Conservation Agriculture Mechanization Practices for Small holders under Soybean-wheat Cropping Pattern

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MK designed the study, wrote the protocol, performed the statistical analysis and wrote the first draft of the manuscript. Author AP managed the analyses of the study. Authors MD and DS supervised the work, managed the literature searches and edited the manuscript. All authors read and approved the final manuscript.

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Original Research Paper

ABSTRACT

The field study was conducted under wheat-soybean cropping pattern during Kharif and Rabi with wheat crops at ICAR-Central Institute of Agricultural Engineering Bhopal to identify the appropriate package of animal drawn implements suitable to small and marginal farmers for conservation agriculture. Different tillage treatment viz. no-tillage, minimum tillage and conventional tillage system was adopted with using animal power during field experiments. The grain yield was found significantly higher in minimum tillage and conventional tillage as compared to no-till for all cropping pattern. Additionally, minimum tillage saves 20% more operational cost and 34% operational energy as compared to conventional tillage. The yield was greatly affected by rainfall in soybean crop. The average soil cone index was found in the range of 1.32 to 1.42 Mpa with different tillage treatments. The soil bulk density was found in the range of 1.20 to 1.22 for all tillage conditions. The soil organic carbon was found significantly higher in next after second year of practice in the case no-tillage (0.64) and minimum tillage (0.60) as compared to conventional (0.55).The result indicated that practice of conservation agriculture through minimum tillage is possible in soybean-wheat crop rotations through animal power that could be benefited for small and marginal farmers and performed better timeliness in operations.

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1. INTRODUCTION

Presently, India is the largest manufacturer of tractors in the world in terms of numbers, accounting for about one third of the global production. The conservation farming practices are gaining popularization through tractor drawn machinery such as no-till seed drill, strip seed drill, happy seeder, slit till drill and many more. Power tillers are becoming popular in lowland flooded rice fields and hilly terrains. Steady growth has been observed in manually operated tools, animal operated implements and equipment operated by mechanical and electrical power sources [1]. Traditionally, draught animal power has been the main source of farm power. There are at present nearly 50 million draught animals. Small and marginal farmers constitute 85% of the land holdings which are less than 2 ha per farmer [2]. This area is within the command of a pair of bullocks [3]. For small holders, except for primary tillage operations, all other farm operations are economically carried out by animal operated machinery as compared to power operated machinery. It is estimated that at present 50% of net sown area is sown out by small and marginal farmers using draught animals [3]. For small farmers, animal traction is the best option as it is affordable, sustainable, profitable and environment friendly in most of the ecological systems. The benefits of conservation farming are proven and they offer smallholders the opportunity to increase their productivity, safeguard their land, environment, and reduce the risks of total crop failure in drought years. Some of the countries in Africa found the use of draught animal in conservation agriculture system is beneficial [4, 5, 6, 7, 8, 9].

Conservation agriculture aims to achieve sustainable and profitable agriculture and improved social, economical and environmental outcomes through three basic principles viz. minimal soil disturbance, permanent soil cover and diversified crop rotations. This practice is adopted in 157 million hectare worldwide which represents approximately 10% of the world arable land and has steadily increasing [10]. Fastest adoption rate of CA has been experienced in South America where some countries are using no-tillage farming on about 70% of the total cultivated area [11]. In India, adoption of conservation agriculture has been increased to 1.5 million hectare [10] which is 1% of total arable land. Conservation tillage is defined as any cropping system which results in conservation of natural or other resources, and sustainable agriculture as the use of agricultural practices which conserve water and soil and are environmentally non-degrading, technically appropriate, economically viable and socially acceptable [12]. Wheat and soybean are two important crops under cereal and oil seed, respectively in India. The production and consumption of these crops are sown in Table 1.

Table 1: Production and consumption of wheat and soybean crops in India

Year	Wheat crop		Soybean crop	
	Production (1000 MT)	Consumption (1000 MT)	Production (1000 MT)	Consumption (1000 MT)
2010	80804	81764	7480	2775
2011	86874	81408	8240	3320
2012	94882	83824	8640	3530
2013	93506	93848	6960	3640
2014	95850	93102	6160	4500
2015	86527	88548	4400	4460
2016	87000	97234	7200	4675
2017	98510	95677	6160	4740
2018	99870	95629	7680	5280

Most of the farmers are not aware that conventional farming systems are destroying the land upon which they depend. In most of the regions, conservation tillage practices have been adopted and practiced by large scale farmers for many years. There is a need to address conservation agriculture practices based on animal draught power that can be effectively adopted by small holders. Mainly the conservation agriculture practices are performed by farmers by using tractor power because large machine and greater power source is required to operate in heavy residue condition which was left by combines harvester. Small holders harvest crop by using hand sickle or by self-propel reaper which does not left heavy residue in field. On the other hand, the traditional practices done by small holders by animal drawn implement which is similar to conservation agriculture practices since they do not offer heavy soil manipulation. Therefore, with little modification in traditional practice by small holders, conservation agriculture practice could be adopted by the farmers which potentially increase the environmental and economic benefits. No such type of conservation agricultural practices has been performed in India for small holders. Under this study the package of animal drawn implements for CA practices viz. no-tillage and minimum tillage is developed and evaluated for soybean-wheat cropping system.

2. MATERIAL AND METHODS

Field Experimental Site

The experimentation was done at research farm of ICAR-Central Institute of Agricultural Engineering Bhopal (Lat, Long: 28.63147, 77.15182), which is located in central part of the India. Bhopal has a humid subtropical climate, with cool, dry winters, a hot summer and a humid monsoon season with annual rainfall of 1090 mm, most of which is concentrated between third week of June and last week of September. The average actual rainfall onset of monsoon at experimental site was 668.80 mm, 906.40 mm and 1250.60 mm, respectively for the years 2014, 2015 and 2016. The soil is clay with 32% sand, 22% silt and 44% clay. The initial average soil organic content and mean weight diameter of soil were 0.50% and 0.70 mm. The study was conducted during Kharif (2014, 2015 and 2016) with soybean crop (JS 6560) and Rabi (2014-15 and 2015-16) with wheat (HI 1544) crops. The soybean-wheat crop rotation was taken for the field experimentations. The experimentation was conducted for no-tillage (NT) and minimum tillage (MT) and compared to conventional tillage (CT) system using animate power. Soybean crop were sown in NT, MT and CT at 0.5 ha land. In next year, wheat was sown at same plot area. The statistical analysis was done by Randomized Block Design by SAS 9.3 and pair wise comparison of different tillage operation for particular year using LSD (least square difference) was performed with 5% level of significance.

2.1 Agronomical Practices

In no-tillage practice, large weed like *Parthenium hysterophorus* was either uprooted or cut depend upon soil hardness before 7-10 days of sowing and non-selective herbicide glyphosate was applied. The pre-emergence herbicide applicator was applied just after no-tillage seeding of crop in conservation agriculture using animal drawn three rows seed-cum-ferti drill. Animal drawn seed-cum-fertilizer drill was used for sowing the crop and improved sickle [13] was used for harvesting the crop. In case of minimum tillage and conventional tillage the field was ploughed one and three times respectively with animal drawn blade harrow before sowing operation. Chemical weeding was done in the case of NT and MT but in the case of its failure uprooting or cutting of weed was also carried out. Weeding operation was done by surface hoeing in the case of CT. Other operations like fertilizer application, irrigation etc. were same for all the operations. To know the representation of 30% of total residue, the wheat crop was harvested at various heights. Average residue density in kg.ha^{-1} and its percentage density which includes weight of leaves and husk w.r.t. different cut height were calculated. Ultimately the wheat crop was harvested at a distance of 300 mm from the ground surface as this height represent crop residue of 3 to 3.5 tonnes/ha (30% of total). The soybean seeds were sown in between two line of previous sown wheat crop. The soybean crop was cut at highest point as possible to keep maximum residue on the field. The entire root biomass was kept below the soil surface in the case of no-tillage practice for all cropping pattern.

2.2 Measurement of Machine Parameters

Various machine parameters like draft (N), operational speed (Km.h^{-1}), theoretical field capacity (TFC, ha.h^{-1}), actual field capacity (AFC, ha.h^{-1}), field efficiency (FE, %), operational cost (Rs.ha^{-1}), operational energy expenditure (MJ.ha^{-1}), etc. were measured for all machines. AFC was calculated by calculating total area cover in unit time. TFC was calculated by using equation shown in equ, (i). FE was calculated by dividing TFC to AFC.

$$TFC = \frac{S.V}{10} \qquad \text{… equ (i)}$$

Where TFC= theoritical field capacity in ha.h^{-1}, S = width of implements in m, V= actual velocity in km/h.

Average depth of operation of NT, MT and CT for all the years and crops were also recorded. Total cost was calculated on the basis of actual cost incurred during field operation by animal drawn machine, manually operated machine, labour and animal pair cost. Total cost of implement was calculated using straight line method which includes fixed cost and operation cost [14]. The energy expenditure during operations includes energy associated with machine, pair of animal and labour with the help of energy equivalent [15]. The draft of different type of animal drawn implements was measured [16]

2.3 Measurement of Crop Attributes

The crop attributes like seed germination, plant stands, plants height, average number of pods (for soybean crops), average number of tiller (for wheat crops), test weight, grain yield and biological weight were recorded. The data were collected randomly from one square metre size of experimental plots. Five replications have been taken. The data of seed germination was taken after 30 days sowing of seed for all crops. All other crop attributes were taken either at a time of harvesting or just after harvesting.

2.4 Measurement of Soil Parameters

The soil parameters such as soil bulk density (SBD, g.cc^{-3}), soil cone index (SCI, Kpa), moisture content (MC, %), mean weight diameter (MWD, mm) and soil organic matter (SOC, %) were measured. The initial data of MWD and SOC were measure before start of field experiment as per standard procedure for SBD [17], SOC [18], for MWD [19] and for SCI [20].

3. RESULTS AND DISCUSSION

3.1 Residue Density and Height of Cut of Wheat crop

Residue density and height of cut of wheat straw is depicted in Table 2. It is clear from the table that wheat straw varied in weight/length. The weight of straw reduces continuously as its height increases. It varied from 730 to 370 kg.ha^{-1} for 0-100 and 500-600 mm height, respectively. It indicates that the weight/length of straw lowest portion is double of its top most portions. The result shows that 33% of the straw is equivalent to height of cut equal to 300 mm from the ground surface which was required to keep on the soil surface for the sowing of next crop in conservation agriculture. Drill Weights of leaf and husk also have greater influence on the weight of biomass which is about 41.66% of total biomass.

Table 2. Percentage residue density vs height of cut

Cut height of straw (mm)	Avg. Residue density (kg.ha^{-1})	Cumulative density (kg.ha^{-1})	% of total
0-100	730	730	11.49
100-200	740	1470	11.68
200-300	670	2140	10.53
300-400	550	2690	8.76
400-500	480	3170	7.55
500-600	370	3540	5.83
600+	170	3710	2.75
Weight of leaf	860	4570	13.58
Weight of husk	1760	6330	27.83
Total weight	6330		100.00

3.2 Adoption of Package of Conservation Agriculture Practice

The packages of practices which were selected for no-tillage (NT), minimum tillage (MT) and conventional tillage (CT) practice is shown in Tables 3. Manual cutting of large weeds was recommended in the case of no-tillage before sowing. Rest of the weed was controlled by non-selective herbicide application. Control of previous weeds was done by using one pass of animal drawn blade harrow for MT and CT. Sowing and fertilizer application was done by animal drawn seed-cum-ferti drill using inverted T-type furrow opener for NT and shoe type furrow opener for MT and CT. For soybean and wheat crop, the weed was control by chemical method using knapsack sprayer. The weed control was done by surface hoeing for MT & CT. The pre-emergence herbicide was applied in NT and MT. Insecticide was applied by knapsack sprayer in the case of soybean only. Harvesting of all crops was done through improved sickle.

Table 3. Adoption of package of conservation agriculture practice

Operations	No-tillage	Minimum tillage	Conventional tillage
Pre-sowing weeding	• Manual • (Uprooting/cutting of large weeds only) • Application of non-selective herbicide	NR	NR
Weed control by tillage (before sowing)	Not required (NR)	Animal drawn blade harrow	Animal drawn blade harrow
Pre-emergence herbicide application	• knapsack sprayer	knapsack sprayer	NR
Land preparation	NR	NR	Animal drawn blade harrow
Sowing and fertilizer application	Animal drawn seed-cum-ferti drill with inverted T furrow opener	Animal drawn seed-cum-ferti drill with shoe type furrow opener	Animal drawn seed cum ferti drill with shoe type furrow opener
Weeding/interculture	• knapsack sprayer • Cutting of the weed in the case of failure of herbicide	• knapsack sprayer (for soybean and wheat crop)	• knapsack sprayer (for soybean crop)
Insecticide/pesticide (only in kharif)	knapsack sprayer	knapsack sprayer	knapsack sprayer
Harvesting	Improved sickle	Improved sickle	Improved sickle

3.3 Measurement of Machine Parameters

The specification of machinery used in the study is given in Table. 4. Both primary and secondary tillage operation was done by bullock drawn improved CIAE blade harrow. The operational cost of different operation is show in Table 5. The effective field capacity (EFC) of animal drawn blade harrow was 0.064 ha/h with operational cost and energy expenditure Rs 622 per ha and 253 $MJ.ha^{-1}$, respectively. The EFC of animal drawn seed-cum-ferti drill was varied from 0.10 to 0.15 depending upon working width, speed of operation and tillage conditions. The operational cost and energy expenditure were found Rs 427 per ha and 130 $MJ.ha^{-1}$, respectively. Average draft varied in the range of 450 N to 550 N depending upon different types of animal drawn implements used in this package. EFC was found 10% less in the case of no-tillage as compared to conventional sowing due to resistance created by residue clogging into furrow opener and more soil hardness was with no-tillage seeding operation. The operational cost and energy were found Rs1500 per ha and 94 $MJ.ha^{-1}$ in harvesting with improved sickle. Manually operated knapsack sprayer having capacity of 15 l and operating pressure 1.5 $kg.cm^{-2}$ with single nozzle was lowest operational cost (Rs 334 per ha) and energy expenditure (42 $MJ.ha^{-1}$) among all adopted machine for conservation agriculture practice. This knapsack sprayer was used mainly with pre and post emergence herbicide and insecticide application.

Table 4. Specification of used implements in conservation agriculture practice

Particulars	Animal drawn CIAE Improved blade harrow	Manually operated Knapsack sprayer	Animal drawn seed cum-ferti-drill	Animal drawn zero-till seed cum-ferti-drill	Improved Sickle
Dimension, mm x mm x mm	1220x850x650	370x150x510	1000x1000x780	1000x1000x780	405x155x40
Weight, kg	45		50	50	0.257
Working width, mm	400		675-900	675-900	
Working depth, mm	50		30–50	30–50	
Operation speed, km.h^{-1}	2.3		2.5	2.2	
Tank Capacity, l	--	15	--	--	
Operating pressure, kg/cm^2	--	1-3	--	--	
Effective Field capacity, ha.h^{-1}	0.064	0.1	0.11–0.15	0.10–0.14	0.018
Field efficiency, %	70	--	65	60	--
Draft, N	550		400	450	
Operational Cost, Rs.ha^{-1}	1368	334	808	808	1500
Operational energy expenditure, MJ.ha^{-1}	130	42	216	216	94

Table 5: Cost calculation of different operations

Particulars	Pre manual weeding	Tillage	Seed-cum-ferti dril	Post Herbicide	Manual weeding	Harvesting
Initial cost of the machine, C, Rs		4000.00	9000.00	2000.00		
Salvage value, Rs		400.00	900.00	200.00		
Wage, Rs per 8 hour	250.00	250.00	250.00	250.00	200.00	200.00
Operation cost of pair of animal , Rs per day (3 h of operation)		350.00	350.00			
Cost of chemical, Rs per liter		0.00	0.00	400		
Man-h/ha	10.00			10.00	150.00	60.00
labour cost, Rs/ha	312.5	0	0	312.5	3750	1500
Depreciation, Rs/h		1.44	6.75	0.90		
Interest, Rs/h		1.06	4.95	0.53		
Total fixed cost, Rs/h		**2.50**	**11.70**	**1.43**		
Insurance, taxes and housing, Rs/h (@ 3 % of initial cost/year)		0.48	2.25	0.24		
Repair&maintenance, Rs/h (@ 5% of initial cost/year)		0.80	3.75	0.40		
Wages, Rs/h	31.25	31.25	31.25	31.25	25.00	25.00
Total operating cost	**31.25**	**32.53**	**37.25**	**31.89**	**25.00**	**25.00**
Total cost, Rs/h	**31.25**	**35.03**	**48.95**	**33.32**	**25.00**	**25.00**
Cost of animal Rs/h	0.00	116.67	116.67	0.00	0.00	0.00
Cost of chemical application, Rs/h				40		
Cost of operation , Rs/hectare	**312.50**	**622.09**	**427.46**	**333.18**	**3750.00**	**1500.00**

3.4 Crop Attributes of Soybean crop

Different crop attributes of soybean crop have shown in Table 6 and Fig. 2. The germinations of soybean seeds were found less in 2014 and 2015 years due to erratic rainfall after seeding and restricted low yield. The yield affected most in the case of no-tillage due to failure of pre-emergence herbicide and poor seed-soil contact. Significant more germination was found in the case of CT as compared to MT and NT due to better seed placement. The average seed depth was found 31 mm in the case of NT which is less than that of MT (49 mm) and CT (54 mm). The highest yield was found in the case of CT which was higher than that NT and MT due to better plant stand and test weight. The yield in case of MT was found intermediate between NT and CT. In 2016, due to normal rainfall and effective application of herbicide, the yield of soybean was found much more than consecutive years. Seed germination and plant stand per unit area were found maximum in the case of CT followed by MT and NT irrespective of rainfall pattern. Number of pods per plants, test weight of seed was also found in similar order. It is basically due to proper placement of seed and other beneficial conditions for the germination in the ploughed field. The highest grain yield was found in CT (8912 kg.ha^{-1}) which is at par with MT (8523 kg.ha^{-1}) and significantly less in the case of NT (7642 kg.ha^{-1}) in 2016. Established soybean crop under different treatments is shown in Fig.1.

Table 6. Crop attributes of soybean crop

Trts	Seed germination, no.m^{-2}			Plant Stands, no.m^{-2}			Plant height, cm		
Year	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
NT	24.0a	34.0a	36.3a	21.3a	28.3a	33.7a	36.0a	35.0a	39.4a
MT	26.9b	36.6b	38.5b	24.3b	33.7b	35.5b	35.9a	36.8a	39.8a
CT	28.6c	37.8b	39.7b	27.1c	34.9b	36.7b	37.3a	38.0a	41.2a
Trts	**No. of pods per plant**			**Test weight of seeds, g**			**Grain yield, kg.ha^{-1}**		
Year	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
NT	21.33a	19.64a	23.32a	97.9a	92.4a	147.6a	4430a	4012a	7642a
MT	20.67a	20.44a	23.91a	115.7b	105.3b	149.1a	5221b	5114b	8523b
CT	21.33a	20.83a	24.25a	119.2c	111.7c	149.3a	5450b	5230b	8912b

Pairwise comparison among different tillage operation for particular year ($p<0.05$)

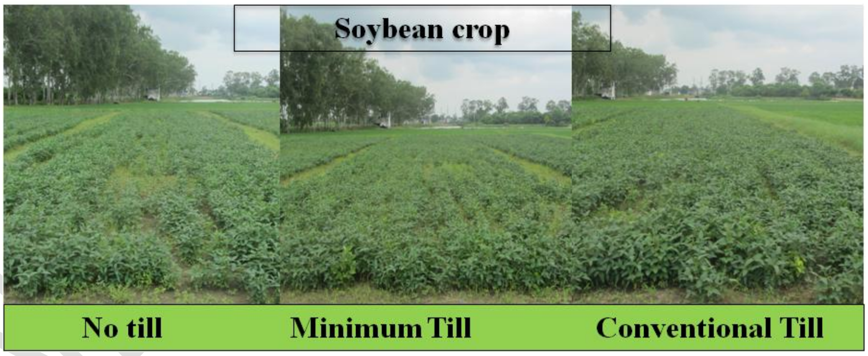

Fig. 1. Established soybean crop under different treatments

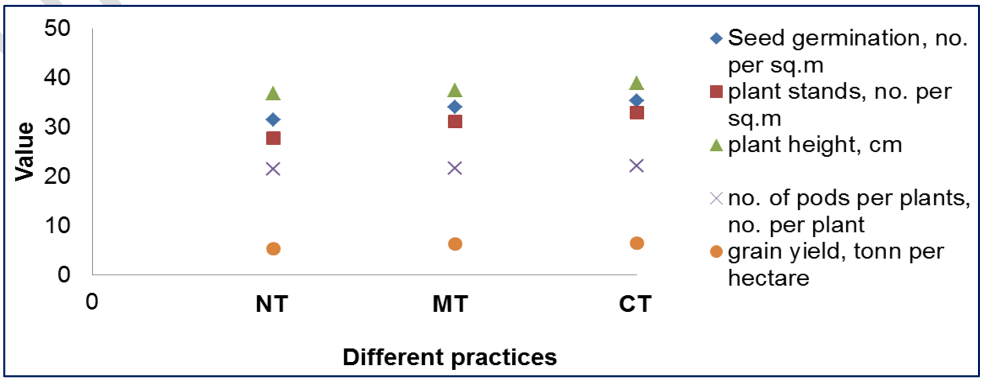

Fig. 2. Different crop attributes of soybean crop

3.5 Crop Attributes of Wheat Crops

Crop attributes of wheat crops have depicted in Table 7 and Fig 3. The seed germinations and plant stands were found significantly less in the case of NT as compared to CT and MT due to less seed of placement. The depth of operation of seed was 37 mm, 46 mm and 49 mm, for NT, MT and CT, respectively. Average number of tiller was found less in NT as compared to MT and CT for both years. It may be due the soil hardness associated with no-tillage restricted the plant growth as compared to MT and CT. The grain yield was also significantly less in the case of NT (4630 and 4762 kg.ha^{-1} for 2014-15 and 2015-16, respectively) as compared to MT (5372 and 5750 kg.ha^{-1} for 2014-15 and 2015-16, respectively) and CT (5462 and 5872 kg.ha^{-1} for 2014-15 and 2015-16, respectively) for both years due to mentioned reason. Seed germination, plant stands and grain yield of MT was found at par with CT for both years.

Table 7. Crop attributes of wheat crop

Trts	**Seed germination, no./m^2**		**Plant Stands, no./m^2**		**Plant height, cm**	
Year	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
NT	97.33a	96.00a	73.00a	76.83a	73.00a	75.53a
MT	110.67b	112.00b	87.67b	88.77b	81.67b	80.50b
CT	112.00b	115.00b	88.00b	89.37b	82.0b	81.87b
Trts	**Avg. no. of tiller**		**Test weight of seeds, g**		**Grain yield, kg.ha^{-1}**	
Year	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
NT	7.33a	7.00a	47.63a	47.75a	4630a	4762a
MT	8.67b	8.10b	48.53a	48.83a	5372b	5750b
CT	9.00b	8.32b	48.10a	48.69a	5462b	5851b

Pairwise comparison among different tillage operation for particular year ($p<0.05$)

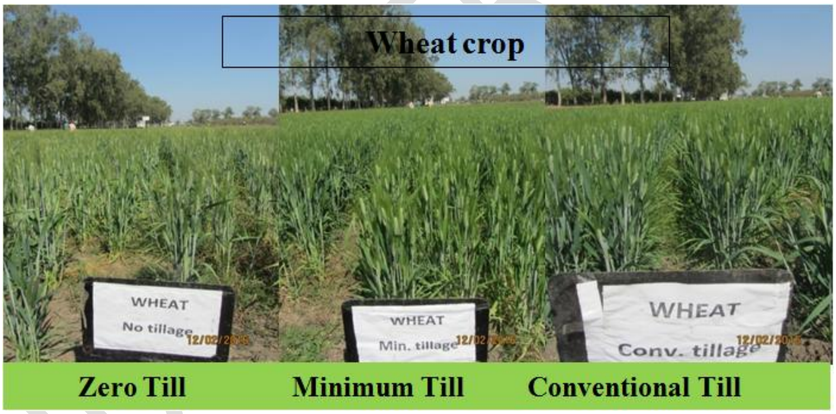

Fig. 3. Established wheat crop under different treatments

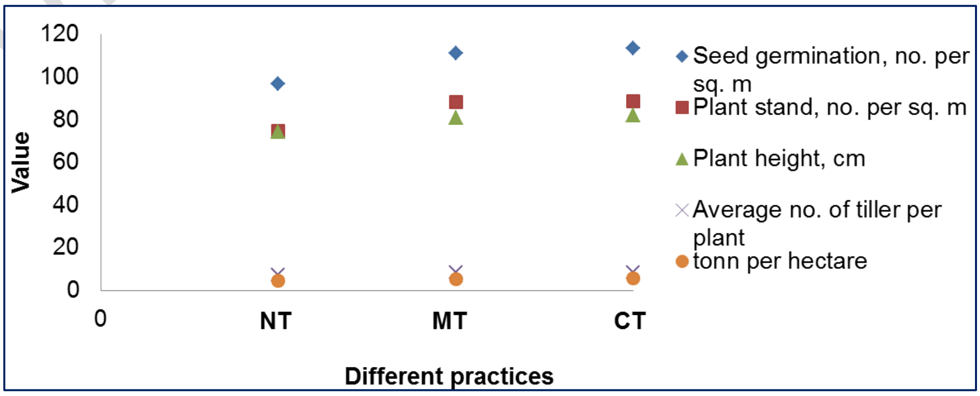

Fig.4. Different crop attributes of wheat crop

3.6 Measurement of Soil Parameter

Different soil parameter like soil cone index (SCI), soil bulk density (SBD), Soil aggregates and soil organic carbon (SOC) were measured and shown in Table 8.

Table 8. Measurement of soil parameters under different tillage conditions

Years	Tillage operations	SCI, Mpa	SBD, g/cc^3	Soil aggregates, mm	SOC, %
	NT	1.32a	1.20a	0.698a	0.50a
2014	MT	1.34a	1.20a	0.698a	0.50a
	CT	1.34a	1.20a	0.698a	0.50a
	NT	1.40b	1.22a	0.707a	0.56a
2015	MT	1.38b	1.20a	0.702a	054a
	CT	1.35b	1.20a	0.715a	0.50a
	NT	1.42b	1.22a	0.712a	0.64b
2016	MT	1.40b	1.20a	0.708a	0.60b
	CT	1.34a	1.20a	0.699a	0.55a

Pairwise comparison among different tillage operation for all years at level ($p<0.05$)

The average soil cone index was found in the range of 1.32 to 1.42 Mpa with different tillage treatments. The SCI in the case of NT was found significantly ($p<0.05$) greater than MT and CT due to complete absence of tillage operation. The lowest SCI was with CT during all the years. The SBD was found in the range of 1.20 to 1.22 for all soil and found slight more in the case of NT. The soil aggregates was found in the range of 0.698-0.715 mm for all soil conditions. The soil organic carbon was found highest in case of NT (0.56 in 2015 and 0.64 in 2016) followed by MT (0.54 in 2015 and 0.60 in 2016) and CT (0.54 in 2015 and 0.55 in 2016). It was due to availability of more residue as similar observation were noted by various researcher [21, 22, 23, 24] while practicing NT. Significant increase of SOC has seen for NT and MT in the year 2016. The increase in SOC in the year was due to combine effect of bullock operation (less soil disturbance in the case of conventional tillage as compared to tractor operated tillage equipment) and conservation tillage. Overall research indicated that the conservation agriculture can be performed with wheat-soybean cropping pattern with these packages of practice which could also save input cost as well as increase in soil organic matter content for the betterment of soil health, environmental safety and profitability of the small holders without compromising any significant productivity loss.

4. CONCLUSIONS

The yield of soybean crop was greatly affected by erratic rainfall. The seed-soil contacts decreases as move towards practice viz. conventional tillage, minimum tillage and no-tillage which affected grain yield. Less grain yield was found in case of NT. It may be due to decomposition of previous straw material soil microbes which reduce the release of nitrogen to the plants and minimum seed-soil contact as compared to MT and CT. The study revealed that practice of conservation agriculture viz. minimum tillage is possible in soybean-wheat crop rotations through animal power that could be benefited for small and marginal farmers. It indicates that MT is more profitable as it saves 20% more operational cost and 34% operational energy as compared to CT. On the other hand it may also be helpful in maintaining timely in operations. No significant ($p<0.05$) changes have been observed in the case of soil bulk density and soil aggregates during three years of experimentations. The soil organic carbon has increased significantly ($p<0.05$) in the case of NT and MT. The benefit of no-tillage could be ascertained by conducting few more experimental trials for more duration.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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