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.

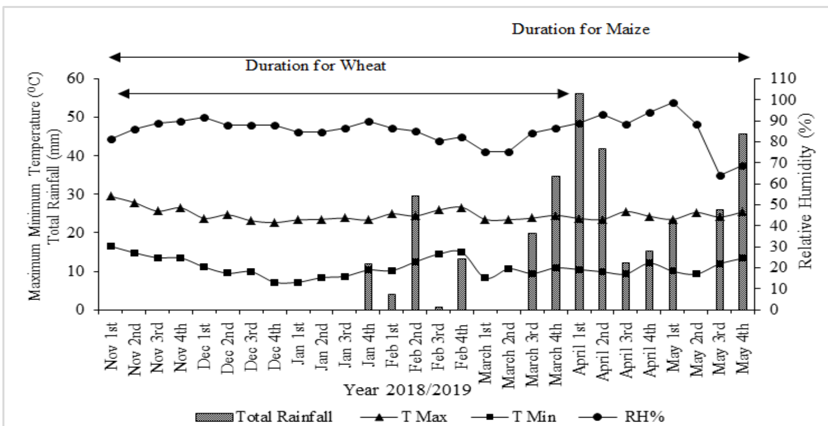

Fig. 1: Minimum and maximum daily temperature (°C), daily rainfall (mm) and daily relative humidity during the experimental period at Rampur, Chitwan, Nepal, 2019 (Source: NMRP, 2019)

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.

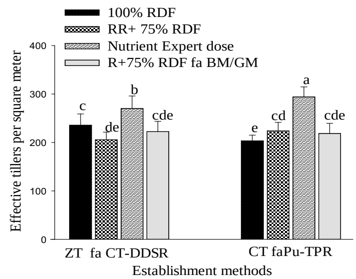

Fig. 2: Number of effective tillers per m^2 at the time harvest of wheat as influenced by the interaction of establishment methods and nutrient management at Rampur, Chitwan, 2018-19.

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.

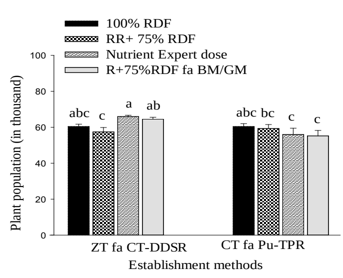

Fig. 3: Final plant population of maize as influenced by the interaction of establishment methods and nutrient management at Rampur, Chitwan, 2018-19

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.

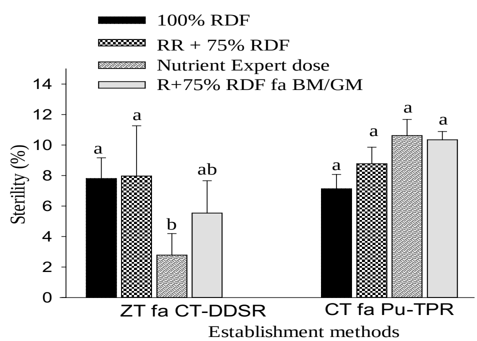

Fig. 4: Sterility of maize as influenced by the interaction of establishment methods and nutrient management at Rampur, Chitwan, 2018-19

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).

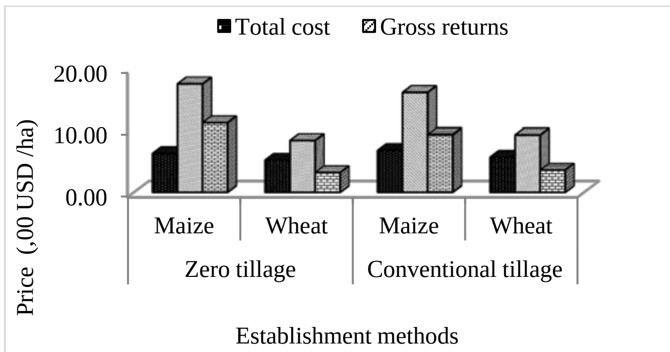

Fig. 5: total cost, gross and net returns of wheat and maize under different establishment methods

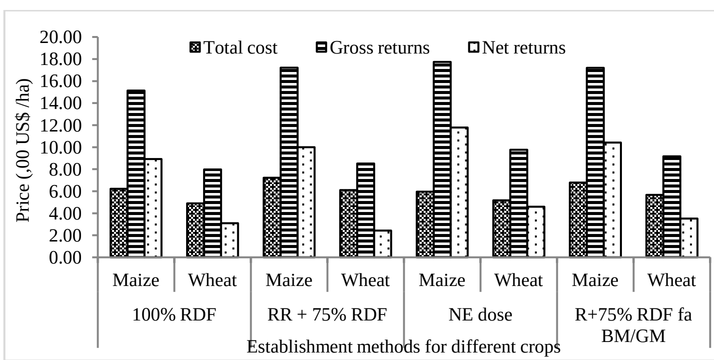

Fig. 6: Total cost, gross and net returns (,00 USD /ha) of wheat and maize under different nutrient management practices.

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).

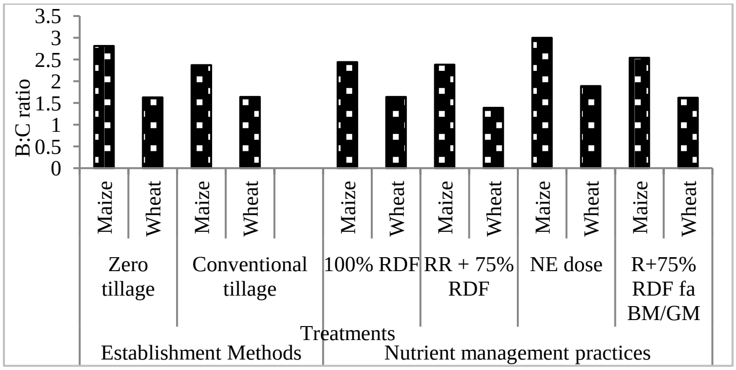

Fig. 7: Total cost, gross and net returns (,00 USD /ha) of wheat and maize under different nutrient management practices

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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