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Growth, Dry Matter Partitioning and Productivity of Wheat (*Triticum aestivum* L.) under Different Establishment Methods and Inter-Culture Practices

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Abstract: A field experiment was carried out under Randomized Block Design at Norman. E. Borlaug Crop Research Centre of GBPUA&T, Pantnagar, Uttarakhand to evaluate the effect of establishment methods and inter-culture practices on growth and productivity of wheat (cv. HD 2967). Seven treatments including five crop establishment methods viz., conventional tillage (CT), reduced tillage (RT), zero tillage (ZT), raised bed 40/20 cm and raised bed 60/20 cm and two inter-culture practices viz. conoweeding (CW) and alternate ridging (AR) at 35days after sowing were evaluated. Wheat grown under ZT, RT and CT conditions produced significantly higher plant height compared to raised bed. Effective tillers (423 m^{-2}) and total dry matter (DM) production (1478.3 g m^{-2}) were higher in RT condition. Tiller mortality was highest (56.0%) with CT practice and lowest in RB 40/20 cm land configuration. Wheat grown on raised bed 40/20 cm recorded significantly higher root weight density compared to remaining treatments followed by raised bed 60/20 cm. Partitioning of DM towards sink (spike) was highest in raised bed method. Wheat grown under reduced tillage condition resulted highest grain yield (5.44 t ha^{-1}) that was statistically similar to CT, and ZT, however it was 17.6 and 11.6% higher than raised bed 40/20 and 60/20cm, respectively. Both CW and AR inter-culture practices resulted less yield than CT.

Keywords: Dry matter, Wheat, Raised bed, Reduced tillage, Zero tillagety

Wheat (*Triticum aestivum* L.) covers about one-fifth of the total area under food grains and contributes to about one-third (40%) of the total food grain production in India (Mukherjee and Mandal 2021). Among different agronomic management practices, the planting method is of great significance as it not only determines optimum plant stand due to proper resource utilization but also enhances the yield potential of the individual plant through minimizing inter plant competition and facilitating the harvest of light energy into economic form. Conventionally, wheat establishment is resource intensive and needs friable seed bed which is obtained by multiple tillage passes consuming huge energy, increasing the cost of cultivation besides taking long turnaround period (Sah et al 2014). Accelerated rate of decomposition of organic matter under conventional tillage without its addition leads to degradation of the soil health and environmental pollution threatening the system stability and sustainability. Thus, there is a need to find out an alternate management strategy which can sustain the crop productivity. Wheat production can be improved through judicious input use; better production technology and tillage practice (Leghari et al 2015). Resource conservation technologies like reduced tillage, zero tillage, raised bed planting etc. have been considered to be the alternatives to conventional method. Retaining residues in conservation tillage has the potential to conserve the soil moisture and reduce soil erosion and runoff (Singh et al 2021). It ensures timely sowing of wheat when harvesting of rice is delayed. Minimizing soil agitation by reduced tillage improves physical, chemical and biological properties of soil (Lopez-Garrido et al 2012). Sowing of wheat on beds provide better solar radiation penetration and aeration within the crop canopy due to more open space available to plants on either sides of the bed. It can save 50% seed, 25% water, reduces lodging, minimizes loss of nitrogen, helps in rain water conservation resulting in nearly 25% yield enhancement (Alwang et a l2018). Piling up of fertile top soil in the form of bed also helps in vigorous root system enabling the plant to explore more soil volume and resist against lodging. Ahmad et al (2010) found that bed planted wheat consumed approximately 35.6% less water as compared to the conventional row planting in flat beds with flood irrigation.

Post-sowing inter-culture soil operations like conoweeding and alternate ridging can also sustain crop growth and development through soil manipulation and resource conservation in terms of water. Mechanical manipulation of soil through conoweeder in the widely spaced wheat crop may enhance root growth and tillering ability of the crop. It not only incorporates the weeds and adds the organic matter in the soil but may also help in effective recycling of the depleted nutrients which in turn could have augmented the nutrient pool of the rhizosphere together with aeration of the root zone. Alternate ridging in relatively wider spaced standing crop provides better anchorage to the plants. Besides saving irrigation water and better aeration for root expansion, post sowing ridging also helps in checking weed growth, conserving soil moisture, mixing of applied fertilizers thoroughly with the soil. Hence, the present study was conducted to assess the impact of establishment methods and inter-culture practices on wheat growth and productivity.

MATERIAL AND METHODS

The field experiment was initiated at Norman. E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand during *rabi* season, 2017. Pantnagar comes under humid sub-tropical climate with cool winter. During the crop period, the average weekly maximum temperature ranged between 12.9 ºC in January to 33.6 ºC in April while the minimum temperature ranged from 4.2 ºC in January to 18.7 ºC in April.

The total rainfall received during crop growing period was 55.8 mm. Soil of the experimental field was sandy loam texture with medium organic carbon (0.65%). Soil bulk density was 1.54 g cm^{-3} with neutral in reaction (pH 7.2), low in available nitrogen (149.6 kg ha^{-1}) and high in available phosphorus (26.9 kg ha^{-1}) and available potassium (286.1kg ha^{-1}). The moisture content of soil at FC and PWP were 20.5 and 8.4%, respectively. The experiment consisting of seven treatments viz. conventional tillage (CT), zero tillage (ZT), reduced tillage (RT), raised bed land configurations of 40/20 cm (RB 40/20) and 60/20 cm (RB 60/20) and two inter-culture practices conoweeding (CW) and flat sowing followed by alternate ridging (AR), was laid out in randomized block design with three replications. In CT, land was prepared by 4 harrowings and 4 plankings that was reduced to 2 harrowings and 2 plankings in RT and totally omitted in ZT. In case of CT, ZT and RT wheat (cv. HD 2967) was sown in rows 20 cm apart. In conoweeding treatment, land preparation was similar to conventional tillage treatment except the widening of row spacing (25 cm). Conoweeder was used manually at the time of second and third irrigations in the field along the rows in single direction. For conoweeding, crop should attain sufficient growth and crop canopy should not be mudded during conoweeding. Hence, conoweeding was done during second and third irrigations. For alternate ridging, sowing was done on flat bed at 30 cm row spacing followed by alternate ridging at 35 DAS. After first irrigation, flat bed was converted in to alternate ridge and furrows by removing soil between two rows and placing it in adjacent two rows in the form of ridge using a small spade and water was applied in the furrows formed. In both raised bed treatments, after tillage operations, the land form was changed into raised beds and furrows. Two and three wheat rows were accommodated on the bed in RB 40/20 and RB 60/20 cm, respectively. The crop was uniformly fertilized with 150 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare with one third dose of nitrogen and the entire amount of phosphorus and potassium were applied as basal. The remaining two third nitrogen was top dressed in three equal splits at CRI, tillering and booting stage after first, second and third irrigation, respectively. After CRI irrigation, subsequent irrigations were scheduled as per IW:CPE ratio 1.0. Total five irrigations were given. A composite soil sample was taken with the help of auger from0-15 cm soil layer before each irrigation and soil moisture content was calculated by thermo-gravimetric method. Volumetric soil moisture content was worked out by multiplying the gravimetric soil moisture content with bulk density. The growth parameters, yield and yield attributes were recorded at specified stages with standard procedure. The economic yield was expressed at 14% moisture content. Tillers mortality was worked out by using the following formula:

$$\text{Tillers mortality (\%)} = \frac{\text{Maximum tillers} - \text{Effective tillers}}{\text{Maximum tillers}} \times 100$$

Dry matter accumulation was recorded at 60 DAS, 100 DAS and at harvest. The plant samples were sun dried for 3-4 days to lose excess moisture, then kept in dryer at 70 ± 2°C temperature for 48 to 78 hours till the samples attained a constant weight. Dry weight of leaf, stem and spike was taken separately to record dry matter partitioning at different stages. Root sampling was done up to a depth of 13 cm along with soil mass with the help of core sampler of diameter 10 cm from the 0.5 m sampled area already used for plant dry matter study. The root samples along with soil mass were kept in fine meshed nylon net bag and washed under running water to get rid of soil and avoid the loss of finer roots. After cleaning, the roots were cut off from the shoots. Roots were separately placed in brown paper bags and were dried in plant drier at 70 ± 2°C till constant weight. The root weight density was worked out as follows:

$$\text{Root weight density (mg cm}^{-3}\text{ of soil)} = \frac{\text{Total root weight (mg)}}{\text{Total soil volume sampled (cm}^{3}\text{)}}$$

The experimental data collected at different stages were analyzed by using analysis of variance technique appropriate to Randomized Block Design as per the statistical programme OPSTAT, developed by CCS Hisar Agricultural University, Haryana.

RESULTS AND DISCUSSION

Plant growth, tiller count and tiller mortality: Wheat grown under ZT, RT and CT conditions produced significantly higher plant height (Table 1) compared to raised bed mainly because of better moisture availability (Fig. 1) facilitating better root growth and utilization of available resources. Wheat sown on raised beds produced shortest plants because of low moisture retention in top soil due to increased surface area of the changed land configuration under raised bed (Zhang et al 2007). On the basis of the availability of natural resources *viz*. light, water and nutrients tillering may affect wheat yield either positively or negatively (Elhani et al 2007). Tiller count at maximum tillering stage (55 DAS), was highest (945 per m^2) in wheat grown under CT condition being statistically at par with the RT and ZT treatments might be because of better soil moisture availability in CT, RT and ZT facilitating effective utilization of resources (Fig. 1). Wheat sown on raised bed produced less number of effective tillers because of its wider row spacing leading to reduced population. Tiller mortality was highest (56.0%) with CT practice and lowest in RB 40/20 cm land configuration. Higher tiller number in CT might have resulted increased intra- plant competition for partitioning of photosynthates, however less production of side tillers in RB resulted in low mortality. Tillers mortality in reduced tillage was 2.4 and 1.9 percent lower as compared to conventional and zero tillage, respectively. Alternate ridging had 3.9 per cent less tillers mortality than conoweeding. Raised bed with three rows per bed showed 1.9 per cent higher tiller mortality than two rows of wheat per bed. This can be attributed to the fact that at lower densities, plants can use different resources (solar radiation, water, soil, nutrients etc.) more efficiently, and also competition among tillers is reduced (Evers et al 2006).

Root weight density: At peak period, root growth is a key factor determining acquisition of nutrients and water from soil, stem elongation, sturdiness, crop growth and productivity. Root weight density measured at 60 DAS varied significantly due to different treatments (Table 1). Wheat

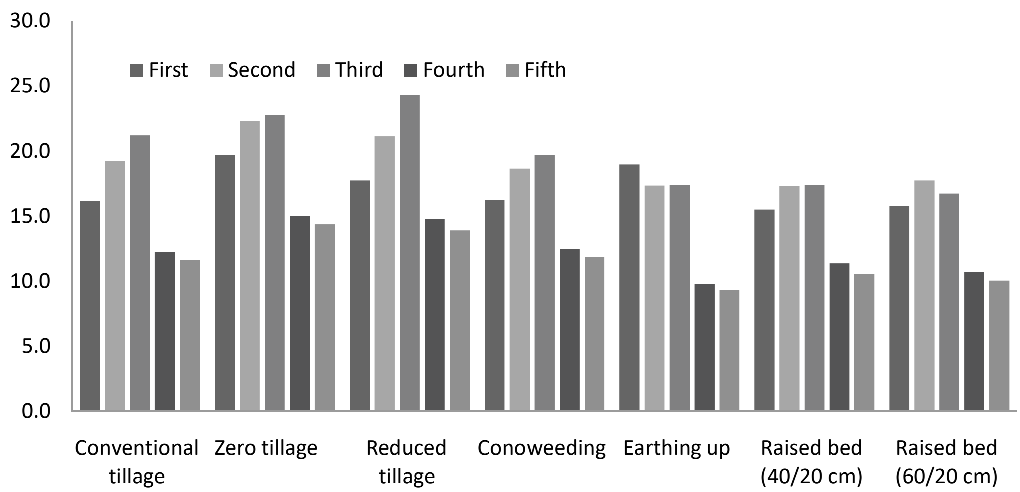

Fig. 1. Volumetric soil moisture content (%) before irrigations under different treatments

Table 1. Wheat growth and yields under different establishment methods and inter-culture practices

Treatment	Plant height (cm)	Tillers per m² at maximum tillering stage	Effective tillers per m²	Tiller mortality (%)	Root weight density (mg cm^{-3})		Thousand grain weight (g)	Grain weight perear (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
					60 DAS	80 DAS				
CT	101.2	945	416	56.0	0.75	1.80	40.8	1.48	5.20	7.70
ZT	98.9	908	404	55.5	0.58	1.34	39.4	1.49	5.20	7.55
RT	100.5	911	423	53.6	0.80	1.41	40.7	1.55	5.44	7.86
CW	100.5	783	374	52.0	0.84	1.87	40.2	1.49	5.00	7.39
AR	99.6	755	388	48.1	0.81	1.61	35.8	1.45	4.51	6.83
RB 40/20cm	97.1	669	344	47.6	1.20	2.32	39.3	1.54	4.48	6.26
RB 60/20cm	96.5	757	363	49.5	1.03	2.10	39.7	1.47	4.81	6.79
CD (p= 0.05)	3.1	150.0	45	NS	0.17	NS	2.5	NS	0.35	0.61

grown on RB 40/20 cm land configuration recorded significantly higher root weight density compared to remaining treatments followed by RB 60/20 cm land configuration. RB 40/20 cm land configuration recorded 51.9 and 28.% higher root dry weight than conventional tillage at 60 and 80 DAS, respectively. Better root development under raised bed configuration was due to less penetration resistance impedance (Naresh et al 2012). Du et al (2021) also explained that raised bed modified the rhizosphere that resulted in better root growth of wheat. Zero till wheat recorded minimum root weight density which was lower by 29.3 and 34% than conventional tillage at both 60 and 80 DAS, respectively. Soil type is also an important consideration for no tillage especially in areas subjected to excessive precipitation and high levels of crop residue. Generally, soils with an imbalance in particle size distribution (*i.e.*, high clay and sand content) are susceptible to compaction and thus demand tillage.

Leghari et al (2015) also reported that conventional tillage recorded higher root dry weight followed by reduced and zero tillage. At both the stages of observation, conoweeded treatment had higher root weight density than conventional, zero and reduced tillage treatments. Mechanical weeder improves aeration of the soil during weeding that allows oxygen to circulate within the soil. This might facilitate emergence of new roots from the roots which got pruned during this operation.

Dry matter yield and its partitioning: Total dry matter yield under various plant growth stages along with dry matter partitioning into leaf, stem and spike were significant for different establishment methods except for leaf and stem at harvest and stem at 100 DAS (Table 2).

Stem dry weight: Stem dry weight (g m^{-2}) increased from 60 DAS reaching maximum at 100 DAS and declined thereafter. Initially (60 DAS), dry weight of stem (m^2) differed significantly but later on differences became non-significant (Table 2). At 60 DAS, conventional tillage attained highest stem dry weight (77.7 g m^{-2}) that might be due to more tillering as well as taller plants and was statistically at par with reduced tillage (71.5 g m^{-2}) but significantly higher than other treatments because of more number of tillers. The stem dry weight was lowest in alternate ridging (45.8 g m^{-2}). Dry weight of stem (m^2) was more in raised bed having three rows per bed (50.6 g m^{-2}) compared to two rows of wheat per bed (47.4 g m^{-2}). At harvest, maximum stem dry weight was noticed with reduced tillage (451.3 g m^{-2}).

Leaves dry weight: Leaves dry weight (g m^{-2}) increased till 100 DAS and declined thereafter and attaining the lowest value at harvest. Leaves dry weight (m^2) showed significant variations up to 100 DAS. Initially, at 60 and 100 DAS, wheat grown under reduced till condition gained highest dry weight of leaves/m^2 (Table 2) because of more number of leaves per m^2 and better moisture availability that might result in more photosynthates accumulation. At 60 DAS, it was at par with conventional tillage, however, at 100 DAS, it was also statistically at par with dry weight of leaves (m^2) obtained under zero till condition. At all the growth stages, leaves dry weight was less in raised bed treatments than conventional tillage that could be attributed to low rate of photosynthesis under low soil moisture (Quanqi et al 2007). Conoweeding

Table 2. Impact of different treatments on dry matter partitioning of wheat at different growth stages

Treatment	60 DAS			100 DAS				At harvest			
	Leaf dry weight (g m^{-2})	Stem dry weight (g m^{-2})	Total dry weight (g m^{-2})	Leaf dry weight (g m^{-2})	Stem dry weight (g m^{-2})	Spike dry weight (g m^{-2})	Total dry weight (g m^{-2})	Leaf dry weight (g m^{-2})	Stem dry weight (g m^{-2})	Spike dry weight (g m^{-2})	Total dry weight (g m^{-2})
CT	155.3 66.7*	77.7 33.3*	233.0	358.7 28.6*	657.7 52.4*	237.7 19.0*	1254.0	137.8 9.5*	442.8 30.5*	872.2 60.0*	1452.8
ZT	141.7 70.1*	60.3 29.9*	202.0	345.0 31.0*	561.2 50.4*	207.2 18.6*	1113.3	132.2 9.2*	440.1 30.6*	867.8 60.3*	1440.1
RT	164.7 69.7*	71.5 30.3*	236.2	403.8 30.0*	681.0 50.7*	259.5 19.3*	1344.3	143.3 9.7*	451.3 30.5*	883.7 59.8*	1478.3
CW	115.5 68.6*	52.9 31.4*	168.4	305.5 27.1*	609.6 54.1*	211.5 18.8*	1126.5	135.9 9.5*	419.1 29.3*	876.8 61.2*	1431.7
AR	110.6 70.7*	45.8 29.3*	156.4	279.4 27.7*	541.3 53.7*	187.4 18.6*	1008.0	119.1 10.1*	347.1 29.5*	710.5 60.4*	1176.6
RB 40/20 cm	114.1 76.7*	47.4 31.9*	148.7	317.3 28.4*	595.7 53.4*	215.9 19.3*	1116.2	127.8 9.2*	399.5 28.7*	863.5 62.1*	1390.9
RB 60/20 cm	101.4 61.6*	50.6 30.7*	164.7	304.6 28.6*	525.0 49.3*	222.7 20.9*	1065.1	118.3 8.5*	397.3 28.7*	869.8 62.8*	1385.5
CD (p= 0.05)	18.7	15.3	30.6	70.6	NS	41.3	169.3	NS	NS	72.7	152.1

* Percent share of the component with respect to total dry weight

treatment recorded higher leaves dry weight than flat bed sowing followed by alternate ridging might be due to better tillering. Wheat grown on raised bed accumulated lower dry weight of leaves than conventional. At harvest, differences were found to be the non-significant among all the treatments.

Spike dry weight: At 100 DAS and harvest, reduced tillage produced highest dry weight of spike. At 100 DAS, it was statistically at par with the conventional tillage and raised bed 60/20 cm. At harvest, it recorded significantly higher dry weight of spike compared to alternate ridging treatment by 24.4%. At both the stages, the lowest dry weight of spike (187.4 and 710.5 g m^{-2}) was noticed with alternate ridging treatment. Conoweeding showed their superiority over alternate ridging with 19.0% higher spike dry weight. Both RB 40/20 cm and 60/20 cm configuration attained almost equal dry weight of spike that was at par with CT. Partitioning of dry matter towards sink (spike) was considerably higher *i.e.,* nearly 62 per cent in raised bed condition which might be due to better light penetration, air circulation and optimized phenological pattern leading to higher total assimilate, thereby, better grain filling and maximum translocation of assimilates towards the wheat spikes (Reynolds et al 2009).

Total dry matter accumulation: Dry matter accumulation increased with time and reached the maximum value at harvest. At 60 DAS, dry matter yield was highest under reduced tillage (236.2 g m^{-2}) due to more leaf and stem dry weight followed by conventional (233 g m^{-2}) and zero tillage (202 g m^{-2}). Hofmeijer et al (2019) also observed higher above ground biomass yield of wheat in reduced tillage with respect to conventional tillage. Total dry matter yield was significantly lower (13.3%) in zero till condition as compared to conventional tillage because of less stem and leaf dry weight. Dry matter yield in raised bed 40/20 cm was 9.7% lower than raised bed 60/20 cm although both of them were at par and superior to alternate ridging treatment mainly due to better root development and aeration owing to free space available at both sides of bed resulted in faster growth (Kumar et al 2010). At harvest, dry matter accumulation was the highest in reduced tillage condition (1,478.3 g m^{-2}) might be due to having higher number of green leaves and tillers (per m^2). Accumulation of dry matter in zero till wheat was at par with conventional tillage. At all the three stages, dry matter of wheat was the lowest in treatment with 30 cm row spacing with alternate ridging. At 60 and 100 DAS, dry weight of leaf and stem was more; respectively than at harvest due to greater dry matter accumulation in those parts, but later on, it reduced slightly. It might be due to more translocation of assimilates towards spike at the time of grain filling. Under high soil moisture condition, dry matter partitioning along with its accumulation were more which improves the yield. Plaut et al (2004) also reported reduced grain weight under moisture stress condition.

Yield and yield attributes: Wheat under RT produced the maximum number of spikes (423 m^{-2}) due to more number of leaves as well as leaf dry weight that might lead to better photosynthesis. Under raised bed condition number of spikes m^{-2} was significantly lower than CT (Table 1) because of increased row spacing. Conservation tillage practice had the highest thousand grain weight (40.8 g) which was closely followed by RT (40.7 g). Higher dry matter accumulation in these treatments might have led to better grain filling in turn the 1000 grain weight got increased. Leghari et al (2015) also found greater thousand grain weight in CT followed by RT and ZT treatments. In the experiment, wheat grown under RT condition produced the maximum grain yield (5.44 t ha^{-1}) which was statistically similar with CT and ZT condition but significantly superior than other treatments. In a similar way, Lopez-Garrido et al (2014) also found more wheat grain yield under reduced tillage than conventional tillage system. Reduced tillage, a form of mulch tillage conserves more moisture on surface due to residues remaining as mulch. Relatively larger clod size than conventional tillage also improve water infiltration, lower bulk density (*i.e.,* soil compaction), increasing root growth, uptake of water and nutrients leading to more tillering, dry matter production and yield attributes and ultimately the grain yield. Conventional and zero tilled wheat also produced identical grain yield of 5.2 t ha^{-1}. Zhang et al (2009) and Martinez et al (2008) found no significant difference in wheat yield under zero and conventional tillage. Zero tillage stored more moisture (Sah et al 2014) than other treatments that might favor tillering and heavier spike. Jat et al (2017) also found improved crop production under no-tilled condition compared with CT. Han et al (2020) explained that straw from previous crop improved wheat crop production. Multiple factors were responsible for the improved wheat performance. Firstly, straw-return increased available plant nutrients in the soil (Bartaula et al 2020). Secondly, addition of organic matter from the left over residue of previous crop contributes to superior soil quality leading to better crop performance (Yang et al 2016). Thirdly, improved hydrological and physical soil conditions (Han et al 2020) under reduced tillage was congenial for increased wheat yield and yield components. Conoweeding on wheat resulted significantly higher grain yield with respect to alternate ridging treatment as it recorded more thousand grain weight and grain weight per spike. Between the raised bed treatments, RB 60/20 cm land form produced 7.4% higher grain yield than RB 40/20 cm (4.48 t ha^{-1}). Kamboj et al (2017) also found better wheat yield realization with three rows per bed with respect to two rows per bed mainly due to lower weed infestation and more efficient utilization of space and nutrient under three rows of wheat per bed. Although, grains per spike and grain weight per spike were higher in RB 40/20 cm than conventional tillage but these were not sufficient to bridge the gap of reduced plant population. Both the raised bed treatments were significantly inferior as compared to conventional tillage. In conventional plots, wheat seeds were spaced 20cm apart while in bed planting, row to row distance was 30 cm and 26.7 cm, respectively. This reduction in number of rows per unit area resulted in reduced wheat crop stand at planting and less number of effective tillers per m^2contributed towards lower yield of bed planted wheat. The results are in accordance with the findings of Kilic (2015) who also obtained lower grain yield in bed planting than flat planting.

CONCLUSION

The present study in sandy loam soil belonging to Mollisols of *Tarai* of Uttarakhand, indicate that for growth parameters and productivity, wheat grown under reduced tillage performs better with highest number of effective tillers, dry matter accumulation that ultimately leaded towards highest grain yield. The grain yield in reduced tillage was 17.6 and 11.6% higher than raised bed 40/20 and 60/20 cm. Conoweeding and alternate ridging practice did not attain comparable yield with other treatments, however tiller mortality was 4- 8% less than conventional method.

REFERENCES

Ahmad M, Ghafoor A, Asif Mand Farid HU 2010. Effect of irrigation techniques on wheat production and water saving in soils. *Soil and Environment* **29**(1): 69-72.

Alwang J, Sabry S, Shideed K, Swelam A and Halila H 2018.Economic and food security benefits associated with raised-bed wheat production in Egypt. *Food Security* pp. 1-13.

Bartaula S, Urbasi P, Anil A, Mohan M, Darbin J and KrishnaA 2020.Effect of different tillage practices andnitrogen level on wheat production under inner terai of Nepal. *Journal of Agriculture and Natural Resources* **3**: 233-239.

Du X, He W, Wang Z, Xi M, Xu Y, Wu W, Gao S, Liu D, Lei W and Kong L 2021. Raised bed planting reduces waterlogging and increases yield in wheat following rice. *Field Crops Research* **265**: 1-8.

Elhani S, Martos V, Rharrabti Y, Royo C and Moral LFG 2007.Contribution of main stem and tillers to durum wheat (*Triticum turgidum* L. var. durum) grain yield and its components grown in Mediterranean environments. *Field Crops Research* **103**(1): 25-35.

Evers JB, Vos J, Andrieu B and Struik PC 2006. Cessation of tillering in spring wheat in relation to light interception and red: Far-red ratio. *Annals of Botany* **97**(4): 649-658.

Han Y, Wei M, Baoyuan Z, Xiaolong Y, Akram S, Congfeng L, Cougui C, Ming Z and Ming Z 2020. Effects of straw return method for the maize-rice rotation system on soil properties and crop yields. *Agronomy* **10**: 461.

Hofmeijer MAJ, Krauss M, Berner A, Peigne J, Mader P and Armengot L 2019. Effects of reduced tillage on weed pressure, nitrogen availability and winter wheat yields under organic management. *Agronomy* **9**: 1- 11.

Jat HS, Datta A, Sharma PC, Kumar V, Yadav AK, Choudhary M, Choudhary V, Gathala MK, Sharma DK and Jat ML 2017. Assessing soil properties and nutrients variability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. *Archives of Agronomy and Soil Science* **64**: 531-545.

Kamboj NK, Hooda VS, Gupta G and Sangwan N 2017. Effect of planting methods and weed management practices on yield and nutrient uptake by wheat (*Triticum aestivum* L.). *Indian Journal of Ecology* **6**: 889-892.

Kilic H 2015. Effect of different planting methods on yield and yield components of bread wheat. *Bothalia Journal* **45**(5): 56-63.

Kumar A, Sharma KD and Yadav A 2010. Enhancing yield and water productivity of wheat (*Triticum aestivum* L.) through furrow irrigated raised bed system in Indo- Gangetic plains. *Indian Journal of Agricultural Sciences* **80**(3): 198-202.

Leghari N, Mirjat MS, Mughal AQ, Rajpar I and Magsi H 2015. Effect of different tillage methods on the growth, development, yield and yield components of bread wheat. *International Journal of Agronomy and Agricultural Research* **6**(5): 36-46.

López- Garrido R, Deurer M, Madejon E, Murillo JM and Moreno F 2012. Tillage influence on biophysical soil properties: The example of a long-term tillage experiment under Mediterranean rainfed conditions in South Spain. *Soil and Tillage Research* **118**: 52-60.

Lopez- Garrido R, Madejon E, Leon-Camacho M, Giron I, Moreno F and Murillo JM 2014. Reduced tillage as an alternative to no-tillage under Mediterranean conditions: A case study. *Soil and Tillage Research* **140**: 40- 47.

Martinez E, Fuentes J, Silva P, Valle S and Acevedo E 2008. Soil physical properties and wheat root growth as affected by no tillage and conventional tillage systems in a Mediterranean environment of Chile. *Soil and Tillage Research* **99**: 232-244.

Mukherjee D and Mandal B 2021. Effect of tillage and herbicide application on broad-leaf weeds and wheat yield under alluvial zone. *Journal of Crop and Weed* **17**(1): 165-173.

Naresh RK, Singh B, Singh SP, Singh PK, Kumar A and Kumar A 2012. Furrow Irrigated Raised Bed (FIRB) planting technique for diversification of rice-wheat system for western IGP Region. *International Journal of Life Sciences Biotechnology and Pharma Research* **1**(3): 134-137.

Plaut Z, Butow B, Blumenthal C and Wrigley C 2004. Transport of dry matter into developing wheat kernels and its contribution to grain yield under post-anthesis water deficit and elevated temperature. *Field Crops Research* **86**: 185-198.

Quanqi L, Yuhai C, Mengyu L, Songlie Y, Xunbo Z and Baodi D 2007. Effects of planting patterns on biomass accumulation and yield of summer maize. *Ecology and Sustainable Development* **4**: 437-445.

Reynolds M, Foulkes MJ, Slafer GA, Berry P, Parry MA, Snape JW and Angus WJ 2009. Raising yield potential of wheat. *Journal of Experimental Botany* **60**: 1899-1918.

Sah G, Shah SC, Sah SK, Thapa RB, McDonald A, Sidhu HS, Gupta RK, Tripathi BP and Justice SE 2014. Effect of tillage and crop establishment methods, crop residues and nitrogen levels on wheat productivity, energy savings and greenhouse gas emission under rice - wheat cropping system. *Nepal Journal of Science and Technology* **15**(2): 1-10.

Singh H, Sharma SK and Bhat MA 2021. Performance of wheat under different tillage methods and potassium levels under irrigated and rainfed conditions of Northern-India. *Journal of Crop and Weed* **17**(1): 99-109.

Yang HS, Xu MM, Koide RT, Liu Q, Dai YJ, Liu L and Bian XM 2016. Effects of ditch-buried straw return on water percolation, nitrogen leaching and crop yields in a rice-wheat rotation system. *Journal of the Science of Food and Agriculture* **96**: 1141-1149.

Zhang J, Sun J, Duan A, Wang J, Shen X and Liu X 2007. Effects of different planting patterns on water use and yield performance of winter wheat in the Huang-Huai-Hai plains of China. *Agricultural Water Management* **92**: 41-47.

Zhang X, Li H, He J, Wang Q and Golabi MH 2009. Influence of conservation tillage practices on soil properties and crop yields for maize and wheat cultivation in Beijing, China. *Australian Journal of Soil Research* **47**: 362-371.

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