yield (Fageria *et al*., 1997). About 78% of the world's rice is grown under irrigated or rainfed lowland conditions (IRRI, 1997). Soils under these conditions are saturated, flooded, and anaerobic having low N use efficiency. Under these situations, increasing rice yield per unit area through the use of appropriate N management practices such as adequate amount, form, and method of application is crucial (Fageria and Baligar, 2001). Hence this study was conducted to evaluate the productivity of the rice-wheat system under different establishment methods and nitrogen levels.

Materials and Methods

The experiment was conducted at Rampur, Chitwan of Nepal from July 2012 to April 2013. The area is located 9.8 km South-West of Bharatpur. The site is located between 27^0 $37'$ North latitude and 84^0 $25'$ East longitude with an elevation of 256 meters above mean sea level (Thapa and Dangol, 1988). The monthly mean maximum temperature was 33.7 ^{0}C in August and the minimum temperature was 7.5 ^{0}C in November during the rice season and 1.8 ^{0}C in January and 34.6 ^{0}C in April during the wheat season. The maximum rainfall was observed in July (485.5mm) and no rainfall at all in November, December, and February. The soil of the experimental site was sandy loam with an acidic pH of 5.6.

The experiment was laid out in strip-split plot design for rice and split-plot design for wheat. During rice season there were three factors of which two level of crop establishment methods (CA and Conventional practices) in a vertical strip in rice and as main plots for wheat, two-level of varieties (Sabitri and Gorakhnath 509 of rice during summer and Gautam of wheat during winter) and four nitrogen levels (0, 60, 120 and 180 N kg/ha) in sub-sub plots. CA comprises dry direct-seeded rice in summer followed by zero tillage wheat in winter whereas, conventional practices comprise puddled transplanted rice in summer followed by conventionally tilled wheat in winter. Mung bean (*Vigna radiata* L.), cultivated in the previous season was used as a source of residue for zero tilled rice. The residue of rice (after harvested 33 cm above the ground surface to retain the standing residue) was used for the wheat crop. The individual plot size was 15 m^2 (5 m × 3 m) with a total experimental area of 957 m^2. Two individual plots were separated by 1 m along with bund and each replication was separated by 2 m along with bund. In direct-seeded rice and wheat (conventional and zero-till) was sown continuously in line with a row to row spacing of 20 cm but in conventional puddled transplanted rice, seedlings were transplanted in 20 cm x 20 cm using 21 days seedling. Various levels of Nitrogen (0, 60, 120, and 180 kg/ha) were applied as per treatment and they were applied in 3 splits and the entire amount of phosphorus and potash were applied as basal doses, at the rate of 40 P_2O_5 kg/ha and 40 K_2O kg/ha. Recorded data were processed and analyzed by MSTAT software. SigmaPlot was used for graphical representation. Data were subjected to analysis of variance (ANOVA). When significant differences were found, means were separated and assessed using the Duncan Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

Results and Discussions

Yield attributes of rice

Effective tillers per square meter were not significantly influenced by the establishment methods. However, higher effective tillers per square meter were recorded in CA. Significantly higher effective tillers per square meter (251.3) were obtained in Gorakhnath 509 as compared to Sabitri variety (211.7). Increasing the N levels consequently increased the effective tillers. Significantly higher effective tillers per square meter were found in 180 N kg/ha (278.4) than N omitted (178.7) and 60 N kg/ha (205.7) but statistically similar with 120 N kg/ha (263.1) applied plots. This is due to increase in the amount of nitrogen absorbed by the crop, increased the number of panicles per square meter (Yoshida *et al.*, (1972). Grains per panicle were significantly influenced by variety and nitrogen levels but not by establishment methods. Thousand grains weight was varied significantly among varieties and nitrogen levels and ranged from 16.1 to 20.4 g (Table 1) but was not significantly influenced by the establishment methods. Sterility percentage was significantly affected by establishment methods and varieties but was not affected due to nitrogen levels.

Table 1. Effect of establishment methods and nitrogen levels on effective tillers per square meter, grains per panicle, thousand grains weight (g) and sterility percentage of rice at Chitwan, Nepal 2012/13

Treatment	Yield attributes of rice			
	ET	Grains per panicle	Thousand grains weight (g)	Sterility (%)
Establishment methods				
CA	239.2	131.3	18.1	18.4[a]
Conv. Practice	223.7	143.7	18.5	15.9[b]
SEm(±)	5.2	2.8	0.2	0.3
LSD (P<0.05)	ns	ns	ns	1.8
Varieties				
Sabitri	211.7[b]	129.3[b]	17.8[b]	18.5[a]
Gorakhnath 509	251.3[a]	145.7[a]	18.8[a]	15.7[b]
SEm(±)	4.3	1.6	0.1	0.4
LSD (P<0.05)	26.2	9.5	0.9	2.4
Nitrogen levels				
0 kg/ha	178.7[c]	106.7[c]	16.1[c]	17.3
60 kg/ha	205.7[b]	126.8[b]	17.5[b]	17.1
120 kg/ha	263.1[a]	152.7[a]	19.2[a]	17.1
180 kg/ha	278.4[a]	163.8[a]	20.4[a]	17.1
SEm(±)	4.0	3.0	0.3	0.4
LSD (P<0.05)	11.6	8.6	0.9	ns
CV, %	6.0	7.5	5.9	8.0
Grand mean	231.5	137.5	18.3	17.1

Note: *ET, effective tillers per square meter; ns, non-significant. Treatments means followed by common letter (s) within column are not significantly different among each other based on DMRT at 5% level of significance*

Grain yield of rice

The grain yield of rice ranged from 2.7 to 5.1 t/ha due to nitrogen levels with the average yield in the experiment being 4.1 t/ha (Table 2). Grain yield was significantly influenced by varieties and nitrogen levels but establishment methods did not significantly influence. Hybrid variety Gorakhnath 509 with 4.3 t/ha had a 10.9% higher yield over Sabitri with 3.9 t/ha. The higher grain yield of Gorakhnath 509 was because of higher LAI, slower leaf senescence, which contributed to better light interception and higher assimilate production thus had a higher harvest index. The grain yield of rice increased with an increase in N levels up to 180 N kg/ha. The highest grain yield of 5.1 t/ha was obtained when 180 N kg/ha was applied. It was significantly higher than no N with 2.7 t/ha and 60 N kg/ha having 3.9 t/ha but was similar with 120 N kg/ha having 4.8 t/ha.

Harvest index of rice

The harvest index of rice was not evident due to establishment methods but significantly influenced by varieties and nitrogen levels (Table 2). However, the harvest index was higher in conventional practice (41.5 %) than conservation agriculture (41.3%). A significantly higher harvest index was observed in Gorakhnath 509 (44.4%) than Sabitri (38.3%). The harvest index of rice increased with an increase in N levels from 0 to 180 N kg/ha. The highest harvest index (44.8%) was obtained in 180 N kg/ha applied plot which was significantly higher than no N (36.5%) and 60 N kg/ha (40.3%) applied plots but was statistically similar with 120 N kg/ha (43.9%) application.

Table 2. Effect of establishment methods, varieties and nitrogen levels on grain yield and harvest index of rice at Chitwan, Nepal 2012/13

Treatments	Yield of Rice	
	Grain yield (t/ha)	Harvest index (%)
Establishment methods		
CA	4.1	41.3
Con. Practice	4.1	41.5
SEm(±)	0.1	0.4
LSD (P<0.05)	ns	ns
Varieties		
Sabitri	3.9[b]	38.3[b]
Gorakhnath 509	4.3[a]	44.4[a]
SEm(±)	0.1	0.5
LSD (P<0.05)	0.3	3.3
Nitrogen levels		
0 kg/ha	2.7[c]	36.5[c]
60 kg/ha	3.9[b]	40.3[b]
120 kg/ha	4.8[a]	43.9[a]
180 kg/ha	5.1[a]	44.8[a]
SEm(±)	0.1	0.9
LSD (P<0.05)	0.3	2.5
CV, %	9.5	7.3
Grand mean	4.1	41.4

Note: *ns, non-significant. Treatments means followed by common letter(s) within the column are not significantly different among each other based on DMRT at 5% level of significance*

Yield attributes of wheat

Effective tillers per square meter was significantly influenced by the establishment methods and nitrogen levels. Significantly more effective tillers per square meter were found in CA (240.1) than conventional practices (213.7). Effective tillers per square meter significantly increased with increase in N levels. Grains per spike were significantly influenced by establishment methods and nitrogen levels. Grains per spike significantly increased with increase of N from 0 to 180 N kg/ha. Thousand grains weight were not affected significantly by the establishment methods but was affected significantly among nitrogen levels (Table 3). However, thousand grains weight was observed higher in CA (48.7 g) than CT (48.4 g). Thousand grains weight had also increased with increase in N level. Non-significant results on sterility percentage due to establishment methods and nitrogen levels were observed. The average sterility percentage was 16.5% and it ranged from 16.1 to 16.6% depending upon the treatments. Sterility percentage was higher in 0 N kg/ha (16.6%) followed by 60 N kg/ha, 120 N kg/ha and 180 N kg/ha application.

Table 3. Effect of establishment methods and nitrogen levels on effective tillers per square meter, grains per spike, thousand grains weight (g) and sterility percentage of wheat at Chitwan, Nepal 2012/13

Treatment	Yield parameters			
	ET	Grains per spike	Thousand grains weight (g)	Sterility %
Establishment methods				
CA	240.1[a]	47.6[a]	48.7	16.6
Conv. practices	213.7[b]	45.5[b]	48.4	16.2
SEm(±)	7.0	0.9	0.7	0.2

Treatment	Yield parameters			
	ET	Grains per spike	Thousand grains weight (g)	Sterility %
LSD (P<0.05)	25.6	1.2	ns	ns
Nitrogen levels				
0 kg/ha	168.6[c]	41.4[d]	44.9[c]	16.6
60 kg/ha	210.8[b]	43.7[c]	47.8[b]	16.5
120 kg/ha	253.9[a]	46.9[b]	50.7[a]	16.3
180 kg/ha	274.3[a]	52.2[a]	50.8[a]	16.1
SEm(±)	8.5	0.8	0.9	0.4
LSD (P<0.05)	24.5	2.2	2.5	Ns
CV, %	13.0	5.8	6.1	8.3
Grand mean	226.9	46.1	48.6	16.5

Note: *ET, Effective tillers per square meter, ns, non-significant. Treatments means followed by the common letter(s) within column are not significantly different among each other based on DMRT at 5 % level of significance*

Grain yield of wheat

The grain yield ranged from 1.6 to 3.2 t/ha due to the various nitrogen levels and the average yield was 2.6 t/ha (Table 4). Grain yield was significantly influenced by establishment methods and nitrogen levels. CA (2.7 t/ha) had 10.5% higher grain yield than conventional practices (2.4 t/ha). Wheat planted under zero tillage increases yield by 6.7-9.7% over plow tillage (Jiaguo, 2000). Grain yield of wheat increased with an increase in N level up to 180 N kg/ha. The highest grain yield of 3.2 t/ha was obtained when 180 N kg/ha was applied. It was significantly higher than 0 N kg/ha having 1.6 t/ha and 60 N kg/ha with 2.3 t/ha but was similar to 120 N kg/ha with 3.2 t/ha. This result was in line with Aggarwal *et al.*, (1995) who reported that wheat productivity was substantially reduced when it followed puddled TPR, rather than other tillage and establishment practices. In the review, Kumar *et al.*, (2008) from many studies reported yield reduction of wheat ranged from 7 to 15% due to puddling for rice compared to non-puddled conditions. It was attributed mainly to subsoil compaction due to intensive wet tillage (puddling) that restricts root penetration of the post rice crop. The reason for the higher grain yield in zero tillage practice might be due to significantly higher effective tillers, grains per spike, and weight per spike. Also, due to the higher thousand grains weight.

Harvest index of wheat

The harvest index was not significantly affected due to establishment methods but was influenced by the N levels (Table 4). However, the harvest index was higher in CA (36.2%) than conventional practices (35.5%). Harvest index of wheat increased with an increase in N level up to 180 N kg/ha. Highest HI (39.1%) was obtained in the 180 N kg/ha applied plot which was significantly higher than 0 N kg/ha (31.4%) and 60 N kg/ha (34.3%) but was similar to 120 N kg/ha (38.6%).

Table 4. Effect of establishment methods and nitrogen levels on grain yield and harvest index of wheat at Chitwan, Nepal 2012/13

Treatments	Yield of wheat	
	Grain yield (t/ha)	Harvest index (%)
Establishment methods		
CA	2.7[a]	36.2
Con. practice	2.4[b]	35.5
SEm(±)	0.1	0.4
LSD (P<0.05)	ns	ns
Varieties		

Treatments	Yield of wheat	
	Grain yield (t/ha)	Harvest index (%)
Sabitri	3.9[b]	38.3[b]
Gorakhnath 509	4.3[a]	44.4[a]
SEm(±)	0.1	0.6
LSD (P<0.05)	0.2	ns
Nitrogen levels		
0 kg/ha	1.6[c]	31.4[c]
60 kg/ha	2.3[b]	34.3[b]
120 kg/ha	3.2[a]	38.6[a]
180 kg/ha	3.2[a]	39.1[a]
SEm(±)	0.1	1.0
LSD (P<0.05)	0.2	2.8
CV, %	8.5	9.3
Grand mean	2.6	35.9

Note: *ns, non-significant. Treatments means followed by the common letter(s) within column are not significantly different among each other based on DMRT at 5 % level of significance*

System productivity

Grain yield has been reported to be influenced highly by direct effects of total effective tillers, days to flowering, plant height, number of panicles, grains per panicle, biological yield, harvest index, and thousand grains weight (Yang, 1986; Surek and Beser, 2003). But the sum of individual crops is assigned as system yield. Grain yield depends on the production of photosynthates and their distribution among various plant parts. The synthesis, accumulation, and translocation of photosynthates depend upon the efficient photosynthetic structure as well as the extent of translocation into the sink (grains) and also on plant growth and development during the early stages of crop growth. The grain yield of the rice-wheat system was significantly influenced by nitrogen levels but non-significant due to establishment methods and varieties. The mean grain yield was 6.7 t/ha. The highest grain yield was obtained in CA with 6.8 t/haas compared to 6.6 t/ha in conventional practices (Figure A). Gorakhnath 509 of rice followed by Gautam variety of wheat had a higher grain yield of 6.8 t/ha than Sabitri followed by Gautam variety of 6.5 t/ha (Figure B). This was due to the significantly higher grain yield of Gorakhnath 509 than the Sabitri variety of rice. The highest grain yield was obtained from 180 N kg/ha (8.1 t/ha) which was significantly higher than 0 N kg/ha (4.3 t/ha), 60 N kg/ha (6.1 t/ha) but was statistically similar with 120 N kg/ha (8.0 t/ha) (Figure C). More system yield was due to more grain yield of both rice and wheat at a higher N level.The higher system yield in CA might be due to the use of crop residue as suggested by Becker *et al.* (2007) who obtained significantly higher system grain yield (5.0 t/ha) on mung bean incorporated plots than bare fallow (2.9 t/ha) plots. Similarly, Hobbs and Gupta (2004) obtained higher grain yield in CA on the rice-wheat system in South Asia.

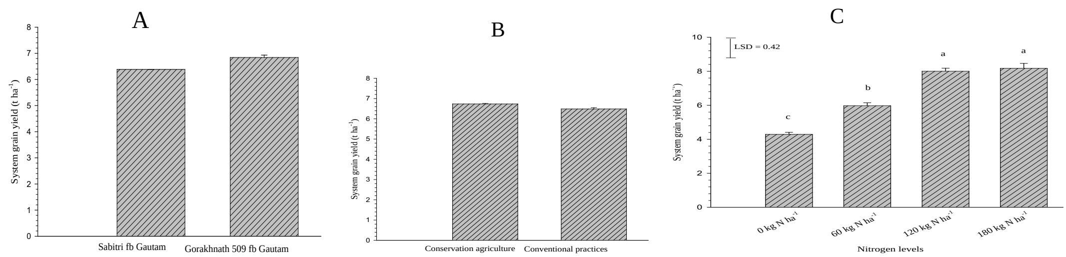

Fig. 1: Effect of establishment methods (B), varieties (A) and nitrogen levels (C) on system grain yield of the rice-wheat system at Chitwan, Nepal

Conclusion

Yield attributes of rice, effective tillers per square meter, grains per panicle and thousand grains weight was non-significant between two establishment methods and these value were higher under conventional practices. Gorakhnath 509 variety of rice had significantly higher effective tillers per square meter, grains per panicle and thousand grains weight than Sabitri variety of rice along with significantly lower sterility. Among yield attributing characters and yield related attributes of wheat, grains per spike, and effective tillers per square meter were significantly higher in CA. Thousand grains weight were also higher in CA. In both rice and wheat, sterility percentage was significantly higher in CA than in conventional practices. All yield related attributes of both rice and wheat were higher as the increasing nitrogen levels up to 180 N kg/ha except the sterility percentage. Hence, grain yield of rice was not influenced by establishment methods but the effect of CA was obvious for grain yield of wheat. Thus, in rice-wheat system either Sabitri followed by Gautam or Gorakhnath 509 followed by Gautam variety under conservation agriculture practices by applying 120 N kg/ha can be successfully grown by the farmers of Chitwan and similar niches.

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Effect of Leguminous winter cover crops on soil fertility and yield of summer maize

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Abstract

A field experiment was conducted at IAAS agronomy farm, Rampur, Chitwan, Nepal from Nov. 2012 to Aug. 2013 to improve soil fertility and production of maize through the inclusion of leguminous winter cover crops in the cropping system. The experiment was conducted for two seasons in single factor randomized complete block design (RCBD) with eight treatments and three replications. Five N fixing legume crops: chickpea (*Cicer arietinum*), garden pea (*Pisum sativum* var. *sativum*), field pea (*Pisum sativum* var. *arvense*), lentil (*Lens culinaris*) and grass pea (*Lathyrus sativus*); one N fixing legume fodder: Berseem (*Trifolium alexandrinum*); one non-fixing legume: rajma bean (*Phaseolus vulgaris*); and maize (as a control) were cultivated in the first season and on the following season maize was cultivated in all plots after incorporating former crop residues. Rajma bean covered the highest area at an early stage but field pea and grass pea covered the maximum land area at a later stage. The highest dry matter production (2.32 t/ha) and nitrogen content in residues (2.57%) were obtained from lentil. Cultivation of leguminous winter cover crops had no significant effect on soil parameters. However, the incorporation of legume residues had significant effects on organic matter content, total nitrogen and available phosphorus in soils. The highest soil organic matter (3.03%) and total nitrogen (0.15%) was observed from field pea plots while the highest available phosphorus (36.00 kg/ha) was from berseem plots. Legumes cultivation and their residues incorporation into the soil had significant effects on grain, straw and dry matter yields of succeeding maize crop. Grain (3.92 t/ha), straw (5.39 t/ha) and dry matter (9.31 t/ha) yields were the highest from lentil plots while the lowest grain (2.51 t/ha), straw (3.96 t/ha) and dry matter (6.48 t/ha) from control plots. Total nitrogen uptake by maize was significant and it was the highest (141.90 kg/ha) from lentil plots and the lowest (109.80 kg/ha) from control plots. Cultivation of lentil in the winter produced satisfactory land coverage and incorporation of its residues into the soil was the best for improving soil fertility and succeeding maize yield under the Chitwan condition of Nepal.

Keywords: Biological nitrogen fixation, cover crops, legumes, soil fertility

Introduction

Cover crops can be defined as any crop grown to provide soil cover before or in between main crops. They can be annual, biennial, or perennial plant (Sullivan, 2003). Cover crops improve the productivity of soils by increasing the amount of organic matter added to the soil due to the increased biomass on the site (Hartwig and Ammon, 2002; Bruce *et al*., 1991). Cover crop, if it is a legume, can also add significant quantities of N to the soil through N sequestration (Seo *et al*., 2006). In Nepal, the cover crop is not so common in the cropping system. Lentil, chickpea, field pea, garden pea, grass pea and rajma bean are major leguminous pulse crops grown in Nepal during the winter season. Some leguminous fodder crops and vegetables are also grown during this season. The area, production and productivity of the grain legumes in the year 2012/2013 were 333436 ha, 356743 tons and 1.07 t/ha respectively (AICC, 2014). Maize ranks second most important staple food crop both in terms of area and production in Nepal. In the year 2012/13 area, production and productivity of maize was 849635 ha, 1999010 tons and 2.35 t/ha respectively (AICC, 2014). The major portion of the crop is grown in hills during the summer season and is one of the important food security crops in the Mid hills of Nepal. Sorghum, millet, cowpea and some vegetable crops are grown during autumn, however, the land remains fallow during winter. At the end of winter fallow, maize is sown in the field. As fertilizer is not timely available and costlier in Nepal, N is the limiting nutrient and its deficiency is the major constraint for the successful production of maize. If that fallow period can be utilized to grow N sparing, N fixing and N immobilizing cover crops, those will supply N to the succeeding maize crop and helps to minimize soil erosion. Thus, this experiment was conducted in the winter and following summer season of 2012/13 to improve soil fertility and production of maize through the inclusion of leguminous winter cover crops in the cropping system.

Methodology

The experiment was conducted at IAAS agronomy farm, Rampur, Chitwan, Nepal during 2012/13. The experiment was conducted for two seasons in a single factor RCBD with eight treatments and three replications. Treatments comprised of five N fixing legume pulse crops (chickpea, garden pea, field pea, lentil and grass pea), one N fixing legume fodder (Berseem), one non-fixing legume (rajma bean) and maize crop as a control. Each plot was 2.5m wide and 4m long with a net plot area of 10 square meters while the distance between the replications was 1m and within the plots was 0.5m. Leguminous cover crops were grown as the treatments in the first season (Nov. 2012 to Mar. 2013) and maize was grown on the same plots after the incorporation of legume residues in the second season (May. 2013 to Aug. 2013). The soil of the experimental site was sandy loam with a bulk density of 1.24 gm/cm^3, moderately acidic (pH 5.65), medium in soil organic matter (SOM) content (2.73%), total nitrogen (0.13%) and available potassium (155.90 kg/ha) while low in available phosphorus (21.60 kg/ha). Total rainfall during the legume period (Nov. to Mar.) was 39 mm and the average monthly temperature was 13.40 to 21.10 ˚C, while during the maize period (May to Aug.) rainfall was 1655 mm and temperature 28.50 to 30.90 ˚C. Land preparation for cover crops was done with conventional tillage and sowing on 6th December 2012. 20:60:40 N: P_2O_5:K_2O kg/ha was applied at basal through urea, di-ammonium phosphate (DAP) and muriate of potash (MOP) and single light irrigation were done at 30 days after sowing (DAS) while twice manual weeding, one at 30 and next at 60 DAS. In this season the ground coverage of cover crops was measured at 30, 60 and 90 DAS with the use of square quadrants and scales. At harvest, their fresh and dry biomass was recorded and nitrogen content in the dry biomass was analyzed.

In the second season, the land preparation was restricted only to strips (rows of the crop) with the spade and the incorporation of legume residues in those rows. Sowing was done on 8th May 2013. Fertilizer was applied at the rate of 90:60:40 N: P_2O_5:K_2O kg/ha. Half N, full P and K were applied at basal and ½ N at 25 DAS. Rainfall was sufficient for the crop while manual weeding at 25 and 50 DAS was done. Grain, straw and dry matter yield of maize was recorded at harvest. Grain and plant samples were analysed for nutrient uptake. Soil samples were collected at legume harvest and maize harvest from each plot and analysed for pH, SOM content, total nitrogen, available phosphorus and available potassium. Methods of soil and plant analysis are tabulated in the table below.

Table 1. Methods of laboratory analysis for soils and plants

Parameters	Analysis methods
Soil pH	Beckman Glass Electrode pH meter (Wright, 1939)
Soil texture	Hydrometer (Klute, 1986)
Soil organic matter	Walkley and Black (1934)
Soil total nitrogen	Kjeldahl distillation (Bremner and Mulvaney, 1982)
Soil available phosphorus	Olsen's bicarbonate (Olsen *et al.*, 1954)
Soil available Potassium	Ammonium acetate (Black, 1965)
Plant total nitrogen content	Kjeldahl distillation (Bremner, 1982)
Plant phosphorus content	Vandomolybdo-Phosphoric yellow color method (Jackson,1967)
Plant potassium content	Flame photometer (Black, 1965)

Results and Discussions

Land coverage of winter legumes

Winter legumes showed a significant variation in land coverage. Rajma bean covered the maximum land area (22.99%) at 30 DAS which was similar to lentil (21.33%) and significantly higher than other legumes. Field pea covered a significantly higher area (43.53%) at 60 DAS and was similar to lentil, grass pea and rajma bean while it was higher than other legumes. Similarly, field pea covered the maximum land area (66.53%) at 90 DAS which was at par with grass pea (64.93%) but higher than other legumes. Land coverage by winter legumes started increasing from early stage to maturity but the rate of increment was higher on field pea and grass pea (Figure 1) than others. Creamer *et al*. (1997) also found that 13 cover crops and mixtures (mainly legumes) achieved 30% ground cover one month after planting, and generally 100% cover within three months in irrigated field condition. Tanaka *et al*. (1997) found that field pea (*Pisum sativum*) provided adequate surface cover to control soil erosion effectively in a four-year rotation of wheat-fallow.

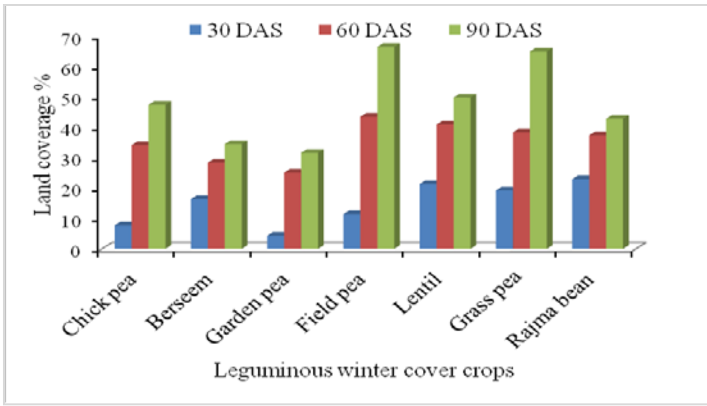

Fig. 1: Land coverage by winter leguminous cover crops at Rampur, Chitwan, Nepal, 2012/13

Table 2. Yields of fresh and dry biomass and Nitrogen content in the residues of leguminous winter cover crops at Rampur, Chitwan, Nepal, 2012/13

Cover crops	Yield of biomass (t/ha)		Residue N (%)
	Fresh	Dry	
Chick pea (*Cicer arietinum*)	5.93[a]	1.99[bc]	2.26[bc]
Berseem (*Trifolium alexandrinum*)	5.08[ab]	1.28[d]	1.82[d]
Garden pea (*Pisum sativum* var. *sativum*)	3.57[bc]	1.81[c]	2.19[c]
Field pea (*Pisum sativum* var. *arvense*)	2.74[c]	2.22[ab]	2.46[ab]
Lentil (*Lens culinaris*)	3.61[bc]	2.32[a]	2.57[a]
Grass pea (*Lathyrus sativus*)	3.93[bc]	2.21[ab]	2.30[bc]
Rajma bean (*Phaseolus vulgaris*)	5.81[a]	1.39[d]	1.48[e]
LSD (P<0.05)	1.77	0.23	0.19
Sem ±	0.57	0.07	0.06
CV%	22.69	7.02	5.17

Note: *Means followed by the same letter(s) in a column are not significant at 5% level of significance as determined by Duncan's multiple range test*

Among these winter legumes, chickpea yielded the maximum fresh biomass (5.93 t/ha) which was at par with berseem and rajma bean but higher than other legumes. Field pea produced the lowest fresh biomass (2.74 t/ha) at the time of harvest. In contrast to this, the dry matter production was maximum (2.32 t/ha) on lentil which was similar to field pea and grass pea but significantly higher than other legumes (Table 2). Berseem produced the lowest dry matter (1.28 t/ha) yield. Nitrogen percentage was the highest on the lentil residue (2.57%) while rajma bean residue had the lowest nitrogen content (1.48%). Legumes greatly varied on fresh and dry biomass production. This finding was in accordance with (Sharma and Mitra, 1988), (Beri *et al*.,1989) and (Ngome *et al*.,2011).

Effects of winter legumes on soil parameters

Legumes didn't show a significant change in SOM content at legumes harvest. After the incorporation of the legume residues, the SOM content of soil on all legumes increased except rajma bean, while it was decreased on control plots. The effect of field pea residue on SOM content was significantly higher (3.03%) than the rajma bean and the control while at par with other legume residues (Table 3). A similar finding was revealed by Yan and Li (1985) that incorporation of legumes into soil increased organic matter content by 0.11%. Similarly, Shashidhara (1986) also reported an increase in organic carbon content in the soil, from 0.49% and 0.51% due to green manuring of cowpea and horse gram, respectively over the initial status of 0.47% and 0.48 %. Total soil nitrogen among treatments was not significant at the harvest of legume (before the incorporation of legume residues). Legume residues significantly affected the total nitrogen contents of soil after the harvest of maize (Table 3). Total nitrogen was the highest (0.15%) on the field pea and lentil plot which were similar to other legumes except for rajma bean. Nitrogen content in rajma bean plots (0.13%) was similar to the garden pea, berseem and grass pea plots but it was significantly higher than control plots (0.12%).

Misra and Misra (1975) also revealed that legumes as green manure crop taken either in rotation or mixture apart from adding organic matter to the soil increased soil N due to symbiotic N fixation of atmospheric N. Yan and Li (1985) also reported that incorporation of legumes into soil increased total soil N by 16.10% and found available nitrogen higher in green manured plots by 14.10% than control. A similar finding was also obtained by Shashidhara (1986) that available nitrogen has increased to 222.00 kg/ha and 220.00 kg/ha over the initial status of 202.00 kg/ha and 198.00 kg/ha by green manuring of cowpea and horse gram respectively. Available phosphorus in soil showed the trend different as compared to SOM and total nitrogen content before and after the incorporation of legume residue. Chickpea, berseem, garden pea, field pea and lentil increased the available phosphorus in the soil after the incorporation of residues into the soil. But grass pea and rajma bean decreased the available phosphorus slightly while on the control plot it remained unaffected.

Available phosphorus in the soil before the incorporation of legume residues was similar in all treatments. After the incorporation of legume residue, plant-available phosphorus in soil was significant. Berseem plot produced the highest available phosphorus (36.00 kg/ha) which was similar to other legumes but higher than the control plot. Available phosphorus on the control plot (26.60 kg/ha) was the minimum and at par with all legumes except berseem. Yan and Li (1985) reported that the incorporation of legumes into soil increased available phosphorus by 10.50 to 24.60 % over the control. Available soil potassium and soil pH were not affected by the residue incorporation.

Table 3. Effects of winter legumes on soil parameters before and after legume residues incorporation at Rampur, Chitwan, Nepal, 2012/13

Treatment	Organic matter %		Total nitrogen %		Available P_2O_5 kg/ha		Available K_2O kg/ha		Soil pH	
	before	after	before	after	before	after	before	after	before	After
Chick pea (*Cicer arietinum*)	2.77	3.00[a]	0.14	0.15[a]	28.90	35.60[ab]	158.60	143.50	5.60	5.50
Berseem (*Trifolium alexandrinum*)	2.78	2.85[ab]	0.14	0.14[ab]	33.30	36.00[a]	147.80	131.40	5.40	5.40
Garden pea (*Pisum sativum* var. *sativum*)	2.76	3.01[a]	0.14	0.14[ab]	33.30	35.10[ab]	158.30	127.00	5.60	5.40
Field pea (*Pisum sativum* var. *arvense*)	2.81	3.03[a]	0.14	0.15[a]	31.00	33.00[ab]	153.90	138.50	5.50	5.30
Lentil (*Lens culinaris*)	2.74	2.98[a]	0.13	0.15[a]	26.50	28.10[ab]	156.90	146.10	5.40	5.40
Grass pea (*Lathyrus sativus*)	2.79	2.97[a]	0.14	0.15[ab]	30.00	29.30[ab]	157.80	141.20	5.60	5.30
Rajma bean (*Phaseolus vulgaris*)	2.69	2.69[bc]	0.13	0.13[bc]	28.50	28.40[ab]	160.80	147.80	5.40	5.40
Control	2.63	2.55[c]	0.13	0.12[c]	26.60	26.60[b]	156.30	136.60	5.70	5.30
LSD ($P<0.05$)	ns	0.24	ns	0.02	ns	8.13	ns	ns	ns	ns
SEm±	0.04	0.07	0.03	0.05	2.10	2.68	6.68	11.99	0.07	0.08
CV%	2.64	4.83	3.16	6.45	12.26	14.75	7.41	14.95	2.43	2.72

Note: *Means followed by the same letter(s) in a column are not significant at 5% level of significance as determined by the Duncan's multiple range test*

Effects of leguminous winter cover crops on summer maize

Legumes cultivation and their residues incorporation had a significant effect on grain, straw and dry matter yields of succeeding maize crop (Table 4). Grain (3.92 t/ha), straw (5.39 t/ha) and dry matter (9.31 t/ha) yields were the highest on lentil plots while the lowest on control plots. A similar finding was also reported by Sogbedji *et al*., (2006) that the use of mucuna (*Mucuna pruriens* L.) and pigeon pea (*Cajanus cajan* L.) as cover crops increased maize grain yield by 37.50% and 32.10 %, respectively in the following year. Ngome *et al*., (2011) also found that maize yield increased by 0.50-2.00 t/ha on *Mucuna pruriens* and 0.50-3.00 t/ha on *Arachis pintoi* cultivated lands of three different soil types in Kenya.

Table 4. Effects of leguminous winter cover crops on grain, dry matter and straw yields of maize at Rampur, Chitwan, Nepal, 2012/13

Treatments	Yield (t/ha)		
	Grain	Dry matter	Straw
Chick pea (*Cicer arietinum*)	3.38[ab]	8.10[ab]	4.72[a]
Berseem (*Trifolium alexandrinum*)	3.33[ab]	8.66[ab]	5.33[a]
Garden pea (*Pisum sativum* var. *sativum*)	3.56[ab]	8.43[ab]	4.86[a]
Field pea (*Pisum sativum* var. *arvense*)	3.60[ab]	8.79[ab]	5.19[a]
Lentil (*Lens culinaris*)	3.92[a]	9.31[a]	5.39[a]
Grass pea (*Lathyrus sativus*)	3.57[ab]	8.69[ab]	5.11[a]
Rajma bean (*Phaseolus vulgaris*)	2.90[bc]	7.73[b]	4.82[a]
Control	2.51[c]	6.47[c]	3.96[b]
LSD (P<0.05)	0.72	1.17	0.72
SEm±	0.24	0.38	0.23
CV%	12.43	8.10	8.41

Note: *Means followed by the same letter(s) in a column are not significant at 5% level of significance as determined by the Duncan's multiple range test.*

Total nitrogen uptake by maize was significant and it was the highest (141.90 kg/ha) on lentil plots and the lowest (109.80 kg/ha) on control plots. While total phosphorus and potassium uptake were not affected by the legumes and their residues but the trend was similar to nitrogen uptake pattern.

Conclusions

Rajma bean covered the highest area at an early stage but later field pea covered the maximum land area while garden pea the minimum land area throughout the crop growing period. Chickpea produced the highest fresh biomass (5.93 t/ha) and field pea the lowest (2.74 t/ha) at the time of harvest. The dry matter production was the maximum (2.32 t/ha) on lentil and the minimum on Berseem (1.28 t/ha). Nitrogen content on residue was also the highest on lentil (2.57%) while the lowest on rajma bean (1.48%). Cultivation of winter legume crops had no significant effects on soil parameters. However, the incorporation of legume residues had significant effects on SOM content, total nitrogen and available phosphorus. The highest soil organic matter (3.03%) and total nitrogen (0.15%) were obtained on field pea plots while the highest available phosphorus (36.00 kg/ha) was recorded on berseem plots. Legumes cultivation and their residues incorporation had a significant effect on grain, straw and dry matter yields of succeeding maize crop.

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Determinants of forage and fodder production practices to cope with climate change adaptation strategy by farmers in Terai region of Nepal

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Abstract

Consequences generated by climate change disasters in the vulnerable agricultural system of Nepal could increase in coming days in the absence of effective adaptation strategies in the both agriculture and livestock sector. There is growing evidence that forage and fodder production activity can be a potential adaptation strategy, but adopted in a limited scale. The objective of this study was to identify the determinants of forage and fodder production activity by livestock farmers in the Terai region of Nepal. Primary data collected through household survey of 600 households, 100 from each district in Morang, Sarlahi, Bara, Chitwan, Rupandehi and Banke were analyzed using logistic regression technique. Results showed that western Terai dummy and family size were negatively affecting the adoption of forage and fodder production. Whereas access to credit, size of livestock holding and training were positively and significantly affecting the adoption of the forage and fodder production activity. The magnitude of effect of these significant variables are western Terai dummy (25.2%), family size (92.60%), access to credit dummy (74.21%), size of livestock holding (10.8%) and training dummy (188.80%). Findings of the study suggested that provided opportunity to dairy farmers for participation in training on livestock production management practices and increased access to credit for making investment in dairy enterprises. Rearing livestock at commercial scale also motivates dairy farmers to produce forage and fodder in their own farm land. It is also recommended to provide lease- in land system for dairy farmers with large size family to grow forage and fodder crops aside from promotional activities are needed in western Terai region of the country in particular.

Keywords**:** Climate change, forage and fodder production, Terai, adoption and logistic regression

Introduction

Change in the climate over a long period of time due to natural processes and anthropogenic activities is termed as climate change (IPCC, 2007). Nepal was predicted to be one of the most severely affected countries by the impacts of climate change in the years to come (Synnott, 2012). Due to impacts of climate change on agriculture, the majority of the people primarily involved in agriculture can be most severely affected. The changes in the hydrograph and water availability during the pre-monsoon, monsoon and post-monsoon seasons are known to have direct impacts in the Nepalese agricultural system (Sharma *et al.,* 2006). Climate change has multidimensional impacts on the environmental, socio-economic and development related sectors including agriculture, livestock, food security, biodiversity, water resources, energy, human health and ecosystems (Dahal, 2005; NCVST, 2009; WFP, 2009).

Crop, livestock and agro-forest are the chief elements of the Nepalese farming system making the whole agricultural system working and self-sustaining. Livestock constitute an important part of the Nepalese farming system where livestock are reared for the variety of products like milk, meat, power, manure, wool, hide that they provide. Cattle, buffalo, goat, pig and poultry are the principal animals reared in Nepal (AICC, 2019). However, in the recent years, livestock sector has become much vulnerable and prone to the disastrous impacts brought about by climate change impact. From the view point of livestock, as it has much closer ties with the nature and the ecosystem, the adverse impacts of climate change are much more severe and direct. With the livestock sector in focus, the impacts of climate change are much more evident. Reduced feed availability and feed intake, lower feed conversion efficiency, decreased productivity, changes in breeding pattern, increased heat stress, increased incidence of diseases and similar other adversities have already begun to hit the farmers' sheds. Thereby resource-poor small farmers are more likely to get affected. Farmers have been adopting different management practices; improvement of cattle shed, fodder and forage production, mixed farming, diversification of livestock species, irrigation of forage field, management of grazing and pasture land, approach extension service providing organizations, business diversification for the adaptation of dairy farm business to cope with climate change impacts. But, levels of adoption of these practices are not at the expected levels. In this context, this study was conducted to assess the different factors which have hindered to adopt one of the important adaptation strategies, forage and fodder production in dairy farmers' own farm.

Methodology

Study area and sampling

The study was conducted in six districts across Terai; Morang, Sarlahi, Bara, Chitwan, Rupendehi and Banke of Nepal. These districts were purposively selected based on the availability of sufficient livestock farmers required for the study and having ample opportunities on expanding dairy farming. Two livestock farming pocket from each of the district were selected purposively in consultation with district level stakeholders working in the promotion of livestock. Multistage random sampling technique was used as the sampling procedure for this study. One hundred households from each district that rely on livestock for their livelihood were randomly selected i.e. from selected pocket of each districts, fifty households were selected randomly making a total of 600 samples.

Literature review and preliminary field visit was done to develop coordination scheme which was developed covering complex variables broken down to the simplest variables along with their unit. This was used to develop the questionnaire. Questionnaire prepared in this manner was finalized after having pretested it in two districts one each from eastern (Morang) and western Terai (Banke) of Nepal. Data collected from interview schedule by well oriented enumerators were then verified by organizing a focal group discussion in each district under study. Collected data were entered in the SPSS spread sheet and managed for units, missing value, outliers etc. Data analysis was done using Stata and SPSS software wherever applicable.

Descriptive analysis of primary data

Socio-economic and farm characteristics of the respondents like family size, age, occupational pattern, education, caste, gender roles in livestock activities, land size, livestock holding were analyzed by using simple descriptive statistics like frequency count, percentage, mean, standard deviation etc. Similarly, descriptive statistics of different variables which were used in logistic regression model were studied using arithmetic mean and standard error.

Analytical technique

Logistic regression is a popular statistical technique in which the probability of a dichotomous outcome like adoption or non adoption is associated with the group of independent variables assumed in the relationship. To accomplish the objective of factors affecting adoption of forage and fodder production logistic regression technique was used considering adoption as the function of different personal, social, economic and institutional factors. Maddison (2006), Seo and Mendelsohn (2008), and Hassan and Nhemachena (2008) studied the impact of climate change and factors affecting the adaptation measures in livestock and mixed crop livestock production in different parts of the world using this technique. Decision of farmers to practice forage and fodder production was estimated through logistic regression to derive the several factors that govern the probability to practicing more adaptation strategies ($Y_i = 1$). Maximum likelihood method leads to least square function under linear regression model (under the conditions of normally distributed error term) and gives value for the unknown parameters which maximizes the probability of obtaining the observed set of data (Wooldridge, 2003). In this process marginal effects were estimated to determine the probability of different factors under study to determine the adoption of particulars adaptation strategy. It was hypothesized that there could be several factors that affect for the practicing different adaptation strategies in the farm level. Decision to practice forage and fodder production at own farm might be influenced by several socioeconomic, demographic, institutional, and financial conditions (Deressa *et al.*, 2009). The logistic model was used to analyze the binary or dichotomous response and allows examining how a change in any independent variable changes all the outcome probabilities following Regmi (2010).

If $Y_i = 1$; $P(Y_i = 1) = P_i$

$Y_i = 0$; $P(Y_i = 0) = 1 - P_i$

Where, $P_i = E(Y = 1/X)$ represents the conditional mean of Y given certain values of X.

The logistic transformation of the probability of the practicing adaptation strategies by farmers were represented as follows (Gujarati, 2003).

$$L_i = \ln [P_i/ 1-P_i] = Z_i = \beta_0 + \sum_{i=1}^{n} \beta i\, Xi + \varepsilon_i$$

Where Y_i = a binary dependent variable (1, if farmers practice forage and fodder production, and 0 otherwise), X_i includes the vector of explanatory variables used in the model, β_i = parameters to be estimated, β_0 = a constant term , ε_i = error term of the model, exp (e) =base of the natural logarithms, L_i = Logit and [$P_i/1-P_i$]= odd ratios for i= 1, 2, 3, 4,……n farm households. Thus, the binary logistic regression model used in the study was expressed as:

$Y_i = f(\beta_i X_i)$ = f (central region dummy, western region dummy, age of household head, sex of household head, ethnicity of respondent household, education of household head, number of family members with above secondary level education, family size, household with engage in abroad job, total land owned by household, livestock holding by household, access to credit, training taken, membership in group). The details of these variables used in the model are shown in Table 1.

Table 1. Description of explanatory variables used in the climate change adaptation strategies adoption model

Variable name	Description
Central region (dummy)	Central region dummy (value 1 if the household is from central region, 0 otherwise) [a]
Western region (dummy)	Western region dummy (value 1 if the household is from western region, 0 otherwise) [a]
Age (years)	Age of household head (years)
Sex (dummy)	Sex of household head (value 1 if the household head is male, 0 otherwise)
Brahmin-Kshetri (dummy)	Ethnicity dummy (value 1 if the household is brahmin or kshetri, 0 otherwise)
Education of household head (dummy)	Years of schooling of household head (years.)
Number of family member with above secondary level education (number)	Number of members with above secondary level education in the household (numbers)
Family size (number)	Family size (numbers)
Abroad job (dummy)	Abroad job dummy (value 1 if the family member is in abroad job, 0 otherwise)
Total land (Kattha)	Total land owned by household (Kattha)
Livestock holding (LSU)	Size of livestock holding (LSU)
Access to credit (dummy)	Access to credit dummy (value 1 if the household has access to agricultural credit, 0 otherwise)
Training (dummy)	Training dummy (value 1 if the member from household has taken training on livestock related areas, 0 otherwise)
Attachment in group (dummy)	Involvement in farmers' group and co-operatives dummy (value 1 if the member from household has membership in farmers' group and cooperatives, 0 otherwise

[a] *Eastern region is treated as the reference region.*

Results and Discussions

Socio-demographic and economic characteristics

This sub-section deals with the major findings on socio-demographic and economic characteristics of respondents and respondent households. These are summarized in terms of sex, size of family, land and livestock holding, occupation, income structure etc. The average age of respondent was found least in Banke (42.34 years) and the highest in Morang (49.57years), whereas the overall average within the study area was 45.71 years Years of schooling of respondent within the study area was overall averaged as 5.36 years which is lower than the national overall average (8.1years) of adults above 15 years (CBS, 2011). Similarly, male and female per household were 3.3 and 3.1, respectively in study area which was more than male and female numbers in household of country, 2.3 and 2.5, respectively (CBS, 2011). The study on age distribution of family members in surveyed districts which depicted economically active population was 64.5 % which found higher than national economically active population level i.e. 57% (CBS, 2011). Average number of family members with primary, secondary, school level education, higher secondary and university was found 0.84 (14%), 1.49 (24.83%), 0.67 (11.12%) and 0.54 (9%), respectively in the study area. The dominant inhabitance of the Brahmin-Kshetri community (46.50%) was found in study area. The highest cultivated land holding per household was found in Rupandehi, followed by Banke, Morang, Sarlahi, Chitwan and the least at Bara. Being the districts of Terai, on an average about two third of land holding was lowland. Area under year round irrigation was found highest (14.98 kattha) in Rupandehi, while the lowest (0.01 kattha) in Banke which is quite below the national average of 18% (ADS, 2015). It was found that, Chitwan, Banke and Bara district have greater number of cow holding than overall average (2.93). Household income based on natural resources of Chitwan district was highest among all districts (65.35%) and least in Bara district (54.40%). Whereas, income from non-natural resource based was highest in Bara (45.60%) and the lowest was in Chitwan district (34.65%).

Adoption of different adaptation strategies by farmers in study area

Different adaptation strategies adopted by dairy farmers in the study area to cope climate change effects are shown in Table 2. Mixed farming system of different species of livestock as a climate change adaptation strategy has been adopted by the largest number of respondents (93%) and water harvest scheme was the least adopted climate change adaptation strategy, being adopted by just over 8% of the respondents. Popular adaptation strategies adopted by more than half of the total number of respondents were found as reduction in herd size (60.67%), diversification of livestock species (77.33%), feeding feed supplement to livestock (75.83%), forage and fodder cultivation (54.67%), improved shed construction (59.16%), diversification of farm activities (82%) and mixed farming (93%).

Mean and standard error of different variables used in the study of factors affecting adoption of forage and fodder production are presented in Table 3. These included both the dummy and continuous variables used in the logistic regression.

Table 2. Adoption of different adaptation strategies to cope with effect of climate change by farmers in study area

Adaptation strategies	Number						Total	
	Morang	Sarlahi	Bara	Chitwan	Rupendahi	Banke	F	%
Reduction in herd size	56	73	52	43	73	67	364	60.67
Water harvest scheme	18	1	5	19	3	3	49	8.17
Diversification of livestock species	78	79	72	81	75	79	464	77.33
Feeding feed supplement to livestock	66	63	88	83	93	62	455	75.83
Adoption of improved	38	17	23	58	68	27	231	38.50

Adaptation strategies	Number						Total	
	Morang	Sarlahi	Bara	Chitwan	Rupendahi	Banke	F	%
dairy breeds								
Livestock insurance	0	4	51	24	12	15	106	17.67
Maintaining of grazing land	28	3	15	8	23	61	138	23.00
Forage and fodder cultivation	55	88	83	87	6	9	328	54.67
Irrigation	54	3	18	62	8	8	153	25.50

Table 3. Descriptive statistics for the explanatory variables used in estimating adoption model

Variable	Descriptive statistics (n=600)	
	Mean	S.E.
Central region (dummy)	0.33	0.01
Western region (dummy)	0.33	0.01
Age (years)	50.34	0.55
Sex (dummy)	0.76	0.01
Brahmin-Kshetri (dummy)	0.77	0.01
Education of household head (dummy)	2.42	0.17
Number of family member with above secondary level education (number)	1.86	0.06
Family size (number)	6.40	0.11
Abroad job (dummy)	0.31	0.01
Total land (Kattha)	18.82	0.98
Livestock holding (LSU)	6.35	0.38
Access to credit (dummy)	0.81	0.01
Training (dummy)	0.28	0.01
Attachment in group (dummy)	0.54	0.02

Factors affecting adoption of forage and fodder production

The result from logistic regression model for adoption of fodder and forage cultivation are presented in Table 4. Results showed that out of fourteen explanatory variables, five factors were significantly contributing adoption of fodder and forage cultivation as climate change adaptation strategy and leaving others non significant. These factors affecting the adoption are western dummy, family size, livestock holding, access to credit and training. Among these, all the factors except western dummy and family size are contributing the diversification of farm activities in positive direction. Access to credit and training are more influencing factors for adoption as compared with other among positively contributing factors.

Table 4. Regression coefficients of logistic regression model for fodder and forage cultivation

Variable[a]	Odds Ratio	SE	Z	P>IzI
Central region (dummy)	1.833	0.688	1.61	0.107
Western region (dummy)	0.252**	0.075	-4.59	0.000
Age (years)	1.004	0.009	0.50	0.617
Sex (dummy)	1.136	0.325	0.45	0.655
Brahmin-Kshetri (dummy)	0.641	0.195	-1.45	0.146
Education of household head (dummy)	1.005	0.031	0.17	0.869
Number of family member with above secondary level education (number)	0.904	0.069	-1.30	0.195
Family size (number)	0.926*	0.039	-1.77	0.076

Variable[a]	Odds Ratio	SE	Z	P>IzI
Abroad job (dummy)	1.265	0.338	0.88	0.379
Total land (Kattha)	1.008	0.005	1.06	0.292
Livestock holding (LSU)	1.108**	0.044	2.57	0.010
Access to credit (dummy)	8.421**	2.396	7.49	0.000
Training (dummy)	2.888**	0.791	2.39	0.017
Attachment in group (dummy)	1.362	0.390	1.08	0.280
Constant	0.732	0.517	-0.45	0.650
Pseudo R^2	0.314			
Log likelihood	-223.43			
Observation	600			

[a]Prob (Y = 1): adopted forage and fodder cultivation.
***, *Significance level at P <0. 0.05 and P<0.010, respectively*

The role of different variables on adoption of forage and fodder production are presented and discussed hereunder in separate sub-headings.

Central/western Terai
The cultivation of forage and fodder in central Terai as compared to eastern Terai was statistically non-significant and correlated positively. Similarly, forage and fodder cultivation in western Terai found statistically highly significant (P<0.05) but negatively correlated. This implies forage and fodder cultivation in western Terai as compared with eastern Terai decreased by 74.8%. It may be due to high family size in western Terai which demands the family to produce more crops instead of fodder ultimately leading to decrease in fodder cultivation. The other possible explanation might be small hand holding, lack of training facilities and poor extension services which prevents small farmers from driving towards modern approaches of farming and climate change adaptation strategies.

Age of household head
The age household head for adoption of fodder and forage cultivation was found non-significant but positively correlated. The result showed that 1 year increase in age of household head, the adoption of fodder and forage cultivation increases by 0.4%. The implication of this result is that with increasing age of household head improves likelihood of adaptation to climatic situations through various strategies. This is consistent with the findings of (Apata, 2011) who reported perceiving climate change increases with age, thus adopting suitable options.

Sex of household head
Similarly the sex of household head was non-significant but is positively correlated to affect fodder and forage cultivation adoption. Household head headed by male increases adoption of fodder and forage cultivation by 13.6% than household head headed by female. The justification behind the fact might be due to most of the families are male headed. It is because culturally conditioned to involve farming activity that required intensive male labor forces like land preparation etc. This is consistent with the finding of Obayelu *et. al.*, 2014 in which being a female head of household head had negative effect on likelihood of adoption of climate change strategies due to lack of information and resource constraint.

Ethnicity of household
The regression model explained fodder and forage cultivation was found non-significantly and negatively associated with adaptation strategies by Bhrahmin and Kshetri communities. It implies if the household ethnicity is Brahmins or Kshetri, the chance of adopting forage and fodder cultivation reduced by 35.9%

as compared to other ethnic groups. This may be due to the engagement of *Brahmins and Kshetris* in nonfarm activities than agriculture.

Education of household head

Many studies on adaptation to climate change showed that education is positively affected by the decision to take climate change adaptation measures. But the result showed education was non-significant for adaptation to climate change but positively correlated. The explanation of non significance in education may be due to lower literacy rate in study areas. It was found that increase in schooling by 1 year adoption of forage and fodder cultivation to adapt climate change increases by 0.5%. This implies that farmers with higher levels of education are more likely to adapt better to climate change due to higher knowledge on adoption strategies. This result is consistent with the findings of Teklay and Teklay (2015). Madison (2016) argued that a person with higher level of education increases the probability of adopting the strategies for climate change.

Education level of family members

The number of family member of household above secondary level of education was non-significant and correlated negatively for adoption of forage and fodder cultivation as a mean to adapt climate change. The result showed that members above secondary level of education odds of for adopting forage and fodder production decreases by 9.6%. The years of formal education of the farmers was positively related to diversification to non-farm activities (Obayelu *et al.,* 2014). It can be justified as the increases in education level of family members usually shift their occupation from agriculture to nonfarm activities. It is because most of uneducated, unemployed and poor people engaged in agriculture sector.

Family size of study households

The family size was found significant ($P<0.1$) but correlated negatively with adoption of fodder and forage cultivation. This implies when the family size increases by 1 member the adoption of fodder and forage cultivation decreases by 7.4%. This result found contrary with the findings of Teklay and Teklay (2015) which pointed out that having sufficient labor in family (economically active members) the adoption of improved forage cultivation increases by factor of 19.09. However, Apata (2011) reported result contrary to our findings which assumes that a large family size is normally associated with a higher labor endowment, which would enable a household to accomplish various agricultural tasks, especially during peak seasons. The negative relation between family size and forage/ fodder cultivation may be due to increase in number of economically inactive members in family, which increases family size but actual working labor force decreases. It can be further explained as the family size increases the likelihood of adopting forage and fodder cultivation decreases due to higher demand of food crops rather livestock commodities.

Abroad job of family members

Abroad job for adoption of forage and fodder cultivation as a measure for adaptation of climate change was found non-significant but associated positively. The family with a member in abroad for adopting forages and fodder cultivation increased by 26.5% than a family without member in abroad. Abroad job increases family income. Family income had positive and significant relationship with adoption of adaptive strategies to climate change effects (Uddin *et al.,* 2014). According to Shiferaw and Holden (1998) households with higher income and greater assets are in a better position to adopt techniques for coping climate which is consistent with above result. Wealth has positive implication to adoption of climate change adaptation strategies (Gbetibouo, 2009).

Land size

Land holding was found non-significant with adoption of forage and fodder cultivation. Works by (Teklay and Teklay, 2015) explained similar results. It may be due to similar land distribution in survey areas. This may also reflect that it is not size of land that affect adoption but specific characteristics of the farm that dictate the need for a specific adaptation method to climate change. However the logistic model revealed land holding was positively correlated to forage and fodder cultivation. It was found that an increase in total lands holding by 1 kattha increased the adoption of forage and fodder cultivation by 0.8%. This might be due to increased opportunity for farmers to expand forage and fodder cultivation as a result of increased land holding.

Livestock holding of study households

The livestock holding found highly significant ($P<0.05$) for adoption of forage and fodder cultivation. It implied that increase in livestock by 1 unit the adoption of fodder and forage cultivation as a means for adaptation to climate change increases by 10.8%. This result indicated that famers who have more livestock holding tend to establish fodder/ forage pasture to increase the quality and quantity of feed available for their animals. It is consistent with the findings of (Jera and Ajayi, 2008) farmers' adoption of tree-based fodder technology in Zimbabwe. It is obvious that higher size of livestock holding demands for higher forage and fodder which might encourages fodder and forage cultivation. Herd size is an asset and indication of wealth that may have been considered by farmers as an insurance against innovation risk.

Access to credit for livestock production

Access to credit found highly significant ($P<0.05$) for adoption of forage and fodder cultivation. The result showed that family with access to agricultural credit increases the adoption of cultivation of forage and fodder for adaptation to climate change by 742.1 % than the family without access to agricultural credit. This is consistent with the findings of (Shongwe, 2014) who mentioned access to credit is an important variable which commonly has a positive effect on adaptation behavior. The access to credit may enables farmers with better availability of inputs, resources and farm decisions to adopt strategies for climate change adaptation.

Training on livestock production and management

The training was found highly significant ($P<0.05$) for adoption of forage and fodder cultivation. This showed that member of family with training related to livestock increases the adoption of fodder and forage cultivation by 188.8 % than a household without training. Training or any other contact with extension workers might provide information about the impacts of climate change, enhances knowledge of farmers, ultimately lead to adoption of climate change adaptation strategies.

Membership in farmers' group

Group found statistically non-significant for adoption of forage and fodder cultivation but with positive coefficient. The result showed involvement in group (farmers group or cooperatives or organizations) increased the adoption of forage and fodder cultivation by 36.2%. Similar results found by (Teklay and Teklay, 2015) in Ethiopia which shows participation of farmers in local organization increased the probability of adopting forage by a factor of 0.363. Perhaps, the possible explanation is that those who participate in local organization might have been easy to enforce and follow up. Farmers in local organization have commitments, and given maximum attention to farming technologies because they are easily accessed for new technology and strict follow. The social groups such as farmers' cooperatives provide information on farming, credits and resources that can be used when adapting to climate change (Shongwe, 2014).

Conclusion and recommendations

The findings of the study explained that out of fourteen variables five of them (Western Terai dummy, family size, access to credit, size of livestock holding, and training) were statistically significant factors for adoption of forage and fodder cultivation in the study area. The result showed that increase in farmers' access to credit was statistically highly significant and correlated positively with adoption of forage and fodder cultivation as a strategy for adaptation to adverse impact of climate change. The adequate access of credit in form of soft loan should be provided by government to overcome major barrier for adaptation to climate change. Farmers with trainings increase chance of adopting forage and fodder cultivation.

Therefore, identification of target group and provision of regular need based trainings by competent and qualified extension agents should be encouraged in order to sensitize the farmers about the impacts of climate change in livestock and adaptation strategies. Association of farmers in group affects farmers to adopt improved forage production due to its impact to work cooperatively and in an organized manner.
Forage and fodder cultivation increases with increase in livestock holdings in farm. Thus, cultivation practices need to be focused in areas of higher livestock size farms through provision of inputs and resources for better adaptation. The increase in family size reduces the adoption of cultivation of fodder and forage. The research station should focus on development of improved forage production techniques that requires low labor. Addressing the problem of land fragmentation is necessary for improving adoption of fodder and forage cultivation. The government should focus on the development of appropriate land utilization and management policy. Furthermore, the access to credit, improved extension services, training and better management of land should be provided to farmers as a measure to adapt in the context of adverse impact of climate change. Hence, livestock production is sensitive to climate change implying that there is an impact of climate change on livestock production system. Thus, it needs to address the impact of climate change through development of sustainable adaptation strategies incorporating suitable policies.

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Short Communicaion

Assessment of chemical parameters of Nepalese rice varieties and imported brands

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Abstract
There has been growing import of fine and aromatic rice in Nepal in recent years. The inherent quality of different rice varieties could be one factor over consumer preference while proper packing and branding could be other factors. Most of the Nepalese rice varieties have not been able to penetrate the market as commercial brands and local landraces are gradually getting popular due to their inherent taste, aroma nutritional value. A study was conducted by the Center for Crop Development and Agro-biodiversity Conservation (CCDABC) in the year 2018/19 to compare the chemical compositions of different Nepalese rice varieties and imported brands, which were collected from major markets of different districts of Nepal. The study was aimed in understanding the chemical composition of these varieties and to know if the growing preference over imported fine and aromatic varieties had better chemical parameters over Nepalese varieties. The study revealed that higher content of zinc was observed in local varieties than in other varieties and brands. It ranged from 10.9 to 13.9 mg/kg in imported brands and from 9.7 to 17.6 mg/kg in released varieties. The highest crude protein was observed in the Dawat (12.64 %), one of the Indian brands and the lowest in Radha 4 (6.02 %) Nepalese released variety is commonly grown in the country. Average crude protein in Nepalese brands, imported brands, released varieties and local varieties were found as 11.22 %, 10.38, 8.62 % and 7.41 % respectively. Local varieties showed the highest crude fat (average 2.19 %) content followed by released varieties (average 1.17 %) and Nepalese brands (average 0.51 %). Likewise, crude fibre and total ash contents in local varieties were observed as 0.96 % and 0.93 % respectively. Therefore, the study revealed that local varieties were found superior in terms of chemical and nutritional perspective (total ash, crude fibre, crude fat and zinc) over other varieties and brands found in Nepal. In terms of protein, Nepalese brands were found superior over other varieties and brands.

Keywords: Chemical composition, iron, rice brand, variety

Introduction
Rice (*Oryza sativa* L.) is the second most widely grown cereal crop and the staple food for more than half of the world's population, providing 20 percent of the world's dietary energy supply (Alexandratos and Jelle, 2012). From this viewpoint, rice is the most important strategic crop for food and nutrition security globally. In the context of Nepal, it is the main staple food crop and contributes significantly to the livelihood of the majority of people and the national economy (nearly 20 percent contribution in the agricultural gross domestic product) (Gadal *et al*., 2019).

Rice quality is a combination of physical and chemical characteristics. Different people from different countries have different preferences for the quality and type of rice. Preference in terms of appearance, taste and texture vary from one consumer to another, some of them prefer aromatic rice and raw milled rice, others like the parboiled rice and others the most conventional rice (Martin *et al*., 1997). Similarly, Indica rice varieties that are hard but non-sticky are generally preferred in India, Pakistan, and Indonesia, while Japonica rice varieties which have moderate elasticity and stickiness are favored in Japan and Korea (Bhattacharya *et al*., 1982, Kang *et al*., 2011). Rice quality is a multi-faceted characteristic consisting of several aspects such as physical appearance, cooking and eating qualities, and nutritional value (Unneverhr *et al*., 1992). In Nepal, rice is the major staple food crop produced and consumed. With most of the population dependent on rice as a significant part of their diet, it is important to analyze and monitor its chemical and mineral composition. This study was carried out to know the chemical compositions of different rice varieties being grown in and/or sold in different districts of Nepal and some imported rice brands available in Kathmandu and to create awareness among the researchers, extension workers and consumers.

Materials and methods

Rice (milled rice) samples were collected during March-April of 2019 from different places of Nepal. Eleven released Nepalese rice varieties from the National Rice Research Program (NRRP), Hardinath, Dhanusha, six imported and three Nepalese rice brands from mall/supermarket of Kathmandu and three local varieties of rice from different districts of Nepal were collected (Table 1) for the study. The collected rice samples were cleaned and properly packed in separate plastic (each containing at least 200 g) before sending for the lab analysis. In the case of released varieties, rough paddy samples of each variety were collected, milled and manually cleaned in NRRP, Dhanusa for preparing the sample for the same. The physical and chemical composition of each sample was analyzed in the central laboratory of the Department of Food Technology and Quality Control (DFTQC), Kathmandu, Nepal. All the methods used for analysis were carried out based on the AOAC (Association of Official Analytical Chemists) method and National Food and Feed Reference Laboratory (NFFRL) Nepal manual. All the observed data of chemical compositions from the lab test were representative of two replications for each sample.

Table 1. Different rice varieties and brands collected for the analysis

S.N.	Rice variety/Brand name	Collection place	Country	Type of rice
	Imported brands			
1	Mithas	Kathmandu	India	Premium reserve rice/Basmati
2	Lal Quilla	Kathmandu	India	Classic white line basmati rice
3	507 Gold	Kathmandu	India	Basmati rice
4	Dawat	Kathmandu	India	Super basmati rice
5	India Gate	Kathmandu	India	Basmati rice classic
6	Sunlee	Kathmandu	Thailand	Jasmine rice
	Nepalese brands			
1	Hulas	Kathmandu	Nepal	Basmati rice
2	Gyan	Kathmandu	Nepal	Fine rice
3	Jira Masino	Banke	Nepal	Fine rice
	Nepalese released varieties			
1	Sawa Masuli Sub 1	Dhanusha	Nepal	Fine rice
2	Sworna Sub 1	Dhanusha	Nepal	Medium fine rice
3	Chaite 5	Dhanusha	Nepal	Medium
4	Sabitri	Dhanusha	Nepal	Medium
5	Ramdhan	Dhanusha	Nepal	Medium rice
6	Radha 4	Dhanusha	Nepal	Coarse rice
7	Bahuguni 1	Dhanusha	Nepal	Fine rice
8	Hardinath 1	Dhanusha	Nepal	Medium fine rice
9	Makawanpur 1	Dhanusha	Nepal	Coarse rice
10	Lalka Basmati	Dhanusha	Nepal	Fine and aromatic rice
11	Khumal 4	Nuwakot	Nepal	Fine rice
	Nepalese local varieties			
1	Jumli Marshi	Jumla	Nepal	Coarse rice
2	Pokhareli Jethobudho	Kaski	Nepal	Fine aromatic rice
3	Chandannath	Kaski	Nepal	Coarse rice

Results and Discussions

Physical rice grain composition (Grading)

Rice grain grading assures that a particular lot of grain meets the required set of standards for the customer. It comprises the presence or absence of foreign organic and inorganic matter, broken rice, damaged grain, chalky kernel, red kernels etc. The observed samples showed different physical grain composition which is given in Table 2.

Table 2. Physical grain compositions of different rice varieties and brands

S. N.	Rice variety/ brand name	Foreign organic matter (%)	Foreign inorganic matter (%)	Damaged grain (%)	Broken rice (%)	Chalky kernels (%)	Red kernels (%)
	Imported brands						
1	Mithas	0	0	0.18	0	0	1.83
2	Lal Quilla	0	0	0.19	0	0	0
3	507 Gold	0	0	0.06	0	0.05	0.1
4	Dawat	0.11	0	0.25	0.37	0	0
5	India Gate	0	0	0	0	0	0
6	Sunlee	0	0	0	0.21	0	0
	Nepalese brands						
1	Hulas	0	0	0	0	0	1.06
2	Gyan	0	0	0	0.61	0.22	0
3	Jira masino	0	0	0.19	0	0	0
	Released varieties						
1	Sawa Masuli Sub 1	0.07	0	0.68	2.1	0	0.37
2	Sworna Sub 1	0.10	0	0.27	1.5	0.01	0.16
3	Chaite 5	0	0.08	0	0.24	0	0.2
4	Sabitri	0	0.87	0.08	0.13	0	0.04
5	Ramdhan	0	0.87	0	0.02	0	0.13
6	Radha 4	0	0	0	2.4	0	0.19
7	Bahuguni 1	0	0	1.10	8.6	0	0
8	Hardinath 1	0	0	3.20	6.1	0	0
9	Makawanpur 1	0	0	0.10	4.6	0	0
10	Lalka Basmati	0	0	7.90	1.9	0	0
11	Khumal 4	0	0	0.6	3.8	0	0
	Local varieties						
1	Jumli Marshi	0	0.08	0	1.4	0.3	0
2	Pokhareli	0	0	0	4.1	0	0
3	Jethobudho Chandannath	0	0	0	12.7	0	0

Source: Lab test report, DFTQC, 2019

A higher percentage of broken rice was observed in released varieties and local varieties than in imported brands and Nepalese brands. The maximum broken rice percentage was observed in Chandannath (12.7 %) whereas the lowest was observed in Ramdhan (0.02 %). Most of the imported brand and Nepalese brands showed zero percentage of broken rice whereas released varieties showed a higher percentage of broken rice but less than the standard limit of 25 % (DFTQC, 2018). Andrews *et al.* (1992) stated that one of the primary factors determining the best milling and quality of rice is the head rice which means the rice containing less amount of broken rice. The percentage of broken rice in released varieties ranged from 0.02 to 8.6 %. This might be due to standard processing involved in branded rice but milling with manual cleaning in case of released and local rice varieties.

Foreign organic matter ranging from 0.07 to 0.11 % was observed in Dawat, Sawa masuli Sub 1 and Sworna Sub 1 only but remained below the standard limit of 0.5 % (DFTQC, 2018). Similarly, there was no presence of foreign inorganic matter in all the brands and varieties except in Chaite, Sabitri and Ramdhan. Among these three varieties, Sabitri and Ramdhan showed the presence of foreign inorganic matter more than the standard limit of 0.1 % (DFTQC, 2018). The damaged grain percentage in 4 out of 6 imported brands ranged from 0.06 to 0.25 % whereas in 8 out of 11 released varieties it ranged from 0.08 to 7.9 % for which the standard limit is 3 % (DFTQC, 2018). The higher percentage of damaged grain in released varieties might be due to poor processing and manual cleaning in the released varieties. Similarly, damaged grains in local varieties could be due to several factors like processing, drying, storing etc. or broken itself. Among all the brands and varieties presence of red kernels and chalky kernels were found below the standard limit of 4 % and 7 % respectively (DFTQC, 2018) but observed only in a few varieties and brands.

Chemical composition analysis

Each rice sample was analyzed to observe the chemical compositions like carbohydrate, energy, crude fibre, total ash, total protein, crude fat, moisture etc. which is presented in Table 3. These chemical compositions are important indicators of rice nutrient content. Rice grain is an excellent source of complex carbohydrates, protein, vitamins and minerals (Yadav and Jindal, 2007). The data showed that amount of different chemical compositions varied among the different rice varieties and brands. The highest crude protein was observed in the Dawat brand (12.64 %) which is Indian super basmati rice and the lowest in Radha 4 (6.02 %) which is a released Nepalese variety. The average crude protein content in Nepalese brands was 11.22 % whereas it was 10.38 % in imported brands. It ranged from 6.02 to 10.18 % in released varieties and from 6.88 to 7.77 % in local varieties. Protein quality is determined by the amino acid composition and its digestibility. Rice protein quality is very high when compared to other crops. Rice has a high amount of lysine and high protein digestibility (Frei and Becker, 2005). Protein in rice is of particular importance for health especially for those whose main staple food is rice. Regarding the crude fat, the highest amount was observed in local varieties (average 2.19 %) followed by released varieties (average 1.17 %) and Nepalese brands (average 0.51 %). Total ash content was found higher in local varieties (average 0.93 %) than in other varieties and brands. In the case of carbohydrate and energy content, their averages were observed as 80.49 % and 366.81 Kcal/100g respectively in imported brands, 79.51 % and 367.49 Kcal/100g respectively in Nepalese brands, 81.00 % and 369.05 Kcal/100g respectively in released varieties and 79.5 % and 367.29 Kcal/100g respectively in local varieties. FAO (1993) stated that the amount of energy of white rice varied from 349 to 373 kcal.

The amount of starch in the grain is an important factor for determining grain quality. Rice starch is digested more rapidly when compared to other starchy foods and can lead to a fast and high increase in blood glucose levels after digestion (Frei and Becker, 2005). Rice has the highest energy contribution to developing countries. In Asia, rice is the main dietary source for energy, protein, thiamine, riboflavin, niacin, iron and calcium (Juliano, 1997). The crude fibre content was found a higher range in local varieties (average 0.96 %) whereas very lower range in imported brands (average 0.14 %) and Nepalese brands (average 0.05 %). Rice has the lowest dietary fibre content when compared to other cereals (FAO 1993). Therefore, in chemical and nutritional perspectives (total ash, crude fibre and crude fat) local varieties were found superior over other varieties and brands. In terms of protein, Nepalese brands were found superior over other varieties and brands. To cope with the increasing population, food security, nutrient security, urbanization, climate change and changing food preferences, there is a need for not only high yielding varieties but also nutritionally adequate rice varieties (Salim *et al*., 2017). With regards to the moisture content, an average of 8.21 % in imported brands, 8.32 % in Nepalese brands, 8.85 % in released varieties and 9.02 % in local varieties were observed. Moisture content is important in maintaining the quality of grain. High moisture content is associated with loss of viability, high incidence of pests and diseases, and reduction in eating quality. For best grain quality, 14 % of moisture content is recommended for rice grain (Unneverhr *et al.*, 1992).

Table 3. Chemical compositions of different rice varieties and brands

S.N	Rice variety/ brand name	Moisture %	Crude fat %	Crude protein %	Total ash%	Crude fiber%	Carbo-hydrate %	Energy (kcal/100g)
	Imported brands							
1	Mithas	6.83	0.36	11.26	0.63	0.18	80.74	371.24
2	Lal Quilla	7.75	0.06	9.08	0.55	0.08	82.48	366.78
3	507 Gold	8.33	0.27	10.33	0.59	0.16	80.32	365.03
4	Dawat	8.4	0.4	12.64	0.18	0.15	78.23	367.08
5	India Gate	7.99	0.53	10.47	0.33	0.14	80.54	368.81
6	Sunlee	9.96	0.61	8.5	0.18	0.15	80.6	361.89
	Average	8.21	0.37	10.38	0.41	0.14	80.49	366.81
	Nepalese brands							
1	Hulas	8.84	0.4	12.04	0.3	0.05	78.37	365.24
2	Gyan	9.04	0.4	10.48	0.17	0.03	79.88	365.04
3	Jira Masino	7.09	0.72	11.15	0.68	0.08	80.28	372.2
	Average	8.32	0.51	11.22	0.38	0.05	79.51	367.49
	Released varieties							
1	SawaMasuliSub1	8.65	0.95	9.55	0.48	0.34	80.03	366.87
2	Sworna Sub 1	8.28	0.73	10.18	0.35	0.1	80.36	368.73
3	Chaite 5	8.84	0.93	9.52	0.34	0.08	80.29	367.61
4	Sabitri	8.88	1.02	9.26	0.13	0.09	80.62	368.7
5	Ramdhan	8.88	1.9	9.3	0.45	0.18	79.29	371.46
6	Radha 4	8.9	1.16	6.02	0.02	0.21	83.69	369.28
7	Bahuguni 1	8.73	1.07	8.49	0.05	0.1	81.56	369.83
8	Hardinath 1	9.06	1.37	8.47	0.02	0.02	81.06	370.45
9	Makwanpur 1	8.47	0.56	6.06	0.04	0.12	84.75	368.28
10	Lalka Basmati	9.11	0.65	9.49	0.03	0.08	80.64	366.37
11	Khumal 4	9.53	2.55	8.53	0.47	0.19	78.73	371.99
	Average	8.85	1.17	8.62	0.22	0.14	81.00	369.05
	Local varieties							
1	Jumli Marshi	8.72	0.99	7.57	1.06	2.29	79.37	356.67
2	Pokhareli Jethobudho	9.57	2.37	7.77	0.57	0.16	79.56	370.65
3	Chandannath	8.76	3.2	6.88	1.16	0.44	79.56	374.56
	Average	9.02	2.19	7.41	0.93	0.96	79.50	367.29

Source: Lab test report, DFTQC, 2019

Mineral composition analysis

The iron and zinc contents of different rice varieties and brands are given in Table 4 which revealed that variation in the amount of mineral contents was observed among the varieties and brands. Average zinc content found 12.38 mg/kg in imported brand, 10.40 mg/kg in Nepalese brands, 13.28 mg/kg in released varieties and 16.37 mg/kg in local varieties. It ranged from 10.9 to 13.9 mg/kg in imported brands and from 9.7 to 17.6 mg/kg in released varieties. Higher content of zinc was observed in local varieties. Regarding iron content, all of the verities and brands had less than 8 mg/kg of iron content except local varieties. In local varieties, it ranged from less than 8 to 16.2 mg/kg.

The nutritional composition of rice grain depends on different factors such as varieties, location, soil fertility, fertilizer application, environmental conditions and post-harvest transformations (Oko *et al*., 2012; FAO, 2006). Minerals are concentrated in the outer layers of rice or the bran fraction. The distribution of minerals in rice kernels is not uniform. About 50% of the mineral content is located in the bran layer and 10% in the embryo; both will be removed when producing white rice. White rice only contains 28% of the total ash of brown rice (Hunt *et al*., 2002). Generally, the deficiency of minerals in rice is due to their low concentration and the presence of inhibitors. Research studies showed that mineral contents in rice occur at low levels and influenced by many factors. For example, iron levels in rice differ with growing regions (Liang, 2007). In other aspects, consumers are becoming more health-conscious in their choice of the quality of food. Therefore, the quality of rice does not only include the physical characteristics but also the chemical and cooking qualities of the grain. Therefore, when selecting a particular variety, there is the need to consider the nutritional value derivable from that variety (Mbatchou and Dawda, 2013).

Table 4. Zinc and Iron contents of different rice varieties and brands

S.N.	Rice variety/Brand name	Zinc (mg/kg)	Iron (mg/kg)
	Imported Brands		
1	Mithas	12.3	< 8
2	Lal Quilla	12.6	< 8
3	507 Gold	11.9	< 8
4	Dawat	10.9	< 8
5	India Gate	12.7	< 8
6	Sunlee	13.9	< 8
	Average	12.38	-
	Nepalese Brands		
1	Hulas	10.6	< 8
2	Gyan	10.5	< 8
3	Jira Masino	10.1	< 8
	Average	10.40	-
	Released Varieties		
1	Sawa Masuli Sub 1	17.6	< 8
2	Sworna Sub 1	10.2	< 8
3	Chaite 5	10.2	< 8
4	Sabitri	17.1	< 8
5	Ramdhan	14.7	< 8
6	Radha 4	10.6	< 8
7	Bahuguni 1	12.6	< 8
8	Hardinath 1	9.7	< 8
9	Makawanpur 1	17.2	< 8

10	Lalka Basmati	11.7	< 8
11	Khumal 4	14.5	< 8
	Average	13.28	-
	Local Varieties		
1	Jumli Marshi	17.6	10.1
2	Pokhareli Jethobudho	13.8	< 8
3	Chandannath	17.7	16.2
	Average	16.37	-

Source: Lab test report, DFTQC, 2019

Conclusion

In this study, differences in rice varieties and brands were reflected by the range of nutritional characteristics. No variety/brand was observed that was superior to another in terms of its overall nutritional content; however, there were some varieties/brands that recorded higher levels of one or more nutrients. Regarding the mineral content (iron and zinc), crude fibre and crude fat the local varieties found superior over branded rice and other varieties. The study showed that local and Nepalese rice varieties are superior or at par in terms of nutritional aspects like crude fat, crude fibre, carbohydrate, energy and zinc with the popular rice brands from a neighboring country. Therefore, promotional activities and branding of these varieties need to be emphasized for increasing the adoption of Nepalese varieties and import substitution. A further study to understand the preference of consumers over different varieties could give a better picture in understanding the market structure of rice.

Acknowledgement

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Study limitations

- A limited number of districts and samples were selected and collected due to limited budget allocation.
- In the case of branded rice samples, coarse varieties (branded) were excluded in the study due to their unavailability in the supermarkets and malls.

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Jensen, NF.1965. Multiple superiority in cereals. *Crop Sci*. 5:566-568.

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