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Assessment of conservation agriculture and intercropping practices for enhanced productivity and profitability in maize (*Zea mays*)

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ABSTRACT

A field experiment was conducted to study the effect of tillage and intercropping on yield, net returns and weed density in maize (*Zea mays* L.) at ICAR-Indian Agricultural Research Institute, New Delhi during 2010, 2011 and 2012. The experiment was conducted in split-plot design with three replications. In main plots, tillage systems, viz. conventional tillage (CT), CT + residues at 3 t/ha, zero-tillage (ZT) and ZT+ residues at 3 t/ha were taken. In sub plots, intercropping systems such as sole maize, sole groundnut, maize + groundnut (1:1) and maize + groundnut (1:2) were taken. The results indicated that ZT + residue at 3 t/ha recorded the highest dry matter (DM) accumulation in maize at all the growth stages except 30 DAS followed by CT + residue at 3 t/ha over the years. The yield attributes such as number of gain rows/cob and number of grains/grain row were recorded highest in ZT + residue at 3 t/ha followed by CT + residue at 3 t/ha. The residue retention at 3 t/ha in ZT enhanced 25.3-28.9% grain yield in maize compared to CT over the years. ZT + residue at 3 t/ha recorded the highest net returns (49.8×10^3 ₹/ha) and B:C ratios (1.7) in maize. In 2010, weed population of broad-leaved weed (BLWs), narrow-leaved weed (NLWs) and total was recorded highest in ZT + residue at 3 t/ha. However, the population of BLWs and total increased in CT compared to ZT at the end of the study period. The intercropped system, viz. maize + groundnut in 1:1 and 1:2 recorded the lowest DM accumulation than the sole maize over the years. The number of grain rows/cob and number of grains/grain row were recorded highest in sole maize compared to intercropped maize. However, higher grain yield and net returns was found in maize + groundnut in 1:1 and 1:2 than sole maize. The intercropped maize + groundnut in 1:1 and 1:2 recorded the lowest population of BLWs, NLWs and total during the years.

Key words: Intercropped maize, Nutrient uptake, Weed population, Zero-tillage + residue

In India, maize (*Zea mays* L.) is the most important crop after rice and wheat. The maize crop is mainly grown during *kharif* season which covers 85% of the total area under maize. It occupies 9.43 million hectare (m ha) and production of 24.35 million tonnes (mt) with an average productivity of 2,583 kg/ha (FAO 2016). The contribution of maize crop is ~9% in to the total Indian food grain production. This crop has high potential and mainly used for feed (63%), food (23%) and industrial purpose (13%). However, the growth rate of maize is much behind the rice and wheat crop. The maize crop is vastly cultivated in rainfed ecologies with the less use of inputs under intensively tilled soil. The low fertility status of soil mainly low soil organic carbon and less availability of N are the major reasons for the low productivity of maize. The poor agronomic practices such as imbalance fertilization and high infestation of weeds under intensively cultivated soil with high erosion capacity are the main reason for the low productivity of maize (Sharma *et al*. 2014). The imbalance fertilization of N, P and K without considering other nutrients could restrain the yield potential of maize. The intensively tilled soil for maize production is not only enhances the cost of cultivation but also deteriorated the soil quality.

The conservation agriculture (CA) could be one of the options to enhance the crop productivity, profitability and soil health in long-run (FAO 2016). It has been reported that CA enhances the grain yield and net returns in zero-tillage wheat in Punjab and Haryana. Therefore, it has been widely promoted in rice-wheat cropping system in India (Bhan and Behera 2014). CA has three principles, viz. minimal disturbance of soil, permanent reside cover and diversified crop rotation (FAO 2016). Sepat and Rana (2013) reported that adoption of ZT in sandy loam soil enhanced the maize yield and net returns compared to CT. A lot has been reported on productivity and soil quality under rice-wheat cropping system with CA practices. However, the conclusive findings of CA on the yield and net returns enhancement in maize need to be investigated.

Intercropping with legume crops is another promising option for enhancing soil fertility and sustainable production of maize. The intercropping is the intensification of area

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in terms of land and time. The maize is widely spaced crop and provides an opportunity to grow short-duration crops such as oilseed and legume. The additional yield from the intercrops enhances the net returns without any additional use of inputs. Besides this, intercrop not only act as smother crop for weeds but also gives additional yield. Therefore, intercropping has potential in developing spatial and temporal advantages (Mahdi *et al*. 2012). Several studies indicated that maize intercropped with mungbean and groundnut produces higher yield and reduces weed population compared to sole maize (Ananthi *et al*. 2017). The inclusion of more competitive crops provides the soil cover and high plant density in intercropping which gives huge competitions to weed infestation and reduces weed biomass (Rajpoot *et al*. 2014). Intercropping reported to enhance N uptake than sole maize in conventional tillage systems. However, other studies reported that in intercropping the total N uptake reduced with the legume intercrop. The different tillage system can influence the N uptake in intercropping system. Likewise, the density of weed flora can be varied in CA based maize crop. The impact of intercropping on yield and weed density has not been studied in detail under CA. Similarly, nutrient uptake studies in intercropping system with different tillage system have not been studied in detail.

Therefore, to assess intercropping effects on yield, economics and broad leaved, narrow leaved and total weed density in maize under different tillage systems an experiment was conducted during 2010 to 2012.

MATERIALS AND METHODS

A field experiment was conducted at the farm of Division of Agronomy at ICAR-Indian Agricultural Research Institute (28^0 40^0 N, $77^0$12 E at an altitude of 228 masl), New Delhi during 2010, 2011 and 2012. The experimental site falls in the agro-climatic zone of “Trans Indo-Gangetic Plains”, having a sub-tropical and semi-arid climate, with hot summers and cold winters with mean annual maximum and minimum temperatures of 40.5° C and 6.5° C, respectively. The mean annual rainfall is 670 mm and its distribution is unimodal. Approximately 70–80% of rainfall is confined to three months from July to September. The quantity of rainfall received during the years of experimentation was 535 mm, 931 mm and 538 mm during 2010, 2011and 2012, respectively. The soil of the experimental field has a sandy loam texture up to 30 cm soil depth and can be classified as Typic Haplustept or Inceptisol. The surface soil layer of 0-15 cm has a neutral pH of 7.5, an organic C (Walkley and Black 1934) content of 0.32%, $KMnO_4$-oxidizable N (Subbiah and Asija 1956) of 172 kg/ ha, and $NaHCO_3$-extractable P (Olsen *et al*. 1954) of 12.8 kg/ha, and NH_4OAc-exchangable K (Hanway and Heidel 1952) of 289 kg/ha.

The experiment was conducted in split-plot design with three replications during *kharif* season of 2010, 2011 and 2012. In main plots, tillage systems, viz. conventional tillage (CT), CT + residues at 3 t/ha, zero-tillage (ZT) and ZT+ residues at 3 t/ha were allotted. In sub plots, intercropped systems such as sole maize, sole groundnut, maize + groundnut (1:1) and maize + groundnut (1:2) were taken. The experiment was conducted in fixed layout over the years. In ZT plots, no tillage was done and crops were sown directly with the help of multi-row crop planter. A crop residue amount of 3 t/ha was retained on the soil surface under ZT+ residues at 3 t/ha. No residues were retained in ZT. In CT, intensive cultivation (two ploughing + one rotovator) was done. In case of In CT + residues at 3 t/ha, the same intensity of tillage was followed. The maize was consequently followed with zero-till wheat crop. Therefore, wheat residue amount of 3 t/ha was incorporated at the time of ploughing. The maize crop was intercropped with groundnut in additive series of 1:1 and 1:2 row ratios.

Prior to the experiment, a maize-wheat rotation was established at the trial site for 3 consecutive years under different tillage and residue management practices. The study was conducted on gross plots size of 8.0 m × 2.8 m with a net plot size of 7.2 m × 1.4 m during each year. The maize crop was sown during 7^{th} July in every year. Sole and intercropped maize was planted at row x plant spacing of 70 × 15 cm while sole groundnut crop was sown at 30 × 10 cm spacing. One row of groundnut in 1:1 ratio was intercropped with maize at a spacing of 35 cm. However, in case of 1:2, two rows of groundnut were added at 25 cm spacing in between the maize crop. A seed rate of 80 and 15 kg/ha was used for sole groundnut and sole maize crop, respectively. The variety such as PEHM 3 and G 4 was used for maize and groundnut sowing, respectively. A uniform dose of 120 kg N/ha, 26 kg P/ha, and 33 kg K/ ha was applied in maize crop. In maize crop, half of the N was applied at the time of sowing while half of N was applied at 30 DAS. However, P and K were applied as basal at the time of sowing. In sole groundnut, 60 kg N/ ha, 26 kg P/ha, and 33 kg K/ha was applied as basal at the time of sowing. Urea, single super phosphate and muriate of potash were the sources of N, P and K, respectively. No additional N, P and K doses were applied in intercropped groundnut. A spray of pendimethalin at 1.0 kg/ha was done as pre-emergence followed by hand weeding at 25 DAS for effective weed control. A spray of imidacloprid 30.5% SC was done at tasseling stage to control thrips infestations in maize crop. The harvesting of crops was done during 21^{st} October in each year.

The yield attributes such as dry matter accumulation, number of rows/cob and number of grains/grain row were recorded from 10 random plants from each treatment. The yields of crops were recorded from net plot area, harvested and reported at moisture content of 12.5 %. In plant, N concentration was estimated by Subbiah and Asija (1956) method, and thereafter the N concentration values in grain and stover were multiplied with grain and stover yield, respectively to obtain N uptake in kg/ha. The weeds were recorded by using quadrat of 0.5 m × 0.5 m. The quadrat was randomly placed four times in each plot. Inside the quadrat, the number of weed species of broad-leaved, narrow-leaved and sedges were recorded. The samples for dry matter accumulation were collected and oven dried at 65°C for 72 h, and thereafter, weighed and expressed in g m^{-2}. Sampling for weed species was done at 30 DAS in each year.

All data were subjected to Kolmogorov-Smirnov and Levene tests for normality and homogeneity of variance. The data were analysed to ANOVA to assess the treatment effects using STATISTIX Version 9.0. The standard error of means (SEm±) and critical difference (CD) at 5% level of significance were worked out for each parameter.

RESULTS AND DISCUSSION

Dry matter accumulation in maize

In maize, dry matter (DM) accumulation was significantly influenced with the tillage practices at 60 and 90 DAS over the years except at 30 DAS (Table 1). In general, DM accumulation steadily increased from 30 to 60 DAS, irrespective of tillage. At 60 DAS, DM accumulation was higher in 2011 and 2012 compared to 2010.

At 60 and 90 DAS, the highest DM accumulation was recorded in ZT + residues at 3 t/ha followed by CT + residues at 3 t/ha and CT over the years. However, at 90 DAS, ZT + residues at 3 t/ha and CT + residues at 3 t/ha recorded at par values of DM accumulation in 2010. ZT without residue recorded the lowest DM accumulation at 60 DAS during 2010, 2011 and 2012 (55.0, 53.5 and 57.0 g/m^2, respectively). At 90 DAS, ZT gave the lowest DM accumulation over the years. The retention of crop retention in the zero tillage conserved the moisture into the soil. Therefore, a consistent availability of the soil moisture to the maize crop during the dry spell contributed in higher DM accumulation (Sepat and Rana 2013).

The intercropping systems significantly influenced the DM accumulation at 60 and 90 DAS over the years (Table 1). In 2010 and 2012, the DM accumulation was not influenced with intercropping systems at 30 DAS except in 2012. The retention of crop residues for consequently for two years enhanced the soil nutrient availability to the crop plant. Therefore, a vigorous growth of maize plant was observed at the end of cropping cycle (Rajpoot *et al*. 2014).

At 60 DAS, the highest DM accumulation was recorded in sole maize than intercropped maize with groundnut in 1:1 and 1:2 ratios over the years. In 2010, intercropped maize with groundnut in 1:1 ratio remained comparable with sole maize followed by 1:2 ratio at 90 DAS. However, in 2011 and 2012, sole maize recorded the highest DM accumulation followed by intercropped maize in 1:1 and 1:2 ratios. The abundance of optimum space to the sole maize crop resulted into the effective utilization of light, water and nutrient compared to intercropped maize (Sepat *et al*. 2012). The more space availability to the sole maize than intercropped maize at 1:1 than 1:2 also contributed in higher DM accumulation over the years (Sharma *et al*. 2010).

Yield attributes of maize

The tillage system significantly influenced the yield attributes such as number of cobs/ha, number of grain rows/cob and number of grains/grain row, and yield of maize over the years (Table 2 and 3). The number of cobs/ha were recorded similar in ZT + residue at 3 t/ha and CT + residue at 3 t/ha over the years. In 2010 and 2011, the highest number of grain rows/cob was recorded highest in ZT + residue at 3 t/ha followed by CT + residue at 3 t/ha and CT. However, in 2012, ZT+ residue at 3 t/ha and CT + residue at 3 t/ha was found at par with respect to number of grain rows/cob. The number of grains/grain row was recorded highest in ZT + residue at 3 t/ha followed by CT + residue at 3 t/ha and CT over the years. The 1000-grain weight was not influenced with the tillage practices over the years. ZT recorded the lowest number of cobs/ha, number of grain rows/cob and number of grains/grain row (60.5, 11.0 and 20.3, respectively) in 2010, 2011 and 2012. No retention of crop residue in ZT enhanced the evaporation rate, and therefore moisture stress was observed at the time of grain filling in maize crop compared to ZT+ residue at 3 t/ha (Sepat *et al*. 2014).

Table 1 Effect of tillage and intercropping on dry matter accumulation (g/m^2) in maize during 2010 to 2012

Treatment	30 DAS				60 DAS				90 DAS			
	2010	2011	2012	Mean	2010	2010	2011	Mean	2010	2010	2011	Mean
Tillage system												
CT	19.5	22.1	21.1	20.9	60.0	64.0	68.0	64.0	82.0	88.0	91.2	87.1
CT+residue	22.3	25.7	24.5	24.2	75.0	82.0	83.0	80.0	96.0	106.0	111.5	104.1
ZT	16.7	17.0	17.0	16.9	55.0	53.5	57.0	55.2	78.0	80.0	81.0	79.7
ZT+residue	24.1	25.8	30.0	26.6	80.0	89.0	94.0	87.7	99.0	115.0	123.0	112.3
CD (*P*=0.05)	NS	NS	NS		4.81	3.28	5.01		7.51	6.87	8.15	
Intercropping system												
Sole maize	24.0	24.0	27.4	25.1	70.0	82.1	84.5	78.8	93.5	112.0	111.5	105.7
Maize+groundnut (1:1)	20.0	22.0	22.3	21.4	67.7	68.0	73.0	69.6	87.3	94.8	101.0	94.4
Maize+groundnut (1:2)	18.0	22.0	19.8	19.9	64.8	66.3	69.0	66.7	85.5	85.0	92.6	87.7
CD (*P*=0.05)	NS	NS	3.59		2.13	2.79	3.11		6.81	5.86	7.31	

Table 2 Effect of tillage and intercropping on yield attributes of maize during 2010 to 2012

Treatment	Number of cobs (×10³/ha				Number of grain rows/cob				Number of grains/grain row				1000-grain weight (g)			
	2010	2011	2012	Mean	2010	2011	2012	Mean	2010	2011	2012	Mean	2010	2011	2012	Mean
Tillage system																
CT	64.0	63.4	63.2	63.5	11.3	11.0	11.0	11.1	22.8	23.1	22.8	22.9	221	220	220	220
CT + residue	66.6	65.8	66.7	66.4	12.4	13.3	14.0	13.2	24.9	26.0	26.4	25.8	223	222	224	224
ZT	60.8	60.5	60.2	60.5	11.1	10.0	12.0	11.0	20.1	21.2	19.5	20.3	220	220	220	220
ZT + residue	67.3	67.9	67.6	67.6	14.8	15.0	15.0	14.9	25.5	27.1	27.2	26.6	225	225	226	225
CD (*P*=0.05)	3.20	2.80	3.80		NS	3.47	4.34		1.21	1.08	1.51		NS	NS	NS	
Intercropping system																
Sole maize	66.6	65.8	66.0	66.1	13.1	12.9	13.0	13.0	24.3	24.4	23.7	24.1	225	223	224	222
Maize + groundnut (1:1)	63.8	64.2	64.1	64.0	13.0	12.3	13.0	12.8	23.1	24.3	24.8	24.1	221	221	221	224
Maize + groundnut (1:2)	63.7	63.2	63.2	63.4	11.1	11.8	13.0	12.0	22.6	24.3	23.5	23.5	221	221	221	221
CD (*P*=0.05)	2.8	1.71	1.91		NS	NS	NS		NS	NS	NS		NS	NS	NS	

Table 3 Effect of tillage and intercropping on yield and economics of maize during 2010 to 2012

Treatment	Grain yield (t/ha)				Stover yield (t/ha)				Cost of cultivation (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	B:C ratio
	2010	2011	2012	Mean	2010	2011	2012	Mean			
Tillage system											
CT	4.92	4.83	4.72	4.82	5.80	5.80	5.94	5.85	25.0	41.2	1.6
CT+residue	5.00	5.20	4.85	5.02	6.00	6.10	6.12	6.07	28.0	40.7	1.6
ZT	4.20	4.10	4.00	4.10	5.30	5.50	5.20	5.33	20.0	36.3	1.5
ZT+residue	5.25	5.32	5.48	5.35	6.20	6.27	6.45	6.31	23.0	49.8	1.7
CD (*P*=0.05)	0.43	0.62	0.58		0.60	0.71	0.67				
Intercropping system											
Sole maize	5.00	5.00	4.92	4.97	6.22	6.11	6.10	6.14	20.0	43.0	1.5
Maize+groundnut (1:1)	4.82	4.92	4.80	4.85	5.99	6.00	6.00	6.00	24.0	41.1	1.6
Maize+groundnut (1:2)	4.71	4.65	4.56	4.64	5.27	5.64	5.68	5.53	25.0	41.9	1.7
CD (*P*=0.05)	0.34	0.52	0.45		0.54	0.58	0.53				

ZT + residue at 3 t/ha recorded the highest grain and stover yield which remained comparable with CT+ residue at 3 t/ha in 2010 and 2011. However, in 2012, ZT + residue at 3 t/ha recorded the highest grain and stover (5.48 and 6.45 t/ha, respectively) yield followed by CT+ residue at 3 t/ha and CT. ZT recorded the lowest grain and stover yield of maize, and a decline was observed over the years (4.10 and 5.33 t/ha, respectively). The retention of crop residues in ZT retained the soil moisture and provided consistently during the grain filling period which could be the reason behind high yield under ZT compared to CT (Sepat and Rana 2013, Sepat *et al*. 2014).

The intercropping systems significantly influenced the number of cobs/ha. However, number of grain rows/cob, number of grains/grain row and 1000-grain weight was not influenced with intercropping systems. The sole maize recorded the highest number of cobs/ha compared to intercropped maize in 1:1 and 1:2 row ratios. Likewise, grain and stover yield in maize was influenced with intercropping system over the years. The intercropping of maize with groundnut in 1:1 and 1:2 row ratios (4.85 and 4.64 t/ha, respectively) recorded the lower grain yield compared to sole maize (4.97 t/ha). The beneficial effects of intercropped legume *via* N transfer in associated crop could be a major factor for yield enhancement in maize crop. Rajput *et al*. (2014) also reported that inclusion of mungbean as an intercrop enhanced the grain yield of intercropped crop.

Intercrop yield

Tillage systems significantly influenced the number of pods/plant, seed and haulm yield in groundnut intercrop over the years (Table 4). The higher pods/plant, seed and haulm yield were recorded in ZT + residue at 3 t/ha which remained comparable with CT + residue at 3 t/ha and CT

Table 4 Effect of tillage and intercropping on yield attributes and yield of intercrop groundnut during 2010 to 2012

Treatment	Number of pods/plant				Seed yield (t/ha)				Haulm yield (t/ha)			
	2010	2011	2012	Mean	2010	2011	2012	Mean	2010	2011	2012	Mean
Tillage system												
CT	38.0	37.0	39.0	38.0	1.10	1.07	1.15	1.11	2.35	2.15	2.61	2.37
CT+residue	42.0	44.0	42.0	42.7	1.21	1.24	1.23	1.23	2.41	2.35	2.78	2.51
ZT	32.0	30.0	33.0	31.7	0.86	0.84	0.92	0.87	1.75	1.70	1.95	1.80
ZT+residue	44.0	45.0	46.0	45.0	0.98	1.04	1.29	1.10	2.10	2.21	2.89	2.40
CD (*P*=0.05)	3.83	3.14	2.85		0.16	0.19	0.12		0.22	0.34	0.28	
Intercropping system												
Sole groundnut	43.0	45.0	43.0	43.7	1.30	1.49	1.61	1.47	2.82	2.90	3.30	3.01
Maize+groundnut (1:1)	38.0	37.0	39.0	37.7	0.85	0.75	0.90	0.83	1.80	1.60	2.18	1.86
Maize+groundnut (1:2)	36.0	35.0	38.0	36.7	0.96	0.91	0.95	0.94	1.83	1.79	2.21	1.94
CD (*P*=0.05)	2.15	2.78	2.63		0.12	0.11	0.09		0.19	0.28	0.19	

in 2010 and 201. However, in 2012, ZT+residue at 3 t/ha recorded the highest number of pods/plant followed by CT +residue at 3 t/ha and CT.

The lowest pods/plant, seed and haulm yield was found in ZT over the years (31.7, 0.87 and 1.8 t/ha, respectively). The intercropping systems significantly influenced the number of pods/ha, seed and haulm yield in groundnut over the years. The sole groundnut recorded the highest number of pods/ha, seed and haulm yield than maize + groundnut in 2:1 and 1:1 as the plant density of groundnut crop was reduced (Sepat *et al*. 2012).

Economics

Tillage significantly influenced the cost of cultivation over the years (Table 3). In CT and CT+residue at 3 t/ha, higher cost of cultivation was recorded as high cost was involved in tillage operations (Sepat and Rana 2013). Further, residue cost enhanced the cost of cultivation in CT+residue at 3 t/ha (28.3 × 10^3 ₹/ha). The exclusion of tillage in ZT lowered the cost of cultivation (20.0 × 10^3 ₹/ha). But, residue retention increased the cost of cultivation in ZT+residue at 3 t/ha than ZT. The higher grain yield in ZT+residue at 3 t/ha resulted in higher net returns and B:C ratio (49.8 × 10^3 ₹/ha and 1.7, respectively) followed by CT+residue at 3 t/ha (40.7× 10^3 ₹/ha and 1.6, respectively). The lowest net returns and B:C ratio was found in ZT. The inclusion of groundnut as intercrop in 1:1 and 2:1 ratio enhanced the cost of cultivation (24.0 and 25.0 × 10^3 ₹/ha, respectively) than sole maize (20.0 × 10^3 ₹/ha). However, additional yield of groundnut intercrop enhanced the net returns and B:C ratio (43.0 × 10^3 ₹/ha and 1.7, respectively) compared to sole maize over the years (41.0 × 10^3 ₹/ha and 1.5, respectively).

Nutrient uptake

The uptake of N in grain, stover and total were influenced with tillage systems over the years (Table 5). In grain, the highest was recorded with ZT+residue at 3 t/ha (88.2, 90.0 and 94.0 kg N/ha in 2010, 2011 and 2012, respectively) followed by CT+residue at 3 t/ha and CT. The

Table 5 Effect of tillage and intercropping on N uptake in intercropped maize during 2010 to 2012 (mean of three years)

Treatment	N uptake (kg/ha)								
	Grain			Stover			Total		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Tillage system									
CT	74.3	72.0	71.4	31.3	30.9	32.7	105.6	102.9	104.1
CT+residue	81.5	85.0	81.5	35.4	36.7	37.9	116.9	121.7	119.4
ZT	61.7	60.2	58.0	26.5	27.4	24.4	88.2	87.6	82.4
ZT+residue	88.2	90.9	94.0	38.4	41.3	45.2	126.6	132.2	139.2
CD (*P*=0.05)	3.10	3.29	3.00	2.45	1.89	2.37	9.80	10.20	11.2
Intercropping system									
Sole maize	72.1	71.1	70.2	27.9	29.2	30.9	100.2	100.3	101.1
Maize+groundnut (1:1)	77.0	79.0	77.3	33.8	36.0	35.8	110.8	115.0	113.1
Maize+groundnut (1:2)	80.0	81.0	81.2	36.9	37.0	38.6	116.9	118.0	119.8
CD (*P*=0.05)	2.89	2.77	2.81	1.12	1.08	1.11	4.06	3.88	4.36

Table 6 Effect of tillage and intercropping on the weed population during 2010 to 2012

Treatment	Weed population (no./m^2)								
	Broad leaved			Narrow leaved			Total		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Tillage system									
CT	1.87(3.5)	2.04(4.2)	1.79 (3.2)	2.02(4.1)	2.26(5.1)	2.65(7.0)	2.76(7.6)	3.05 (9.3)	3.19(10.2)
CT+residue	1.41(2.0)	1.73(3.0)	1.58 (2.5)	1.73(3.0)	1.73(3.0)	2.26(5.1)	2.24(5.0)	2.45 (6.0)	2.76(7.6)
ZT	2.26(5.1)	2.28(5.2)	2.30 (5.3)	2.51(6.3)	2.59(6.7)	2.92(8.5)	3.38(11.4)	3.45 (11.9)	3.71(13.8)
ZT+residue	2.05(4.2)	1.76(3.1)	1.95 (3.8)	2.24(5.0)	2.00(4.0)	2.53(6.4)	3.03(9.2)	2.67 (7.1)	3.19(10.2)
CD (*P*=0.05)	0.42	0.39	0.44	0.51	0.44	0.93	0.96	0.46	0.88
Cropping system									
Sole maize	2.49(6.2)	2.55(6.5)	2.66 (7.1)	2.45(6.0)	2.72(7.4)	2.97(8.8)	3.49(12.2)	3.73 (13.9)	3.99(15.9)
Sole groundnut	1.73(3.0)	1.78(3.2)	1.79(3.2)	2.27(5.2)	2.03(4.1)	2.83(8.0)	2.85(8.2)	2.70 (7.3)	3.35(11.2)
Maize+groundnut (1:1)	1.82(3.3)	1.73(3.0)	1.58 (2.5)	2.24(5.0)	2.05(4.2)	2.49(6.2)	2.88(8.3)	2.68 (7.2)	2.95(8.7)
Maize+groundnut (1:2)	1.52(2.3)	1.67(2.8)	1.41 (2.0)	1.50(2.3)	1.76(3.1)	2.00(4.0)	2.13(4.6)	2.43 (5.9)	2.45(6.0)
CD (*P*=0.05)	0.40	0.28	0.37	0.41	0.37	0.82	0.88	0.32	0.72

highest N uptake in straw was recorded in ZT+ residue at 3 t/ha (38.4, 41.3 and 45.2 kg N/ha, respectively) in 2010, 2011 and 2012, respectively. However, total N uptake remained comparable with ZT + residue at 3 t/ha (126.6, 132.2 and 139.2 kg N/ha, respectively) and CT + residue at 3 t/ha (116.9, 121.7 and 119.4 kg N/ha, respectively) in 2010, 2011 and 2012. The lowest uptake of N in grain, straw and total were observed in ZT over the years. The intercropping systems significantly influenced the uptake of N in grain, straw and total over the years. The intercropped maize + groundnut in 2:1 and 1:1 recorded the highest values of N uptake in grain, stover and total compared to sole maize. The N transfer by the intercrop groundnut as legume to the main maize crop (Sharma *et al.* 2017) enhanced the N uptake in intercropped maize compared to sole maize.

Weed population

The population of broad-leaved weeds (BLWs), narrow-leaved weeds (NLWs) and total was significantly influenced with tillage systems over the years (Table 6). In general, initially, population of BLW, NLW and total was low which increased at the end of study period. In 2010, a higher BLWs population was recorded in ZT which remained at par with ZT+ residue at 3 t/ha. The lowest BLWs population was recorded in CT + residue at 3/ha (1.41, 1.73 and 1.58, respectively) in 2010, 2011 and 2012. In general, the population of NLWs recorded in ZT (2.51, 2.59 and 2.92, respectively in 2010, 2011 and 2012, respectively) and CT (2.02, 2.26 and 2.65, respectively). The lowest total population was recorded in CT + residue at 3 t/ha followed by ZT + residue at 3 t/ha during the end of three year period.

The tillage operations cut, upheaval and buried deep the weed in to the soil which reduced the weed population in CT (Dass *et al.* 2017). However, retention of residue and use of herbicides to kill the weeds diminished the weed seed bank at the end of study (Sepat and Rana 2013). The intercropping also significantly reduced the BLW, NLW and total weed population over the years. The population of BLW, NLW and total was recorded low in intercropped maize + groundnut (1:1 and 1:2 ratio) compared to sole maize. The groundnut intercrop suppressed the weed emergence compared to sole maize. The inclusion of intercrop groundnut also provided the ground cover which suppressed the weed infestation than sole maize. Rajpoot *et al.* (2014) also reported that intercropping with legume have smothering effect on weed emergence. Based on the study, it can be concluded that intercropping of maize with groundnut provides an advantage of additional yield over the sole maize. The inclusion of residues at 3 t/ha in zero-tillage and conventional tillage could be the sustainable option for enhancing the yield and net returns in maize under long-run.

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