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Mamta Phogat
Department of Soil Science, CCS Haryana Agricultural University Hisar, Haryana, India

Rita Dahiya
Department of Physics, CCS Haryana Agricultural University Hisar, Haryana, India

PS Sangwan
Department of Soil Science, CCS Haryana Agricultural University Hisar, Haryana, India

SK Kakraliya
Central Soil Salinity Research Institute, Karnal, Haryana, India

Vishal Goyal
Department of Soil Science, CCS Haryana Agricultural University Hisar, Haryana, India

M Santhosh Kumar
Department of Soil Science, CCS Haryana Agricultural University Hisar, Haryana, India

Sunil Kumar
Department of Soil Science & Agricultural Chemistry, Swami Keshwanand Rajasthan Agriculture University, Bikaner, Rajasthan, India

Corresponding Author:
Mamta Phogat
Department of Soil Science, CCS Haryana Agricultural University Hisar, Haryana, India

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

Mamta Phogat, Rita Dahiya, PS Sangwan, SK Kakraliya, Vishal Goyal, M Santhosh Kumar and Sunil Kumar

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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 $M_{0.90}$ (16.60 and 13.59; and 15.71 and 12.74%) and $M_{0.75}$ (8.70 and 5.87; and 6.06 and 4.98%) 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 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) [19]. Due to conventional production practises, the sustainability 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) [6, 7]. Therefore, conventional production practises 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) [22].

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 practises 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) [5]. Sustainable intensification of cereal (rice/maize/pearlmillet) 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.

Our study goal was to research how nutrient uptake in wheat is affected by long term zero tillage and different moisture regimes in cereal-cereal based cropping systems of north-western Indo-Gangetic Plains. In evaluating its suitability for crop production, the properties of a soil play a significant role. Properties of soil including support strength, soil air space or root penetration, microbial properties, nutrient availability, nutrient uptake and water use efficiency are all closely connected with each other. There is a lot of literature available on the impact of zero tillage practises on soil chemical properties but there is little knowledge on the combined effect of zero tillage adoption and the introduction of legumes into the cropping system and moisture regimes on chemical properties of soil in various cropping systems. It was hypothesised that, for a few uninterrupted years, the adoption of zero tillage in the agricultural production system in general and in wheat, particularly with different crop rotations, might significantly improve the soil macro- and micronutrient, eventually affecting sustainability of the system. The present investigation was therefore conducted to tackle this issue.

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 29.10^0N, 75.46^0E 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 classified as Typic Haplustepts. The experimental soil was slightly alkaline, low in organic carbon content, low in available nitrogen, medium in available phosphorus and high in available potassium (Kumar, 2008) [21]. The experimental site has a semi-arid climate with hot and dry summer and extremely cold winter. The mean monthly maximum and minimum temperature show a wide range of fluctuations during summer as well as winter seasons. The mean maximum and minimum temperature was 39.0 °C in May, 2018 and 12.4 °C in January, 2018 and 42.2 °C in May 2019 and 13.0 °C in February, 2019, respectively. Total rainfall received during study period was 29.9 mm and 44.1 mm from November, 2017 to April, 2018 and November, 2018 to April, 2019, respectively.

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 tilth 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:

Nutrient uptake (kg ha-1) = Nutrient concentration in grain/straw (%) × grain/straw 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 treatment 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 $M_{0.90}$ (16.60 and 13.59; and 15.71 and 12.74%) and $M_{0.75}$ (8.70 and 5.87; and 6.06 and 4.98%) 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 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].

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

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	CT-ZT	ZT-ZT		CT-CT	CT-ZT	ZT-ZT	
Grain								
$M_{0.60}$	17.32	19.55	25.29	20.66	19.56	24.31	27.21	23.65
$M_{0.75}$	18.74	21.31	25.66	21.87	21.28	26.31	29.64	25.71
$M_{0.90}$	21.42	22.86	26.15	23.46	23.08	28.16	31.69	27.58
Mean	19.13	21.23	25.70	21.98	21.29	26.24	29.49	25.62
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							
Straw								
$M_{0.60}$	157.12	168.57	192.82	172.70	173.32	209.59	237.94	206.70
$M_{0.75}$	166.18	179.55	198.50	181.30	186.97	220.95	250.37	219.21
$M_{0.90}$	181.69	190.57	212.14	194.70	206.44	234.35	277.64	239.17
Mean	168.23	179.49	201.09	182.82	188.76	221.54	255.13	221.55
CD (p= 0.05)	A=10.33, B=5.22, A x B= 7.39, C=2.15, A x C= 3.05, B x C= 3.74, A x B x C=5.28							

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

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	15.15	12.29
$M_{0.75}$	8.37	10.73	14.44	11.04	10.01	14.62	17.49	13.86
$M_{0.90}$	10.11	11.42	14.46	11.93	11.12	15.24	19.08	14.97
Mean	8.68	10.51	14.07	10.98	10.09	14.24	17.20	13.69
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	39.59	33.53
$M_{0.75}$	26.08	28.77	32.60	29.10	29.48	37.54	43.54	36.66
$M_{0.90}$	28.55	31.16	35.91	31.81	33.10	40.16	48.32	40.34
Mean	26.19	28.76	33.07	29.28	29.90	37.24	43.75	36.79
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							

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

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	18.76	15.68
$M_{0.75}$	11.94	14.09	17.65	14.56	13.36	17.46	21.19	17.33
$M_{0.90}$	13.76	15.49	18.56	15.94	14.99	18.63	22.68	18.77
Mean	12.19	14.09	17.79	14.69	13.50	17.40	20.88	17.26
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	20.24	17.41
$M_{0.75}$	13.82	15.18	17.09	15.36	15.54	18.65	22.33	18.84
$M_{0.90}$	15.05	16.04	18.30	16.46	17.11	20.23	23.89	20.41
Mean	13.99	15.14	17.26	15.46	15.67	18.84	22.15	18.89
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 $M_{0.90}$ (16.46 and 14.11; and 13.49 and 11.70%) and $M_{0.75}$ (8.65 and 6.21; and 5.90 and 4.20%) 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 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) [12]. 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].

Table 4: Effect of long-term zero tillage on Cu 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								
$M_{0.60}$	1.88	2.17	2.87	2.31	2.12	2.74	3.15	2.67
$M_{0.75}$	2.03	2.36	2.96	2.45	2.30	2.90	3.51	2.90
$M_{0.90}$	2.32	2.54	3.03	2.63	2.51	3.13	3.69	3.11
Mean	2.08	2.36	2.95	2.46	2.31	2.92	3.45	2.90
CD (p= 0.05)	A=0.064, B=0.061, A x B= 0.086, C=0.044, A x C= 0.063, B x C= NS, A x B x C=0.108							
Straw								
$M_{0.60}$	8.23	8.82	10.01	9.02	9.10	11.01	12.52	10.88
$M_{0.75}$	8.64	9.30	10.24	9.40	9.85	11.64	13.08	11.52
$M_{0.90}$	9.41	9.91	10.89	10.07	10.73	12.15	14.31	12.40
Mean	8.76	9.34	10.38	9.49	9.89	11.60	13.30	11.60
CD (p= 0.05)	A=0.201, B=0.122, A x B= 0.173, C=0.161, A x C= 0.228, 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

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. Aadoption 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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