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Soybean response to contrasting tillage and nutrient management under vertisolic soil

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Abstract
A field investigation on "Soybean response to contrasting tillage and nutrient management under vertisolic soil" to study the impact of tillage and nutrient management on soybean and to assess the physicochemical properties of soil under vertisolic soil. The trial was conducted at the Department of Agronomy, Dr. PDKV, Akola during 2019-20. The experiment was laid out in split plot design with five main plot and three sub plot treatments replicated for three times. The main plot treatments were constituted of five tillage practices *viz*. (1) Conservation tillage (CnT), Minimum tillage (MT), Subsoil tillage (ST), Roto Tillage (RT) and Conventional Tillage (CvT). Sub plot treatments were comprised of three nutrient management i.e.100% RDF (100 RDF), 75% RDF + 2 t ha^{-1} FYM (75RDF) and 50% RDF + 4 t ha^{-1} FYM (50RDF). The other cultural practices were kept common, as recommended. Results shows that, on a clayey soil with subsoil tillage exhibited better growth and yield attributes and recorded significantly higher seed yield. Nutrient management with 100% RDF (30:75:30 NPK kg/ha), being comparable to 75RDF, resulted in higher growth and yield attributes and seed yield of soybean whereas 50%RDF + 4 t ha^{-1} FYM. Improvement in soil physical properties *viz*., soil moisture content, porosity, mean weight diameter, rate of infiltration, Hydraulic conductivity was observed with subsoil tillage practice and 50RDF integrated nutrient management practices. Significantly higher gross monetary returns and net monetary returns along with maximum benefit: cost ratio were obtained with subsoil tillage. Application of 100% RDF recorded significantly higher gross monetary returns and net monetary returns along with maximum benefit: cost ratio. In terms of energetic values, subsoil tillage practice and nutrient management with 100% RDF recorded higher energy output and energy balance, however conservation tillage practice recorded maximum energy balance per unit input and higher energy output: input ratio.

Keywords: Tillage practice, nutrient management, conservation tillage, farm yard manure, mean weight diameter, porosity

Introduction
Soybean (*Glycine max*. (L.) Merill.) is one of the leguminous pulse and oilseed crops in the tropical and sub-tropical regions. It originated in Eastern Asia, probably in north and central China. The important soybean growing countries are Brazil, USA and Argentina. Brazil is the largest producer of soybean in the world with 137.00 million metric tonnes followed by USA (112.55 million metric tonnes), Argentina (47.00 million metric tonnes), China (19.60 million metric tonnes) and India (10.45 million metric tonnes) (Anonymous, 2021) [2]. The Brazil alone has about 37 per cent of the world soybean production followed by USA (31%), Argentina (13%) and China (5%). India contributes 3% of world soybean production (Anonymous, 2021) [2]. Soybean is an industrial crop, cultivated for oil and protein. Despite the relatively low oil content of the seed (about 20% on moisture free basis), soybean crop is the largest single source of edible oil and account for 59 per cent of the world's oilseed production. Other key benefits are related to its excellent protein content of about 40% (contains all 8 essential amino acids), high levels of essential fatty acids, numerous vitamins and minerals, isoflavones, and fiber. Soybeans have considerable amounts of α-linolenic acid, omega-6 fatty acid and isoflavones (genistein and daidzein) (Messina, 1995) [13]. While the isoflavones reduces the risk of developing cancer of breast, cervical, ovarian, lung and colon, protein helps in lowering cholesterol levels, thus helpful in reduction heart and blood pressure associated diseases.

Production of soybean in India at present is restricted mainly to Madhya Pradesh, Maharashtra, and Rajasthan. It is also grown on a small acreage in Andhra Pradesh, Karnataka, Chhattisgarh, and Gujarat. In India during *kharif* 2020 soybean was grown over an area of 118.385 lakh ha with a production of 104.559 lakh metric tons and average productivity of 883 kg/ha. Madhya Pradesh (58.541 lakh ha), Maharashtra (40.398 lakh ha) and Rajasthan (11.002 lakh ha) are the major soybean producing states. Soybean in central India has emerged as a predominant rainy season crop. Soybean is an integral part of cropping system in Maharashtra state because it fits well in the crop rotation, crop mixture and diversifying cropping systems. In Maharashtra state, the area under soybean cultivation was 43.565 lakh ha which produced 62.011 lakh tones with productivity of 1423.41 kg/ha (Anonymous, 2020-2021) [2]. It has shown an unparalleled growth in area and production in the Vidarbha region. Area under soybean in Vidarbha was 17.296 lakh ha which produced 19.663 lakh tones with productivity of 1137 kg/ha (Anonymous, 2020-21) [2].

Therefore, the repeated tillage experiments under black-cotton soil conditions would lead to draw a definite conclusion i.e. whether shallow, deep or very deep tillage are efficient to optimize resource use efficiency and productivity. Moreover, the practical feasibility of the tillage practice would also play a major role when it comes to disseminate the technology to farmer's field. Hence, the outcome of present investigation will certainly be beneficial to the researchers of semi-arid region with vertic soil on long term basis. Lack of proper nutrient management is one of the major causes for low yields. Nutrient inadequacy and imbalance is limiting the oilseed productivity in India. Balanced fertilization is the key to achieve higher productivity and nutrient use efficiency and balanced nutrition with NPK was proved beneficial in all the oilseed crops both under rain fed and irrigated conditions. Fertilizer management has to be practiced on a system basis rather than on an individual crop or field basis for achieving higher efficiency and economy, which leads to greater sustainability.

In view of above, however, it is essential to rediscover the most viable tillage system and nutrient management in soybean crop that would work on a sustained basis for rain fed region of Vertisols in Vidarbha where the present research work is found to be meager in respect of soil manipulation at various depth through tillage practices and nutrient management system.

Materials and Methods

The field experiment was carried out at the farm of Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola on vertisol under rain fed condition during kharif season of 2019-20. The experimental site is situated in the subtropical zone at latitude 200 42' N and longitude 770 01' E. The altitude of the place is 307.41 meters above mean sea level. Most of the rainfall received from south-west monsoon during June to October. The total rainfall received during 2019-20 was 929.4 mm in 49 rainy days as against normal rainfall of 783.5 mm received in 41.2 rainy days (1971 to 2000).

The experiment was laid out in split plot design with 5 tillage management practices in main plot and 3 nutrient management practices in sub plot replicated three times. Tillage management constituted of conservation tillage (CnT)- one harrowing by tractor mounted disc harrow before sowing, minimum tillage(MT)- one tyne harrowing + one blade harrowing), subsoil tillage(ST)-one sub soiler + one tyne harrowing + one rotavator), roto tillage (RT) -one tyne harrowing + one rotavator and conventional tillage (CvT) - one ploughing + two tyne harrowing + one blade harrowing), Nutrient management practices were 100% RDF (100 RDF) [30:75:30 NPK kg/ha], 75% RDF + FYM 2 t/ha (75 RDF) and 50% RDF + FYM 4 t/ha (50 RDF)

The soil of experimental plot was medium black with uniform and levelled topography. Soil was clayey in texture, slightly alkaline in reaction with medium status of organic carbon content (0.52%), low available nitrogen (192.32 kg/ha), medium phosphorus (17.06 kg/ha) and fairly rich status of available potassium (320.35 kg/ha).Rainfall received during various crop growth stages *viz*., 0-20, 20-40, 40-60, 60-80 DAS and 80DAS and at harvest was 253.42, 178.40, 35.20, 87.60, and 141.60 mm, respectively. In general, the status of rainfall (696.22 mm) was quite higher than the normal during the crop period. Sowing of soybean (cultivar Yellow Gold) was undertaken on 25 June, 2020. Prior to sowing, all the tillage treatments were applied to the selected site of experimentation. Simultaneously nutrient management practices were also carried out. Crop was harvested on 4 October, 2020.

Result and Discussion

The result obtained from present investigation as well as relevant discussion have been summarized under heads.

Soil physical properties

Soil Moisture content (%)

From the data (Table 1), it is apparent that the tillage treatments behaved differently and the status of moisture was according to the depth of tillage, i.e. it increased significantly with the increase in intensity of tillage. Soil moisture content observed periodically from sowing to 80 DAS showed that deep tillage practices consistently maintained higher status of soil moisture content not only during adequate rainfall but also under inadequate rainfall period. Subsoil tillage (T_3) showed highest soil moisture content at all the observed stages and it was at par with conventional tillage (T_4), except at 20 DAS. By 80 days stage subsoil tillage maintained significantly higher soil moisture content statistically at par with conventional tillage only.

Nutrient management regime of 50% RDF + 4 t/ha FYM recorded significantly higher status of soil moisture at all the observed stages and 75% RDF + 2 t/ha FYM proved statistically equivalent. Integration of FYM in these treatments caused higher porosity with minimum bulk density, consequently more soil moisture content was observed. There might be aggregation of soil particles due to partly addition of organic manure replacing the chemical fertilizer resulted in formation of good soil structure leading to high soil moisture content. Interaction effect between the tillage and nutrient management practices for soil moisture content was found to be statistically non-significant.

Table 1: Soil moisture content (%) at 0-30 cm depth as influenced by treatments

Treatment	Soil moisture content (%) at 0-30 cm soil depth				
	At sowing	20 DAS	40 DAS	60 DAS	80 DAS
Tillage management					
T_1- Conservation tillage	29.12	35.62	23.14	32.26	21.71
T_2- Minimum tillage	27.65	35.64	22.64	31.12	19.93
T_3- Sub-soil tillage	31.25	36.98	29.54	34.84	22.82
T_4- Conventional tillage	30.14	35.76	27.22	34.15	22.52
T_5- Roto tillage	29.54	35.43	23.78	32.87	21.32
SE (m) ±	0.47	0.35	0.53	0.64	0.56
CD (P = 0.05)	1.53	1.04	1.72	2.10	1.66
Nutrient management					
N_1- 100% RDF	26.95	35.17	24.23	32.06	20.40
N_2- 75% RDF + 2 t/ha FYM	29.78	36.02	26.11	33.21	22.16
N_3- 50% RDF + 4 t/ha FYM	31.90	36.44	25.45	33.86	22.41
SE (m) ±	0.34	0.31	0.27	0.51	0.34
CD (P = 0.05)	0.99	0.94	0.79	1.51	1.02
Interaction					
SE (m) ±	0.75	0.86	0.60	1.14	0.74
CD (P=0.05)	NS	NS	NS	NS	NS
GM	29.54	35.88	25.26	33.05	21.66

Porosity (%) [P_t]

Porosity values of soil attained up to a depth of 0-15 cm are enumerated in Table 02. Distinct differences were observed when effect of tillage management was analyzed over porosity. Porosity improved significantly with subsoil tillage (T_3) and consistently recorded the figures ranging from 52.45% at 20 DAS to 50.94% at 80 days stage. It was followed by conventional tillage (T_4) with marginal decline. Conservation tillage (T_1) noted significantly lowest porosity values and it was in proximity with minimum tillage practice (T_2). It appears that tillage had a pronounced effect on porosity. Improvement in soil moisture status and reduction in bulk density might have reduced soil strength and compactness with subsoil tillage, enhancing soil porosity. These results are in conformity with the findings of Padmavati *et al*., 2012 [18]. Porosity improved significantly with FYM integrated treatment of 50% RDF + 4 t/ha FYM being at par with 75% RDF+2 t/ha FYM. FYM integration improved water retention and in turn soil moisture status that reduced soil bulk density consequently improving the soil porosity. Application of FYM may lead to good soil physical structure with highest aggregation stability. Pagliai *et al*. (2004) [19] and Aziz *et al*. (2019) [3] also noted that application of compost and manure improved the soil porosity and the soil aggregation. Interaction effect was statistically not significant in respect of porosity of soil.

Table 2: Porosity (%) of soil at 0-15 cm depth as influenced by treatments

Treatment	Porosity (%) at 0-15 cm soil depth				
	At sowing	20 DAS	40 DAS	60 DAS	80 DAS
Tillage management					
T_1- Conservation tillage	50.94	49.85	50.57	50.19	50.19
T_2- Minimum tillage	50.94	50.19	50.94	50.57	50.19
T_3- Sub-soil tillage	51.70	52.45	52.08	52.45	50.94
T_4- Conventional tillage	52.02	52.45	51.70	51.32	50.57
T_5- Roto tillage	51.00	50.19	50.57	50.19	50.19
SE (m) ±	0.24	0.85	0.48	0.47	0.21
CD (P=0.05)	0.71	2.54	1.58	1.54	0.62
Nutrient management					
N_1- 100% RDF	49.80	50.42	50.12	50.03	49.90
N_2- 75% RDF+2 t/ha FYM	52.08	51.08	51.70	51.30	50.35
N_3- 50% RDF+4 t/ha FYM	52.08	51.58	51.71	51.50	51.00
SE (m) ±	0.37	0.47	0.24	0.32	0.22
CD (P = 0.05)	1.11	NS	0.71	0.93	0.67
Interaction					
SE (m) ±	0.54	1.13	0.74	0.70	0.46
CD (P = 0.05)	NS	NS	NS	NS	NS
GM	51.32	51.03	51.17	50.94	50.42

Bulk density

From the mean values presented in Table 03, It could be said that changes in values of bulk density observed at periodical stages were the reflection of soil moisture status at the corresponding stage.

Noticeable change in the values of bulk density at 0-15 cm was noticed with tillage treatments of varying depth. By and large, significantly higher soil denseness (1.30 to 1.33 Mg/m^3) was registered with shallow depth tillage practices *i.e* conservation tillage which was followed by minimum tillage. It's logical to assume that increased number of macropores may remain open and improve the soil porosity resulting in reduction in bulk density and improvement in soil structure to a greater depth after sub soiling (T_3). On the contrary soil structure at the greater depth could not be improved with minimum tillage. Further, it's noteworthy to indicate the relation between changes in the amount of water with corresponding changes in the values of bulk density. It was observed that there was a linear negative relationship with these two soil physical characteristics. On similar lines, Rajkanan *et al.* (2001) [21], Borghei *et al.* (2008) [5], Parvin *et al.* (2014) [20] and Wang *et al.* (2019) [31] also reported that deep tillage significantly decreased soil bulk density.

Table 3: Bulk Density (Mg/m^3) of soil as influenced by treatments

Treatment	Bulk density (Mg/m^3) at 0-15 cm soil depth				
	At sowing	20 DAS	40 DAS	60 DAS	80 DAS
Tillage management					
T_1- Conservation tillage	1.30	1.33	1.31	1.33	1.33
T_2- Minimum tillage	1.30	1.32	1.30	1.31	1.33
T_3- Sub-soil tillage	1.28	1.26	1.26	1.26	1.30
T_4- Conventional tillage	1.27	1.26	1.29	1.29	1.31
T_5- Roto tillage	1.30	1.32	1.31	1.32	1.32
SE (m) ±	0.01	0.02	0.01	0.02	0.01
CD (P=0.05)	NS	0.06	0.04	0.06	0.02
Nutrient management					
N_1- 100% RDF	1.31	1.33	1.31	1.32	1.33
N_2- 75% RDF+2 t/ha FYM	1.28	1.28	1.29	1.29	1.31
N_3- 50% RDF+4 t/ha FYM	1.28	1.28	1.28	1.29	1.30
SE (m) ±	0.01	0.01	0.01	0.01	0.01
CD (P = 0.05)	NS	0.04	0.02	NS	0.02
Interaction					
SE (m) ±	0.02	0.03	0.02	0.04	0.02
CD (P = 0.05)	NS	NS	NS	NS	NS
GM	1.29	1.30	1.29	1.30	1.32

By and large, higher bulk density (1.31 to 1.33 Mg/m^3) was noticed with nutrient management of 100% RDF, significantly at 20, 40 and 80 days stage. Comparatively, FYM integrated treatments of 50% RDF + 4 t/ha FYM and 75% RDF+2 t/ha FYM recorded lower bulk density being at par with each other. Bulk density of soil is inversely proportional to the soil moisture content and porosity of soil as these lead to increase in soil volume. So it is logical to assume that 100% RDF gave maximum value of bulk density. Pagliai *et al.* (2004) [19], Hati *et al.* (2006) [8] and Aziz *et al.* (2019) [3] expressed similar views of lower bulk density with integration of organic manures (FYM) with NPK.

Mean weight Diameter [MWD] (mm), rate of infiltration [RI](cm hr^{-1}) and Hydraulic conductivity [HC] (cm hr^{-1})

A perusal of Data in Table 3 showed that, Mean weight diameter was found to be significantly improved with subsoil treatment (ST) ranging from 0.74 and 0.76mm and conventional tillage (CvT) ranging from0.73 and 0.75 mm at sowing and at harvest of the crop, indicating improved soil aggregation status, indicating suitability of the tillage practice both for greater underground storage of moisture and improved aeration, that too under inadequate and excess rainfall situations. Rate of infiltration was found to be significantly highest with subsoil treatment (2.81 and 2.39cm hr^{-1}) followed by with conventional tillage treatment (2.67 and 2.33cm hr^{-1}) whereas in conservation tillage (2.04 and 1.82 cm hr^{-1}) when recorded at sowing and at crop harvest. Hydraulic conductivity of the soil under saturated condition was significantly improved with subsoil treatment (ST) and conventional tillage (CvT) assuring adequate moisture availability at the lower soil profile. Due to consistent lower bulk density with ST and CvT, it can be assumed that status of porosity (macropores) must have been improved, which ultimately metered the aeration, supporting greater multiplication of aerobic microorganisms within the soil layer causing stabilized aggregates of higher diameter. Hence, it can be stated that under vertisol with semi-arid climatic conditions, the intensive tillage with sub soiling significantly improves the water stable aggregates as compared to minimum tillage, which result in improvement in MWD, RI and HC in deep tillage treatment as compared to shallow tillage treatment. These results are in conformity with those obtained by, Mikha and Rice (2004) [14], Pagliani *et al.* (2004) [19], Oswal (2007) [17] and Alvaro-Fuentes *et al.* (2008) [1].

Table 4: Mean weight Diameter, Rate of infiltration and Hydraulic conductivity of soil of soil as influenced by treatments.

Treatment	Mean Weight Diameter (mm)		Rate of Infiltration (cm hr^{-1})		Hydraulic conductivity (cmhr^{-1})	
	At sowing	At harvest	At sowing	At harvest	At sowing	At harvest
A) Tillage Management						
T_1- Conservation tillage	0.64	0.64	2.04	1.82	2.16	1.97
T_2- Minimum tillage	0.66	0.69	2.20	1.96	2.43	2.31
T_3- Sub-soil tillage	0.74	0.76	2.81	2.39	3.03	2.67
T_4- Roto tillage	0.68	0.70	2.57	2.31	2.87	2.50
T_5- Conventional tillage	0.73	0.75	2.67	2.33	2.90	2.57
SE (m) ±	0.00	0.02	0.04	0.03	0.07	0.07
CD (P=0.05)	0.01	0.05	0.11	0.11	0.22	0.23
B) Nutrient Management:						
N_1- 100% RDF	0.68	0.71	2.46	2.15	2.67	2.39
N_2- 75% RDF+2 t/ha FYM	0.69	0.71	2.46	2.16	2.68	2.40
N_3- 50% RDF+4 t/ha FYM	0.69	0.71	2.46	2.17	2.68	2.41
SE (m) ±	0.00	0.00	0.00	0.00	0.00	0.00
CD (P = 0.05)	NS	NS	NS	0.01	0.00	0.01
C) Interaction: Tillage x Nutrient Management						
SE (m) ±	0.01	0.01	0.01	0.01	0.00	0.01
CD at 5%	NS	NS	NS	NS	NS	NS
GM	0.69	0.71	2.46	2.16	2.68	2.40

Nutrient management treatments influenced Mean Weight Diameter, Rate of infiltration and Hydraulic conductivity non-significantly. When various nutrient management treatment were compared among each other, higher values were recorded in treatments with 50RDF, followed by 75RDF for MWD, RI and HC. It might have resulted from addition of organic matter added through FYM and soybean straw increase the soil aeration and the oxygen level due to decomposition of organic matter added by FYM and root channel formed due to deep rooted crops increase soil aeration and soil's ability to hold water, whereas 100%RDF treatments recorded less values for above said properties at sowing and at harvest. Considering other things constant, the inferior performance due to CnT could attribute to its failure to offset soil compaction. Such a phenomenon was reported in their studies by Laddha and Totawat (1997) [11], Soltanabadi *et al.* (2008) [28], Rasmussen (1999) [22].

The interaction effect due to tillage with any of nutrient management treatment could not be obtained significantly.

Energy studies

Energetics means science of energy. Therefore in relation to crops or cropping system, energetics is an approach to gauge, quantify and determine relationship between action and reaction, input and output energy to augment energy use efficiency and crop productivity both singly and in various adoptable combinations. Energy equivalents of different inputs and energy coefficients of various equipment/machinery have been used as given in Mittal *et al.* (1985) [15]. Energy output (MJ/ha) of the crop was worked out by multiplying the energy coefficients with seed/grain and straw separately and recorded as MJ/ha. Data on energetics as influenced by different treatments are presented in Table 05. The mean energy input amounted to 6373 MJ/ha.

Energy output

Energy output varied significantly among various tillage management practices. Significantly higher energy output (62643 MJ/ha) was obtained with subsoil tillage (T_3) which was at par with conventional tillage (T- 60413 MJ/ha). The latter was at par with roto tillage (T_4- 57438 MJ/ha). Conservation tillage (T_1) recorded the lowest energy output (52357 MJ/ha) being at par with minimum tillage (T_2, 54622 MJ/ha). This is a consequence of higher yield output in deep tillage treatments of subsoil tillage and conventional tillage. This corroborates the findings of who observed maximum output energy in conventional tillage as compared to minimum tillage and zero tillage in soybean crop.

Amongst the nutrient management practices studied, application of 100% RDF (N1) recorded significantly higher energy output value (59536 MJ/ha) as compared to N2-75% RDF+ FYM @ 2 t/ha (56970 MJ/ha) and N3-50% RDF+ FYM @ 4 t/ha (55978 MJ/ha). This could be attributed mainly to the higher yield levels and consequent higher energy output of soybean under 100% RDF. Treatment interactions did not reach to the level of significance.

Table 5: Energetics as influenced by different treatments

Treatment	Energy output (MJ/ha)	Energy Input (MJ/ha)	Energy balance (MJ/ha)	Energy balance /unit input (MJ/ha)	Energy output/ input ratio
Tillage management					
T_1- Conservation tillage	52357	5361	46995	8.77	9.77
T_2- Minimum tillage	54622	6053	48569	8.02	9.02
T_3- Sub-soil tillage	62643	7300	55343	7.58	8.58
T_4- Roto tillage	57438	6053	51385	8.49	9.49
T_5- Conventional tillage	60413	7095	53318	7.51	8.51
SE (m) ±	1351	--	1351	--	--
CD (P = 0.05)	4407	--	4407	--	--
Nutrient management					
N_1- 100% RDF	59536	6485	53050	8.18	9.18
N_2- 75% RDF+2 t/ha FYM	56970	6373	50597	7.94	8.94
N_3- 50% RDF+4 t/ha FYM	55978	6260	49719	7.94	8.94
SE (m) ±	724	--	724	--	--
CD (P = 0.05)	2137	--	2137	--	--
Interaction					
SE (m) ±	1620	--	1620	--	--
CD (P = 0.05)	NS	--	NS	--	--
GM	57495	6373	51122	8.02	9.02

Energy input

Energy input varied under different tillage management. Subsoil tillage (T_3) required maximum energy input value (7300 MJ/ha) closely followed by T_4-conventional tillage (7095 MJ/ha). Minimum tillage (T_2) and roto tillage (T_2) required similar energy input value (6053 MJ/ha). Conservation tillage needed the lowest energy input value (5361 MJ/ha).This was due to the fact that subsoil tillage and conventional tillage needed more machine and labour energy comparative to remaining the tillage management practices.

Marked differences were not observed in energy input value among different nutrient management practices. Application of 100% RDF (N_1) required numerically higher energy input value (6485 MJ/ha) followed by N_2-75% RDF+ FYM @ 2 t/ha (6373 MJ/ha) and N_3-50% RDF+ FYM @ 4 t/ha (6260 MJ/ha). This could be attributed to the higher energy input value of NPK in 100% RDF treatment and quite close total energy input value of reduced NPK integrated with higher quantity of FYM.

Energy balance

The mean energy balance was 51122 MJ/ha. Energy balance differed significantly due to various tillage managements. Significantly higher energy balance (55343 MJ/ha) was obtained with subsoil tillage (T_3) which was at par with conventional tillage (T_4, 53318 MJ/ha). The latter was at par with roto tillage (T_5, 51385 MJ/ha). Conservation tillage (T_1) recorded the lowest energy balance (46995 MJ/ha) being at par with minimum tillage (T_2, 48569 MJ/ha). This was due to higher energy output in deep tillage treatments of subsoil tillage and conventional tillage reflecting in relatively higher energy balance.

Application of 100% RDF (N_1) recorded significantly higher energy balance (53050 MJ/ha) as compared to N_2-75% RDF+ FYM @ 2 t/ha (50597 MJ/ha) and N_3-50% RDF+ FYM @ 4 t/ha (49719 MJ/ha). This could be attributed mainly to the higher energy output under 100% RDF. Interaction effects were found to be statistically non-significant.

Energy balance per unit input

Data as regards energy balance/unit input as influenced by different treatments are presented in Table 05. The mean energy balance /unit input was 8.02 MJ/ha.

Maximum value of energy balance /unit input was observed with T_1-conservation tillage (8.77 MJ/ha) followed by T_5-roto tillage (8.49 MJ/ha) and T_2-minimum tillage (8.02 MJ/ha). Comparatively, deep tillage management practices of T_3-subsoil tillage (7.58 MJ/ha) and T_4-conventional tillage (7.51 MJ/ha) recorded lower energy balance/unit input which could be due to the higher energy input in these treatments.

Nutrient management practices did not differ markedly in respect of energy balance /unit input. However, numerically higher energy balance /unit input was observed with 100% RDF (8.18 MJ/ha) followed by 75% RDF+ FYM @ 2 t/ha and 50% RDF+ FYM @ 4 t/ha both of which recorded similar value of energy balance /unit input of 7.94 MJ/ha. This could be attributed mainly to the comparatively higher energy output under 100% RDF.

Energy output: input ratio

The mean energy output/ input ratio was 9.02.Conservation tillage (T_1) recorded the maximum energy output/ input ratio (9.77) closely followed by T_5-roto tillage (9.49 MJ/ha) and T_2-minimum tillage (9.02 MJ/ha). Conventional tillage (T_4) recorded the minimum energy output/ input ratio of 8.51, whereas subsoil tillage (T_3) also recorded lower energy output/ input ratio of 8.58. Lower energy output/ input ratio in deep tillage treatments of subsoil tillage and conventional tillage could be mainly due to the higher energy input in these treatments. This is in conformity with the findings of Singh *et al.*(2008) [25] who reported the maximum output: input energy ratio in zero tillage ZT for soybean–lentil followed by minimum tillage for soybean–pea cropping system.

Marginal differences were observed among the nutrient management practices in respect of energy output/ input ratio. However, numerically higher energy output/ input ratio was observed with 100% RDF (9.18 MJ/ha) followed by 75% RDF+ FYM @ 2 t/ha and 50% RDF+ FYM @ 4 t/ha both of which recorded similar value of energy balance /unit input value of 8.94 MJ/ha. This could be due to the comparatively higher energy output under 100% RDF.

Yield attributes of soybean

Yield contributing characters i.e. no. of pods plant^{-1}, seed weight plant^{-1}, no. of seed pod^{-1}, test weight etc. designate the ability of the soybean plant to convert the plant metabolites in to final plant product. Management practices largely influences the plant and soil environment, affecting the plant growth and development, and similarly the physico-chemical properties of soil. The changes thus induced due to managerial involvement are precisely reflected in the yield attributes of the plant. Hence, any significant differences observed in the values of various yield attributes can directly be correlated with the treatment effects. Therefore, an effort has been made to measure all these characters to the highest extent of accuracy. The relevant data is placed at Table 06.

Number of pods plant^{-1}, seed weight plant^{-1}, 100 seed weight, 31.02,6.58 g 6.25g 11.27g respectively was found significantly highest with subsoil tillage, except number of seed pod^{-1}and test weight (2.48). Whereas, in the conservation tillage treatment consisting of tillage with only one blade harrow (CnT) could not produce higher performance in yield attributes. Performance of both the shallow tillage i.e. Roto and Minimum tillage treated plot in respect yield attributes was found intermediary.

From the perusal of yield attribute figures in Table 06, it is obvious that changes in management practices, especially by way of modifying the depth and intensity of preparatory tillage, might have resulted in obtaining significant differences in the yield attributes of soybean crop in vertisols. The vertisol is mostly dominated by smectite and feldspar clay minerals. These soils swells when moistened and shrinks when dried. Most significant character of such soil is that it requires optimum conditions of moisture for improving its physical status, or otherwise physical properties improves under optimum moisture status, which in present investigation, might have been provided by way subsoil in treatment (ST) and CvT, resulting in soil with all the favorable physical characters, reflecting in healthy plant growth through profuse root system, as compared to other treatments, eventually producing higher amount of metabolites and carbohydrates, and their successful diversion towards the final plant product, i.e. pods and the grains. Conversely, the physical status of soil was much inferior in MT and CnT than that of ST, causing unsatisfactory growth of plant. Kayombo (2000) [10], Singh and Sharma (2005) [27], Samra and Dhillon (2000) [23] also found the increased growth and yield attributes

Table 6: Yield attributes as influenced by different treatments

Treatment	Pods/ plant	Seed weight / plant (g)	Seeds/pod	100 seed weight (g)
Tillage management				
T_1- Conservation tillage	24.84	5.04	2.48	10.46
T_2- Minimum tillage	25.78	5.42	2.46	10.55
T_3- Sub-soil tillage	31.02	6.58	2.48	11.27
T_4- Roto tillage	25.67	5.67	2.52	10.68
T_5- Conventional tillage	27.02	6.09	2.59	11.16
SE (m) ±	0.44	0.16	0.06	0.22
CD (P = 0.05)	1.44	0.51	NS	0.72
Nutrient management				
N_1- 100% RDF	28.81	6.22	2.52	11.06
N_2- 75% RDF+2 t/ha FYM	26.77	5.71	2.54	10.82
N_3- 50% RDF+4 t/ha FYM	25.01	5.35	2.45	10.77
SE (m) ±	0.69	0.18	0.06	0.21
CD (P = 0.05)	2.05	0.54	NS	NS
Interaction				
SE (m) ±	1.55	0.41	0.14	0.47
CD (P = 0.05)	NS	NS	NS	NS
GM	26.87	5.76	2.50	10.82

Yield attributes mentioned above significantly influenced by different nutrient management treatments over 50RDF treatment except test weight. Nutrient regime of 100% RDF recorded significantly higher number of pods plant-1 (28.81), seed weight/ plant^{-1} (6.22 g) and it was on par with the nutrient regime of 75RDF (26.04). Nutrient regime of 50RDF recorded the lowest values for yield attributes and being statistically equal to 75RDF. Under various nutrient management regimes, the mean values of yield attributes were higher when the crop was fertilized with 100% RDF which could be attributed to higher vegetative attributes that led to higher accumulation of photosynthates for pod development indicating that the said nutrient management enabled the crop to express the inherent potential to the maximum.100% RDF proved statistically comparable to 75RDF. This is in line with the findings of Chaturvedi and Chandel (2005) [6], Deshmukh *et al*. (2005) [7], Maheshbabu *et al*. (2008) [12], Shivakumar and Ahlawat (2008) [24] and Hati *et al*. (2006) [8].

Seed yield, biological yield (kg ha^{-1}) and Harvest Index (%)

Economically, seed yield is an end product of soybean crop production, and physiologically a cumulative result of many factors applied to the crop right from pre-sowing operations to the harvest of the crop. Moreover, studies of soil physical properties and plant growth parameters are much more immediate (direct) measures of the plant response to applied treatments than yield. The relevant data as obtained are presented in Table 07.

Different tillage management had a significant influence on the seed yield and biological yield of soybean. From the data, it revealed that subsoil tillage (ST) recorded significantly higher seed yield (2184 kg ha^{-1}), biological yield (4627 kg ha^{-1}) which was statistically at par with conventional tillage (CvT) for seed yield (2040kg ha^{-1}) and biological yield (4474 kg ha^{-1}). Seed yield and straw yield recorded under conventional tillage (CvT) and roto tillage (RT) was comparable. Lowest seed yield, and biological yield was recorded with conservation tillage (1740 and 3882 kg ha^{-1}) which was statistically comparable to minimum tillage treatment (1820 and 4049 kg ha^{-1}). Harvest index was also highest in ST (47.17%) followed by CvT (45.57%), RT (45.33%), MT (44.93%) and CnT (44.81%).

Superior yield level with subsoil tillage and conventional tillage was due to better expression of growth characters - leaf area, branches and dry matter accumulation resulting in increased yield components. In fact these tillage treatments benefitted the crop through availability of more moisture through better absorption and retention of water, greater root proliferation through loose and porous soil strata and in turn better nutrition to plants. It indicates that plant did not respond well to shallow tillage which might be due to non-improvement of soil physical status with shallow tillage operation. This is also in accordance with the findings of Ferhat Ozturk and Tahsin Sogut (2016) [32]; and Mourtzinis *et al*. (2017) [16], reported that deep ploughing allows maximum absorption of rain water and reduces weed populations at the initial stage of crop growth.

Table 7: Seed yield, biological yield and harvest index as influenced by different treatments

Treatment	Seed yield (kg/ha)	Biological (kg/ha)	Harvest index (%)
Tillage management			
T_1- Conservation tillage	1740	3882	44.81
T_2- Minimum tillage	1820	4049	44.93
T_3- Sub-soil tillage	2184	4627	47.17
T_4- Roto tillage	1929	4256	45.33
T_5- Conventional tillage	2040	4474	45.57
SE (m) ±	46	101	-
CD (P = 0.05)	151	330	-
Nutrient management			
N_1- 100% RDF	2020	4407	45.76
N_2- 75% RDF+2 t/ha FYM	1942	4216	46.00

N_3- 50% RDF+4 t/ha FYM	1865	4150	44.92
SE (m) ±	35	53	-
CD (P = 0.05)	104	156	-
Interaction			
SE (m) ±	79	118	-
CD (P = 0.05)	NS	NS	-
GM	1942	4258	45.56

Economics of the treatment

Considering the prevailing cost of labors and inputs required for different treatments, economics of different treatments *viz*. Cost of cultivation, Gross Monetary Return, Net Monetary return and B:C ratio were worked out and presented in Table 08.

Cost of cultivation (Rs ha^{-1})

Cost of cultivation (Rs/ha) differed to some extent due to tillage operations of various magnitudes in different tillage management treatments. Maximum increase in cultivation cost was noted with conventional tillage treatment (Rs.33750 ha^{-1}) which might be due to increased number of tillage operations (1 ploughing+ 2 tyne harrowing+1 blade harrowing at vertical depth of 25-30 cm). It was followed by subsoil tillage (Rs.32050 ha^{-1}) and Roto tillage (Rs.31525). Minimum Tillage & Conservation tillage treatment showed the minimum cost of cultivation (Rs.31175 ha^{-1}) and (Rs.30150 ha^{-1}) due to only 1 tyne harrowing+ 1 blade harrowing and 1 disc harrowing respectively. Fortuitous rise in cost of cultivation (Rs.31175 ha-1) and (Rs.30150 ha^{-1}) with minimum tillage practice (MT) and conservation tillage (CnT) likely due to an extra expenditure incurred towards controlling the weeds in those plots by way using herbicides and additional hand weeding and hoeing operation with MT and CnT. Blaise *et al*., (2005) [4] also reported that herbicide is the single most costly input.

Table 8: Economics as influenced by different treatments

Treatment	COC (Rs/ha)	GMR (Rs/ha)	NMR (Rs/ha)	B:C ratio
Tillage management				
T_1- Conservation tillage	30150	60892	30742	2.06
T_2- Minimum tillage	31175	63687	32512	2.08
T_3- Sub-soil tillage	32050	76423	44373	2.44
T_4- Roto tillage	31525	67505	35981	2.18
T_5- Conventional tillage	33750	71410	37660	2.17
SE (m) ±	--	1622	1622	--
CD (P=0.05)	--	5291	5291	--
Nutrient management				
N_1- 100% RDF	27463	70696	43233	2.57
N_2- 75% RDF+2 t/ha FYM	29997	67979	37982	2.26
N_3- 50% RDF+4 t/ha FYM	37729	65275	27546	1.73
SE (m) ±	--	1231	1231	--
CD (P = 0.05)	--	3633	3633	--
Interaction				
SE (m) ±	--	2753	2753	--
CD (P = 0.05)	--	NS	NS	--
GM	31730	67983	36254	2.19

COC- Cost of cultivation, GMR-Gross Monetary Returns, NMR Net Monetary Returns, B: C – Benefit: Cost ratio

Higher cost of cultivation was noted with 50RDF (Rs.37729 ha^{-1}) followed by treatment 75RDF (Rs.29997 ha^{-1}) and 100% RDF (Rs.27463 ha^{-1}). Differences in cost of cultivation with various nutrient management treatments were due to variations in the application rate of chemical fertilizers and FYM.

Gross monetary return (GMR Rs. ha^{-1})

Among tillage management practices, Gross Monetary Returns was maximum with ST-Subsoil tillage (Rs.76423 ha^{-1}) which was at par with CvT-Conventional tillage (Rs.71410 ha^{-1}) and significantly superior over rest of the tillage treatments. Tillage Treatment CvT statistically significant to roto tillage (Rs.60892 ha^{-1}). Conservation tillage (CnT) and MT-minimum tillage are at par to each other recorded the lowest GMR (Rs.60892ha^{-1}) on par with (Rs.63687 ha^{-1}) respectively. Deep tillage treatments of subsoil and conventional tillage resulted in better growth and yield attributes and consequently higher yield output and in turn higher gross monetary returns. Usman *et al*. (2013), Heatherly and Spurlock (2001) [9], Singh *et al*. (2008) [25] also reported an increase in GMR with greater intensity of tillage in cotton.

In case of nutrient management treatment, GMR was significantly influenced, application of 100% RDF recorded significantly higher GMR (Rs. 70696 ha^{-1}) which was significantly superior over the treatment of 75% RDF+ 2 t FYM ha^{-1} (Rs.67979 ha^{-1}) and 50% RDF+ 4 t FYM ha^{-1} (Rs.65275 ha^{-1}).The latter two treatments were statistically at par. Higher yield output under 100% RDF and 75RDF resulted in higher gross monetary returns.

Net monetary return (Rs. ha-1)

Subsoil tillage with NMR Rs.44373 ha^{-1} was statistically equal with Conventional tillage (CvT) with NMR Rs.37660 ha^{-1} are significantly superior over rest of the tillage treatments. Tillage practices where tillage intensity was kept to the minimum extent did not improve NMR as Minimum tillage (MT) recorded the lowest NMR (Rs.32515 ha^{-1}) at par with Conservation tillage (Rs.30742 ha^{-1}).

Nutrient management practices significantly influenced net monetary return. Application of 100% RDF recorded significantly highest NMR (Rs. 43233ha^{-1}) than treatment of 75RDF (Rs37982 ha^{-1} and 50RDF (Rs.27546 ha^{-1}). Higher yield output with 100% RDF and 75RDF resulted in higher net monetary returns. The interaction effect due to tillage with any of nutrient management treatment could not be obtained significantly for GMR and NMR.

B: C ratio

Benefit: cost ratio (B: C ratio) as influenced by different treatments are presented in Table 08. It is evident from the data that as compared to the cost incurred towards cultivation of crop, almost two-fold or more than that benefit was noticed as the mean value of B: C ratio was 2.19.

Difference in tillage management resulted in variation of B: C ratio. Maximum benefit cost ratio 2.44 was observed with subsoil tillage (ST) followed by Roto tillage 2.18 Conventional tillage 2.17.Comparatively, shallow tillage practices minimum tillage (2.08), conservation tillage recorded 2.06. Singh *et al*. (2008) also found greater benefit to the cost ratio of various crops grown with greater tillage intensity.

Nutrient management with application of 100% RDF recorded the maximum B:C ratio (2.57) followed by treatment of 75% RDF+ 2 t FYM ha^{-1} (2.26) and the lowest with application 50% RDF+ 4 t FYM ha^{-1} (1.73).

Conclusions

According to finding of this study, rain fed soybean with subsoil tillage (one subsoil + one tyne harrowing + one rotavator) exhibited better growth and yield attributes and recorded significantly higher seed yield and at par with Conventional Tillage (one ploughing + two tyne harrowing + one blade harrow).Nutrient management with 100% RDF (30:75:30 NPK $kgha^{-1}$), being comparable to 75% RDF+FYM 2t ha^{-1}, resulted in higher growth and yield attributes and seed yield of soybean. Improvement in soil physical properties *viz*., soil moisture content, porosity, mean weight diameter, rate of infiltration, Hydraulic conductivity was observed with tillage practice of subsoil tillage and integrated nutrient management practices of 75% RDF+ 2 t FYM ha^{-1} and 50% RDF+ FYM 4 t ha^{-1}. Significantly higher gross monetary returns and net monetary returns along with maximum benefit: cost ratio were obtained with subsoil tillage and 100% RDF nutrient management. In terms of energetic values, subsoil tillage practice and nutrient management with 100% RDF recorded higher energy output and energy balance, however conservation tillage practice recorded maximum energy balance per unit input and higher energy output: input ratio.

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