Micronutrient uptake in wheat as affected by long term zero tillage and different moisture regimes in legume based cropping systems of north-western Indo-gangetic plains

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Abstract

A field experiment “Micronutrient uptake in wheat as affected by long term zero tillage and different moisture regimes in legume based cropping systems of north-western Indo-Gangetic Plains was conducted during 2017-18 and 2018-19 on an on-going long term experiment on ‘Effect of varying moisture regimes in zero-till wheat succeeding mungbean and sorghum’ since 2006 at, CCS HAU, Hisar.

The experiments consisted of two cropping systems (mungbean-wheat, MW and sorghum-wheat, SW), three tillage practices viz. CT-CT (conventional tillage in both kharif & rabi seasons), CT-ZT (conventional tillage in kharif & zero tillage in rabi seasons) and ZT-ZT (zero tillage in both kharif & rabi seasons); and three moisture regimes (IW/CPE = 0.60 (M0.60), 0.75 (M0.75) and 0.90 (M0.90)).

The adoption of ZT-ZT practice increased uptake of micronutrients (Fe, Mn, Zn and Cu) as compared to CT-ZT and CT-CT practices in all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems. The uptake of Fe was significantly higher in mungbean-wheat cropping system (16.56 and 21.19%) as compared to sorghum-wheat cropping system by grain and straw, respectively. It was significantly higher in ZT-ZT (38.49 and 34.34; 35.16 and 19.53%) and CT-ZT (23.22 and 10.95 and 17.37 and 6.69%) as compared to CT-CT over all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. In present study, uptake of Fe was significantly higher at M0.60 (16.60 and 13.59; and 15.71 and 12.74%) and M0.75 (8.70 and 5.87; and 6.06 and 4.98%) as compared to M0.90 over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. The similar trends were observed for uptake of Mn, Zn and Cu by the wheat grain and straw. Therefore long term zero tillage with inclusion of legumes can be a promising alternative to sustainably increase uptake of micronutrients in soil for cereal-cereal cropping systems which ultimately plays a pivotal role to sustain the crop productivity and optimum ecosystem functioning with improving soil health.

Keywords: Zero tillage, moisture regimes, legumes, soil health, sustainability, micronutrient uptake

Introduction

In the beginning zero tillage practice was aimed to conserve soil, water, to reduce cost of production (Holland 2004). Beyond this, the practice has multiple benefits in increasing the overall system performance (Kakraliya et al. 2018). Due to conventional production practices, the sustainibility of cereal-cereal cultivation systems in the IGP of India is at risk. In recent years, water, energy and labour scarcity, the increasing production costs, decreasing farm profitability and variability caused by climate change are major challenges facing farmers in India's Indo-Gangetic Plains (IGP). Wheat is India's second most important cereal crop after rice, occupying an area of 31.2 million ha and producing 95.8 million tonnes. For better crop production, the common perception among farmers is to plough the soil 2-3 times after harvesting the rainy season crops. This has, however, contributed to the growth of hard-pan and low efficiency of input use (Das et al. 2014). Therefore, conventional production practices need to be enhanced or replaced with resource-conserving technologies (RCTs) by repeated ploughing adopted in wheat under the rice-wheat or maize-wheat cropping system to adapt to evolving climate changes and to increase productivity and farm profitability and soil health on a sustainable basis (Ladha et al. 2014).

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It's necessary to increase crop production on a sustainable basis while keeping resources like the environment and our resources for food sources. In India, the cradle of the Green Revolution, the Indo-Gangetic Plains (IGP) covers about 20% and 27% of the total geographical and net cultivated area, respectively, and produces about half of the food consumed in the country (Dhillon et al., 2010; Das et al., 2018) [11, 9]. By 2050, the world’s population will be over 9 billion and 37% will live in China and India, requiring an expected 59% to 98% increase in food demand, putting more pressure on natural resources. India will have to double its cereal production to feed the 1.6 billion people of India by 2050 (Swaminathan and Bhavani, 2013) [30]. The challenge is to reach this aim with less resources and with a lower environmental footprint while buffering the risks of climate variability to ensure long-term sustainability. Over the next 50 years, five of the top ten issues facing humanity (i.e. food, electricity, water, the atmosphere and poverty) are directly linked to soil health. The growing concern for food security by improved soil management practices therefore calls for the adoption of conservation agriculture. Conservation agriculture is a resource-saving system for agricultural crop production that, in this era of climate change, aims to offer equal benefits along with high and sustainable levels of production while at the same time protecting the environment (FAO, 2010) [14]. Several studies have shown that we can increase the nutrient uptake by crops by introducing zero tillage systems (Powlson et al. 2012) [26]. Zero tillage method has major effect on nutrient availability to the crops and uptake by the plants. In zero tillage, nutrients near the soil surface increased and hence uptake by plants also increased (Bhatt et al., 2016) [2]. In the literature, there’s far less attention given to the effect of tillage on plant nutrient uptake as compared to other properties of soil. Tillage increases the decomposition of crop residues because it facilitates nutrient supply and enables closer interaction between plant tissue and soil aggregate surfaces, the primary biome of soil microbes (Bronick and Lal 2005) [3]. In addition, avoiding soil disturbance in zero tillage protect the soils and improve the preservation of carbon, thereby increasing availability and uptake of essential nutrients in the soil (Corbeels et al. 2006) [9]. Sustainable intensification of cereal (rice/maize/pearl millet) systems focused on conservation agriculture (CA) integrated with mungbean enhanced soil organic carbon and chemical properties (Choudhary et al., 2018) [4]. Legumes with their inherent characteristics such as leaf dropping, deep root, biological N fixation, and greater root exudate release enhance soil health (Hazra et al., 2018; Kakraliya et al. 2018a)) [16, 18]. In wheat after mungbean, the enhanced carbon and other nutrient concentration improve the soil’s overall consistency (Singh et al. 2015). The inclusion of legumes in cereal-cereal rotation shifts the balance of nutrient input-output, nutrient and carbon input through non-harvested crop residues (root carbon) that are likely to impact long-term productivity (Hazra et al., 2014) [17]. The use of legume crops and zero tillage systems has been shown to greatly reduce the risk of soil erosion (Lentz and Bjorneberg, 2003) [23]. Good soil health plays a pivotal role to sustain the crop productivity and optimum ecosystem functioning. Improved soil aggregation and higher soil organic carbon (SOC) stock are the essential components of good soil health (Denef et al., 2001) [10]. In fact, land use pattern and crop management practices have a differential influence on soil carbon and aggregate dynamics (Pinheiro et al., 2004) [25]. The rate of N and P uptake by wheat, sown after pearl millet was significantly at par to each other and significantly higher than that of pearl millet, sown after cowpea and cluster bean (Singh et al., 2003) [28]. The N uptake was higher by 16.7 and 13.1 percent and P uptake by 22.2 and 16.5 percent when cowpea and cluster bean were grown after wheat, respectively, compared to pearl millet. In the research conducted by Balyan (1997) [1], wheat grown after legume crop either alone or as an intercrop during kharif was observed to have higher N uptake than wheat grown after pearl millet alone. Irrigation scheduling based on IW/CPE improved nitrogen absorption by grains. According to Singh and Singh (2001) [29], the higher content of nitrogen in the treatment resulted in lower protein. The amount of the nutrient absorption by crops increased with the rise in the irrigations (Dhindwal et al., 1993) [12]. Therefore, location-specific management practices are required in tillage and residue management practices suitable to varying soils, crops, and climatic conditions.

Material and Methods

Study site characteristics

The present investigation was carried out at an on-going long-term experiment at Soil Research Farm, Department of Soil Science, CCS HAU, Hisar. The coordinates of the experimental site is 29.10°N, 75.46°E and at an altitude of 215.2 meters above mean sea level. The experimental soil was sandy loam (71.5% sand, 9.3% silt and 19.2% clay) and slightly alkaline, low in organic carbon content, low in available potassium (Kumar, 2008) [24]. The present investigation was therefore conducted to tackle this issue.

Treatments and experimental design

The experiment was carried out with two main-plot treatments, viz. (i) Mungbean-wheat and, (ii) Sorghum-wheat
cropping systems and with three sub-plot treatments viz. (i) Conventional tillage in both kharif & rabi seasons, (ii) conventional tillage in kharif & zero tillage in rabi seasons and, (iii) zero tillage in both kharif & rabi along with three sub-sub-plot treatments of soil moisture regimes viz., IW/CPE of 0.60, 0.75 & 0.90. The experimental design was split-split-plot and replicated thrice in CT-CT plots, the fields were ploughed during both kharif and rabi seasons. In CT-ZT plots, the fields were ploughed during kharif only and no tillage was done during rabi season. In ZT-ZT plots, no tillage was done during both the kharif and rabi seasons. In CT practice, the residues of the preceding crop i.e. wheat/mungbean/sorghum were manually removed, and seed bed tilled for wheat/mungbean/sorghum was prepared by two disc to about 10 cm followed by planking (leveling with a 3 m long wooden block) of the fields. In plots with ZT practice, the crop was harvested and no tillage was done for preparation of seed bed for the succeeding crop, and crop was sown with zero till machine. The wheat (WH 1105) was sown on November 23, 2017 during 2017-18 and on November 25, 2018 during 2018-19. The wheat was harvested on 25 April 2018 during 2017-18 and on 24 April 2019 during 2018-19.

Measurement for uptake of micronutrients by the Crop
The uptake of micro-nutrients (Fe, Mn, Zn and Cu) by the grain and straw of the wheat crop for both the years i.e. 2017-18 and 2018-19 (data has been showed as pooled of both years in results) was obtained by multiplying the nutrient concentration in grain and straw with their respective yield using the following formula:

\[ \text{Nutrient uptake (kg ha}^{-1}) = \text{Nutrient concentration in grain/straw} \times \text{yield (kg ha}^{-1})/100 \]

Statistical analysis
Data were exposed to analysis of variance for split-split plot design to know the significant difference among the treatments. Least significant difference values were used to compare the treatments means at p= 0.05 using OPSTAT software (Sheoran et al., 1998) [27].

Results and Discussion
Fe uptake: The ZT-ZT practice increased uptake of Fe as compared to CT-ZT and CT-CT practices in all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems (Table 1). The uptake of Fe was significantly higher in mungbean-wheat cropping system (16.56 and 21.19%) as compared to sorghum-wheat cropping system by grain and straw, respectively. It was significantly higher in ZT-ZT (38.49 and 34.34; 35.16 and 19.53%) and CT-ZT (23.22 and 10.95 and 17.37 and 6.69%) as compared to CT-CT over all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. In present study, uptake of Fe was significantly higher at M0.90 (16.60 and 13.59; and 15.71 and 12.74%) and M0.75 (8.70 and 5.87; and 6.06 and 4.98%) as compared to M0.60 over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. The uptake of Fe by grain was lower as compared to straw of wheat. The interactive effects of cropping system and tillage; cropping system and moisture regimes; and cropping system, tillage and moisture regimes was found significant for Fe uptake by grain and straw in wheat whereas, interactive effect of tillage and moisture regimes was significant in case of straw not in grain. This higher uptake of Fe by wheat grain and straw occurred due to more availability of nutrients, as a result grain and straw yield was higher and consequently Fe uptake was increased under zero tillage. More crop residues under zero tillage caused high soil organic matter and favourable soil environmental conditions. Higher moisture regimes and legume based cropping system had more organic matter, therefore more Fe uptake was in case of mungbean-wheat cropping system as compared to sorghum-wheat cropping system. These results are in accord with the findings of Gupta and Seth (2007) [15] and Mukherjee (2008) [24]. More organic residues on the surface caused more root growth and resulted in increased uptake of nutrients by crops (Thiagalingam et al., 1991) [31]. These results are in agreement with the results of Dwivedi and Thakur (2000) [13], and Das et al. (2001) [8]. The nutrient uptake by crop increased with the increase moisture regimes mainly owing to higher yield (Dhindwal et al., 1993) [12]. The increase in Fe uptake was more due to higher yield under zero tillage and in mungbean-wheat system at higher moisture regimes and these results is consistent with the results of Singh et al. (2003) [28] and Kumar et al. (2000) [20].

| Moisture Regime (IW/CPE) | Sorghum-Wheat | Mungbean-Wheat |
|--------------------------|---------------|----------------|
|                          | Grain Mean    | CT-CT          |
|                          |               | CT-ZT          |
|                          |               | ZT-ZT          |
| M0.60                    | 17.32         | 19.55          |
| M0.75                    | 18.74         | 21.31          |
| M0.90                    | 21.42         | 22.86          |
| Mean                     | 19.13         | 21.23          |
| CD (p=0.05)              | A=1.06, B=0.44, A x B= 0.62, C=0.42, A x C= 0.60, B x C= NS, A x B x C=1.03 |

Table 1: Effect of long-term zero tillage on Fe uptake (kg ha$^{-1}$) by grain and straw at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Mn uptake: Uptake of Mn by grain and straw as affected by long term zero tillage in wheat under different moisture regimes in mungbean-wheat and sorghum-wheat cropping systems are presented in Table 2. The uptake of Mn was significantly higher in mungbean-wheat cropping system (24.64 and 25.66%) as compared to sorghum-wheat cropping...
system by grain and straw, respectively. It was significantly higher in ZT-ZT (70.41 and 62.08; 46.32 and 26.29%) and CT-ZT (41.04 and 21.06 and 24.56 and 9.84%) as compared to CT-CT over all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. In present study, uptake of Mn was significantly higher at M$_{0.90}$ (21.76 and 19.20; and 20.31 and 17.69%) and M$_{0.75}$ (12.78 and 10.35; and 9.33 and 7.66%) as compared to M$_{0.60}$ over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. The uptake of Mn by grain was lower as compared to straw of wheat. The interactive effects of cropping system and tillage and cropping system and moisture regimes was observed significant for Mn uptake by grain and straw in wheat whereas, interactive effects of tillage and moisture regimes; and cropping system, tillage and moisture regimes were found significant for Mn uptake by grain and non-significant by straw in wheat. This higher uptake of Mn by wheat grain and straw occurred due to more availability of nutrients, as a result grain and straw yield was higher and consequently Mn uptake was increased under zero tillage. More crop residues under zero tillage caused high soil organic matter and favourable soil environmental conditions. Higher moisture regimes and legume based cropping system had more organic matter; therefore more Mn uptake was in case of mungbean-wheat cropping system as compared to sorghum-wheat cropping system. These results are in accord with the findings of Gupta and Seth (2007) [15] and Mukherjee (2008) [24]. The increase in Mn uptake was more due to higher yield under zero tillage and in mungbean-wheat system at higher moisture regimes and these results is consistent with the results of Singh et al. (2003) [28] and Balyan (1997) [1].

Table 2: Effect of long-term zero tillage on Mn uptake (kg ha$^{-1}$) by grain and straw at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

| Moisture Regime (IW/CPE) | Sorghum-Wheat | Mean | Mungbean-Wheat | Mean |
|--------------------------|----------------|------|----------------|------|
|                          | CT-CT | CT-ZT | ZT-ZT          | CT-CT | CT-ZT | ZT-ZT |
| Grain                    |       |       |                |       |       |       |
| M$_{0.60}$               | 7.66  | 9.43  | 13.33          | 10.01 | 9.19  | 12.91 |
| M$_{0.75}$               | 8.37  | 10.73 | 14.44          | 11.04 | 10.01 | 14.62 |
| M$_{0.90}$               | 10.11 | 11.42 | 14.46          | 11.93 | 11.12 | 15.24 |
| Mean                     | 8.68  | 10.51 | 14.07          | 10.98 | 10.09 | 14.24 |
| CD (p=0.05)              | A=0.355, B=0.215, A x B= 0.303, C=0.177, A x C= 0.250, B x C= 0.306, A x B x C=0.433 |
| Straw                    |       |       |                |       |       |       |
| M$_{0.60}$               | 24.01 | 26.45 | 30.80          | 27.03 | 27.24 | 34.15 |
| M$_{0.75}$               | 26.08 | 28.77 | 32.60          | 29.10 | 29.48 | 37.54 |
| M$_{0.90}$               | 28.55 | 31.16 | 35.91          | 31.81 | 33.10 | 40.16 |
| Mean                     | 26.19 | 28.76 | 33.07          | 29.28 | 29.90 | 37.24 |
| CD (p=0.05)              | A=1.51, B=0.78, A x B= 1.10, C=0.55, A x C= 0.78, B x C= NS, A x B x C=NS |

Zn uptake: The adoption of long term zero tillage practice increased uptake of Zn as compared to conventional tillage in all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems (Table 3). The uptake of Zn was significantly higher in mungbean-wheat cropping system (17.51 and 22.15%) as compared to sorghum-wheat cropping system by grain and straw, respectively. It was significantly higher in ZT-ZT (54.67 and 45.99; 41.39 and 23.43%) and CT-ZT (28.94 and 15.58 and 20.24 and 8.23%) as compared to CT-CT over all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. In present study, uptake of Zn was significantly higher at M$_{0.90}$ (19.69 and 17.48; and 17.20 and 13.09%) and M$_{0.75}$ (10.56 and 7.31; and 8.18 and 5.52%) as compared to M$_{0.60}$ over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. The uptake of Zn by grain was lower as compared to straw of wheat. The interactive effects of cropping system and tillage; and cropping system and moisture regimes were found significant for Zn uptake by grain and straw in wheat. The increase in Mn uptake was more due to higher yield under zero tillage and in mungbean-wheat system at higher moisture regimes. Singh et al. (2003) [28] and Balyan (1997) [1] reported the same results.

Table 3: Effect of long-term zero tillage on Zn uptake (kg ha$^{-1}$) by grain and straw at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

| Moisture Regime (IW/CPE) | Sorghum-Wheat | Mean | Mungbean-Wheat | Mean |
|--------------------------|----------------|------|----------------|------|
|                          | CT-CT | CT-ZT | ZT-ZT          | CT-CT | CT-ZT | ZT-ZT |
| Grain                    |       |       |                |       |       |       |
| M$_{0.60}$               | 10.86 | 12.68 | 17.16          | 13.57 | 12.14 | 16.13 |
| M$_{0.75}$               | 11.94 | 14.09 | 17.65          | 14.56 | 13.36 | 17.46 |
| M$_{0.90}$               | 13.76 | 15.49 | 18.56          | 15.94 | 14.99 | 18.63 |
| Mean                     | 12.19 | 14.09 | 17.79          | 14.69 | 13.50 | 17.40 |
| CD (p=0.05)              | A=0.46, B=0.25, A x B= 0.35, C=0.23, A x C= 0.33, B x C= NS, A x B x C=0.57 |
| Straw                    |       |       |                |       |       |       |
| M$_{0.60}$               | 13.08 | 14.19 | 16.40          | 14.56 | 14.36 | 17.64 |
| M$_{0.75}$               | 13.82 | 15.18 | 17.09          | 15.36 | 15.54 | 18.65 |
| M$_{0.90}$               | 15.05 | 16.04 | 18.30          | 16.46 | 17.11 | 20.23 |
| Mean                     | 13.99 | 15.14 | 17.26          | 15.46 | 15.67 | 18.84 |
| CD (p=0.05)              | A=0.18, B=0.34, A x B= 0.48, C=0.29, A x C= 0.41, B x C= NS, A x B x C=NS |

CT = conventional tillage, ZT = zero tillage, M$_{0.60}$ = moisture regime at IW/CPE=0.60, M$_{0.75}$= moisture regime at IW/CPE= 0.75, M$_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor


**Cu uptake**

Uptake of Cu by grain and straw as affected by long term zero tillage in wheat under different moisture regimes in mungbean-wheat and sorghum-wheat cropping systems are presented in Tables 4. The adoption of ZT-ZT practice increased uptake of Cu as compared to CT-ZT and CT-CT practices in all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems. The uptake of Cu was significantly higher in mungbean-wheat cropping system (17.56 and 22.16%) as compared to sorghum-wheat cropping system by grain and straw, respectively. It was significantly higher in ZT-ZT (49.34 and 42.31; 34.49 and 18.47%) and CT-ZT (26.48 and 13.60 and 17.26 and 6.63%) as compared to CT-CT over all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. In present study, uptake of Cu was significantly higher at M0.90 (16.46 and 14.11; and 13.49 and 11.70%) and M0.75 (8.65 and 6.21; and 5.90 and 4.20%) as compared to M0.60 over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems by grain and straw, respectively. The uptake of Cu by grain was lower as compared to straw of wheat. The interactive effects of cropping system and tillage; and cropping system and moisture regimes were observed significant for grain and straw whereas, tillage and moisture regimes interactive effect was non-significant for grain and straw. This higher uptake of Cu by wheat grain and straw occurred due to more grain and straw yield and consequently Cu uptake was increased under zero tillage. More crop residues under zero tillage caused high soil organic matter and favourable soil environmental conditions. Higher moisture regimes and legume based cropping system had more yield, therefore more Cu uptake was in case of mungbean-wheat cropping system as compared to sorghum-wheat cropping system. These results are in accord with the findings of Gupta and Seth (2007) [15] and Mukherjee (2008) [24]. These results are in agreement with the results of Das et al. (2001) [8]. The nutrient uptake by crop increased with the increase moisture regimes mainly owing to higher yield (Dhindwal et al., 1993) [16]. The increase in Cu uptake was more due to higher yield under zero tillage and in mungbean-wheat system at higher moisture regimes and these results are consistent with the results of Singh et al. (2003) [28].

**Conclusion**

The results from the present investigation concluded that long term zero tillage practices had potential to enhance micronutrient uptake in wheat under mungbean-wheat and sorghum-wheat cropping systems. The results also concluded that legume based cropping system is better as compared to non-legume based cropping system at different moisture regimes in arid and semi-arid climatic conditions in sandy loam soils. Adoption of long term zero tillage in wheat and inclusion of legumes in the cropping systems would be beneficial for improving the soil health on sustainable basis and consequently micronutrient uptake in wheat of north-western Indo-Gangetic Plains.

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**References**

1. Balyan JS. Production potential and nitrogen uptake by succeeding wheat (*Triticum aestivum*) under different cropping sequences. Indian Journal of Agronomy 1997;42:250-252.

2. Bhatt R, Kukal SS, Busari MA, Arora S, Yadav M. Sustainability issues on rice–wheat cropping system. International Soil and Water Conservation Research 2016;4:64-74.

3. Bronck IC, Lal R. Soil structure and management: A review, Geoderma 2005;124, 1

4. Choudhary Madhu, Jat Hanuman S, Datta Ashim, Yadav Arvind K, Sapkota Tek B, Mondal Sandip et al. Sustainable intensification influences soil quality, biota, and productivity in cereal-based agroecosystems. Applied Soil Ecology 2018, S0929139317313136-. doi:10.1016/j.apsoil.2018.02.027.

5. Corbeels M, Scopel E, Cardoso A et al. Soil carbon storage potential of direct seeding mulch-based cropping systems in the Cerrados of Brazil. Glob Chang Biol 2006;12:1773-1787. doi:10.1111/j.1365-2486.2006.01233.x

6. Das TK, Bhattacharyya R, Sudhishri S, Sharma AR, Saharawat YS, Bandopadhyay KY et al. Conservation agriculture in an irrigated cotton–wheat system of the western Indo-Gangetic Plains: crop and water productivity and economic profitability. Field Crop Res 2014;158:24-33 2.
7. Das A, Ghosh PK, Lal R, Saha R, Ngachan S. Soil quality effect of conservation practices in maize rapeseed cropping system in eastern Himalaya. Land Degradation and Development 2014, DOI: 10.1002/dd.2325.
8. Das DK, Medhi DN, Guha B. Recycling effect of crop residues with chemical fertilizers on physico-chemical properties of soil and rice (O. sativa) yield. Indian Journal of Agromony 2001;46(4):648-653.
9. Das TK, Saharawat YS, Bhattacharyya R, Sudhishri S, Bandyopadhyay KK, Sharma AR et al., Conservation agriculture effects on crop and water productivity, profitablity and soil organic carbon accumulation under a maize- wheat cropping system in the North-western Indo-Gangetic Plains. Field Crop Res 2018:215:222-231.
10. Deneff K, Six J, Paustian K, Merckx R. Importance of macro aggregate dynamics in controlling soil carbon stabilization: short-term effects of physical disturbance induced by dry-wet cycles. Soil Biol. Biochm 2001;33:2145-2153.
11. Dhillon BS, Kataria P, Dhillon PK. National food security vis-à-vis sustainability of agriculture in high crop productivity regions. Curr. Sci 2010;98:33-36.
12. Dhindwal AS, Jagdev Singh, Poonia SR. Irrigation needs of field crops under shallow water table conditions. In: Proc. of National Workshop on Crop and Water Use. March 10-13, WALMI, Lucknow, India 1993.
13. Dwivedi DK, Thakur SS. Production potential of wheat (Triticum aestivum L.) crop as influenced by residual organics, direct and residual fertility levels under rice (Oryza sativa)-wheat cropping system. Indian Journal of Agronomy 2000;45(4):641-647.
14. FAO. What is conservation agriculture 2010. FAO CS website http://www.fao.org/ag/ca/1a.html. Accessed on 13/08/2019.
15. Gupta R, Seth A. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains (IGP). Crop Protection 2007;26:436-447.
16. Hazra KK, Singh SS, Nath CP, Borase DN, Kumar N, Parihar AK et al. Adaptation mechanisms of winter pulses through rhizospheric modification in mild-alkaline soil. National Academy Science Letters 2018;41:193-196.
17. Hazra KK, Venkatesh MS, Ghosh PK, Ganeshamurthy AN, Kumar N, Nadarajan N et al. Long-term effect of pulse crops inclusion on soil-plant nutrient dynamics in puddled rice (Oryza sativa L.) wheat (Triticum aestivum L.) cropping system on an Inceptisol of Indo-Gangetic plain zone of India. Nutrient Cycling in Agro ecosystem 2014;100:95-110.
18. Kakrliya SK, Singh U, Bohra A, Choudhary KK, Kumar S, Meena RS et al. Nitrogen and legumes: A meta-analysis, in Legumes for Soil Health and Sustainable Management, eds R Meena, A Das, G Yadav, and R Lal (Singapore: Springer) 2018a, 277-314. doi: 10.1007/978-981-13-02534-9
19. Kakrliya SK, Jat HS, Singh I, Sapkota TK, Singh LK, Sutaliya JM et al. Performance of portfolios of climate smart agriculture practices in a rice-wheat system of western Indo-Gangetic plains. Agricultural Water Management 2018;202:122-133.
20. Kumar R, Singh G, Walia SS. Long-term effect of manures and fertilizers on rice yield and soil fertility status in rice-wheat system. Environment and Ecology 2000;18(3):546-549.
21. Kumar S. Effect of varying moisture regimes in zero-till wheat succeeding moong and sorghum and simulation of crop growth models, Ph.D. Thesis, Department of Agronomy, CCS HAU, Hisar 2008.
22. Ladha JK, Kumar V, Alam MM, Sharma S, Gathala M, Chandna P et al., Integrating crop and resource management technologies for enhanced productivity, profitablity, and sustainability. In: Ladha JK, Singh Y, Erenstein O, Hardy B. (Eds.), Integrated Crop and Resource Management in the Rice–Wheat System of South Asia. International Rice Research Institute, Los Bahos, Philippines 2014, 69-108.
23. Lentz RD, Bjorneberg DL. Polyacrylamide and straw residue effects on irrigation furrow erosion and infiltration. J Soil Water Conserv 2003;58:312-319.
24. Mukherjee D. Effect of tillage practices and fertility levels on the performance of Wheat (Triticum aestivum) under mid hill condition of West Bengal. Indian Journal of Agricultural Sciences 2008;78(12):1038-1041.
25. Pinheiro EFM, Pereira MG, Anjos LHC. Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Lat 2004.
26. Powlson DS, Bhogal A, Chambers BJ, Coleman K, Macdonald AJ. The potential to increase soil carbon stocks through reduced tillage or organic material additions in England and Wales: A case study. Agricultural Ecology and Environment 2012;146:23-33.
27. Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. In: Hooda DS, Hasija RC. (Eds.), Statistical Software Package for Agricultural Research Workers. Recent Advances in Information Theory, Statistics & Computer Applications. Department of Mathematics Statistics, CCS HAU, Hisar 1998, 139-143.
28. Singh J, Singh KP, Yadav SS, Yadav JS. Effect of preceding crops and fertility levels on wheat (Triticum aestivum) in light-textured soil. Indian Journal of Agronomy 2003;48:86-88.
29. Singh M, Singh VP, Reddy KS. Effect of integrated use of fertilizer nitrogen and farmyard manure or green manure on transformation of N, K and S, and productivity of rice-wheat system on a vertisol. Journal of the Indian Society of Soil Science 2001;49:430-435.
30. Swaminathan MS, Bhavani RV. Food production & availability- Essential prerequisites for sustainable food security. Indian J Med Res 2013;138:383-91.
31. Thiagalingam K, Gould N, Watson P. Effect of tillage on rainfed maize and soybean yield and the nitrogen fertilizer requirements for maize. Soil & Tillage Research 1991;19:47-54.