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Tillage practices for enhancing yield and physical properties of soils of soybean in vertisols

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Abstract
A field experiment was conducted to assess the effect of tillage on soil physical properties and yield of soybean at agronomy farm Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during Kharif season of 2011-12. The experiment was laid out in randomized block design with five tillage treatments replicated four times. The tillage treatments constituted of conservation tillage (one harrowing by blade harrow), conventional tillage (one ploughing + one harrowing by tyne cultivator + one harrowing by blade harrow), very deep tillage (one subsoiler + one ploughing + one harrowing by tyne cultivator + one harrowing by blade harrow), shallow tillage by tractor (one tyne cultivator + one blade harrow), shallow tillage by bullock (one ploughing by MB plough + two harrowing by bakhar). The other intercultivation practices were kept common as recommended. Significant differences were observed for the soil physical parameters when various tillage treatments were compared with each other during the course of present investigation. The values of soil physical properties like dry bulk density, penetration resistance (cone index) were found to be the significantly lowest in very deep tillage treatment comprising of sub soiling. Similarly, the values of other physical parameter *viz*., soil porosity and hydraulic conductivity were increased to a level of significance in treatment where sub soiling was undertaken. The values of yield attributes and yield of soybean were increased in treatment of sub soiling as compared with other tillage treatments. Thus, it can be concluded that under the rainfed soybean with the package of tillage operations including one sub soiling + one ploughing +two harrowing can give the highest crop yield and improves the soil physical properties of Vertisols.

Keywords: Tillage practices, vertisols, soybean, sub soiling

Introduction
Over the last few decades there has been increasing interest in environmentally sound soil management. When the soil is compacted, deep loosening gave higher yield and quality. According to the statistics of FAO, the total area of minimum or Conservation tillage has reached 169 million hectares all over the world, and in China, it has been about 20 million hectares from the early 1990's (Zhang *et al*., 2005) [21]. Compared to the traditional plough tillage, conservation tillage is a novel technique. It can increase soil water content, prevent soil erosion caused by wind and water and reduce soil degradation via minimum-tillage, no tillage, and crop covering. Subsoiling was accomplished by using a subsoiler at a soil depth ranging from 30 to 40 cm which showed that it is beneficial to ecology (Guo, 2005) [10]. Subsoiling will not overturn the top-soil but disturbs and breaks the plow layer, which result in improving the permeability of soil water, creating a "water reservoir" underneath the soil surface, increasing the efficiency of rainwater use and improving the ability of water conservation in arid areas. Subsequently, subsoiling can minimize the effect of drought and lead to an increase in crop yield (Gao *et al*. 1995) [7]. Wang *et al*. (2009) [18] found that in comparison with traditional tillage, subsoiling technique caused an increase in winter wheat yield by 18.8 per cent and water use efficiency was also increased by 16 per cent. Therefore, under shallow and deep cultivation conditions, the precise comparison is necessary. Soil temperature, water content, bulk density, porosity, penetration resistance, and aggregate distribution are some of the physical properties affected by tillage systems. Changes in soil physical properties due to use of no tillage depend on several factors including differences in soil properties, weather conditions, history of management, intensity, and type of tillage. Several authors found greater soil bulk density under conservation tillage than conventional tillage (Hammel 1989) [11]. while others did not find the differences (hill and Cruse, 1985, Chang and Llndwall, 1989) [12, 5], or obtained lower values of bulk density under soils with a residue layer on the surface (Edwards *et al*., 1992) [6]. Soybean is a major crop grown in Maharashtra as well as in Vidarbha region.

At this time, wide range of tillage methods are being used in Vidarbha region without evaluating their effects on soil physical or engineering properties and crop yield. There is a need to standardize the package of practices for higher yield of soybean. Therefore, the present investigation was planned to determine the effect of different practices of soil physical properties on soybean production. Hence, the outcome of present investigation will certainly be beneficial to the farmers of this region on long term basis.

Material and Methods

This field experiment was conducted on the Research Farm of Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *kharif* 2011-12. Treatments are given as T_1- (one harrowing by blade harrow), T_2- (one ploughing + one harrowing by tyne cultivator + one harrowing by blade harrow), T_3- (one sub soiler + one ploughing + one harrowing by tyne cultivatior + one harrowing by blade harrow), T_4- (one tyne cultivator + one blade harrow), T_5- (one ploughing by MB plough + two harrowing by bakhar) statistically analyzed with Randomized Block Design with four replications. Soil of experimental site was moderately alkaline in reaction (8.2), medium in organic carbon (0.50 %) content and having swell shrink property. The soil is low in nitrogen (221.50 kg ha^{-1}), medium phosphorus (14.33 kg ha^{-1}) and high in available potassium (371 kg ha^{-1}). The yield and yield attributes of soybean was recorded. The treatment wise soil samples were collected at the harvest of soybean, processed and analyzed for Bulk density core method (Blake and Hartze, 1986), Porosity (R. A. Singh, 1980), Hydraulic conductivity (Klute and Dirksen, 1986), Penetration resistance Cone Penetrometer method (Perumpral, J.V., 1987) and statistical analyzed by (Gomez and Gomez, 1984).

Results and Discussion

Grain and Straw yield

In respect of grain and straw yield, it can be stated that significantly higher yield was recorded by conventional tillage (24-25 cm) to very deep tillage (55-60 cm) which was practices in Table 1. The yield was recorded respectively to the tune of (16.87 q ha^{-1} and 13.86 q ha^{-1}). Shallow tillage by tractor (14-16 cm depth) and shallow tillage by bullock (16-18 cm depth) also performed better in getting maximum yield respectively to the tune of (12.18 q ha^{-1} and 13.05 q ha^{-1}) over conventional tillage practice. The proportionate increase in the yield of straw was registered when soil manipulating was increased from conservation tillage (8-10 cm) to very deep tillage (55-60cm); the straw yield was registered in the range of (11.88 to 20.84 q ha^{-1}). The highest straw yield to an extent of (20.84 q ha^{-1}) was recorded in very deep tillage (SS+CvT). This treatment was statistically superior over all the remaining tillage treatments and was followed by treatment conventional tillage (CvT) with the stover yield of (18.12 q ha^{-1}.) The third highest yield of stover was recorded in the treatment shallow tillage by bullock (STB) with the value of (16.44 q ha^{-1}). It can be inferred that soybean responded as well to the deep to very deep tillage practices due to increase in root length and root density as a result of deep tillage. Similar results observed by Ghosh *et al.* (2006) [8], though there was reduction in growth and yield of intercrops, higher soybean equivalent yield (SEY) and area- time equivalent ratio (ATER) value in soybean - pigeonpea intercropping system as compared to sole soybean had a yield advantage. The average yield advantage in intercropping system was 60 per cent higher than that from sole soybean. The yield advantage of intercropping system in terms of ATER was 7 per cent greater with subsoiling than conventional tillage. A field trail was conducted during kharif season of 2003 at Junagarh on pigeonpea in clayey soil to evaluate the effect of different tillage practices and mulches on growth and yield of crop as well as on moisture conservation. Among the different tillage practices, 30 cm deep ploughing by tractor plough registered significantly higher plant height, spread as well as grain straw yield of pigeonpea. This treatment also recorded higher soil moisture content at flowering and pod stage, indicating more conservation of rain water under deep tillage.

Table 1: Effect of different tillage practices on grain and straw yield of soybean

Treatments	Yield (q ha^{-1})	
	Grain	Straw
CnT	10.71	11.88
CvT	13.86	18.12
SS+CvT	16.87	20.84
STT	12.18	15.10
STB	13.05	16.44
SE(m) $\pm$	0.42	0.75
CD at 5%	1.42	2.32

Effect of various tillage practices on physical properties of soil.

Effect of tillage practices on bulk density (0-15 cm)

The Data in respect of bulk density at the depth 0-15 cm influenced by various tillage practices are presented in Table 2. In general, the bulk density was increased upto 30 days, thereafter, it is decreased and at 90 DAS and at harvest, further, it was inclined. The lowest value of bulk density (1.27 Mg m^{-3}) was recorded where soil manipulated with very deep tillage (SS+CvT). The other tillage treatments were found to be intermediate in terms of bulk density. Similar trend was recorded at 30, 60 and 90 DAS. At harvest, the significantly lowest value of bulk density (1.36 Mg m^{-3}) was recorded with the very deep tillage (SS+CvT) followed by conventional tillage (CvT) and shallow tillage by bullock (STB) (1.407 Mg m^{-3} 1.456 Mg m^{-3}). The significantly highest bulk density (1.45 Mg $m^{-3)}$ was recorded treatment conservation tillage (CnT). Treatment shallow tillage by tractor (STT) was found to be intermediate. Similar results recorded by Bruce *et al.* (1990) [4] reported that the bulk density of Vertisol reduced significantly in conventional tillage than in minimum tillage and conservation tillage. Salinas-Garcia *et al.* (1997) [17] reported that the soil bulk density increased with depth and was significantly influenced by tillage treatment at all sampling depth, deeper tillage system (mould bould plough and chisel plough) generally exhibited lower bulk densities as compared to the shallower tillage (minimum tillage) and no tillage treatments.

Table 2: Bulk density of soil at 0-15 cm depth as affected by various tillage practices

Treatments	Bulk density (Mg m^{-3})				
	At sowing	30 DAS	60 DAS	90 DAS	At harvest
CnT	1.325	1.270	1.294	1.378	1.456
CvT	1.291	1.247	1.251	1.301	1.407
SS+CvT	1.275	1.230	1.239	1.287	1.369
STT	1.314	1.258	1.274	1.338	1.448
STB	1.309	1.263	1.265	1.327	1.417
SE(m) $\pm$	0.004	0.003	0.003	0.009	0.004
CD at 5%	0.012	0.010	0.011	0.028	0.012

Effect of tillage practices on bulk density at the depth of 15-30 cm

The significantly lowest bulk density (1.47 Mg m^{-3}) was recorded (Table 3) in very deep tillage (SS+CvT) which was followed by conventional tillage (CvT) (1.49 Mg m^{-3}). Significantly highest bulk density (1.51 Mg m^{-3}) was recorded by conservation tillage (CnT), which was at par with shallow tillage by bullock (STB) and shallow tillage by tractor (STT). The consecutive decrease in bulk density were recorded at 30 DAS. From 60 DAS onwards upto harvest the progressive increase in bulk density among all treatments under study was recorded. At harvest significantly lowest bulk density (1.57 Mg m^{-3}) was recorded in very deep tillage (SS+CvT).Treatment conservation tillage (CnT) recorded the highest of bulk density (1.65 Mg m^{-3}), however, the conventional tillage (CvT) (1.60 Mg m^{-3}) and shallow tillage by bullock (STB) (1.62 Mg m^{-3}) were found to be at par with each other. The lowest value of bulk density among all observations under study were found to recorded in very deep tillage (SS+CvT) which may be attributed to higher percentage of moisture and porosity due to subsoiling treatment at depth of 55-60 cm in the present study. Similar results were reported by Rashidi *et al.*, (2007) [16] conducted field experiment and were observed effect of different tillage method on bulk density of soil. They were studied two year experiment and showed that different tillage treatments affected soil bulk density during both the years of study. The highest soil bulk density of 1.52 g cm^{-3} was obtained for no-tillage treatment and lowest bulk density of 1.41 g cm^{-3} for conventional tillage. Borghei *et al.*, (2008) [3] observed that prior to tillage practices, the average bulk density values at soil layers of 0-20, 20-40, and 40-60 cm were 1.24, 1.48 and 1.65 g cm^{-3}, respectively.

Table 3: Bulk density of soil at 15-30 cm depth as affect of various tillage practices.

Treatments	Bulk density Mg m^{-3}				
	At sowing	30 DAS	60 DAS	90 DAS	At harvest
CnT	1.512	1.490	1.492	1.543	1.659
CvT	1.490	1.445	1.450	1.490	1.601
SS+CvT	1.473	1.431	1.435	1.467	1.570
STT	1.523	1.461	1.472	1.520	1.651
STB	1.508	1.455	1.463	1.510	1.621
SE(m) ±	0.004	0.002	0.006	0.001	0.008
CD at 5%	0.013	0.007	0.019	0.005	0.024

Effect of tillage practices on porosity (0-15 cm)

At the time of sowing significantly highest values of porosity (52.07 %) was recorded (Table 4) with very deep tillage (SS+CvT) which was followed by conventional tillage (CvT) (51.32%). The lowest values of porosity were recorded by treatments conservation tillage (CnT) (50.56%) and shallow tillage by tractor (STT) (50.18%). At 30, 60 and 90 DAS the very deep tillage consistently recorded the highest values of soil porosity were found to be statistically lowest during the period of observations and found significantly superior over remaining treatments. It was followed by treatment conservation tillage (CnT) with second best values of soil porosity. The values of soil porosity were found to be statistically lowest during this period of observations. At harvest of the crop the porosity decreased markedly among all the tillage treatments. however, the lowest value of porosity was recorded with treatments conservation tillage (CnT) (45.28%) and shallow tillage by tractor (STT) (45.66%). Among all the tillage treatments very deep tillage (SS+CvT) proved to be superior in terms of porosity percentage by recording the highest value (48.67%), it was followed by conventional tillage (CvT) (47.16%). The higher value of percent porosity may be attributed to lower bulk density and increased moisture content due to very deep tillage treatments supported by the sub-soiler. The soil compaction in treatment CnT might be the cause for lower soil porosity in that treatment. Similar results were reported by Hossain *et al.*, (2004) [14] that soil porosity was statistically influenced by different tillage operation.

Table 4: Porosity of Soil at 0-15 cm depth as affected by various tillage practices

Treatment	Porosity (%)				
	At sowing	30 DAS	60 DAS	90 DAS	At harvest
CnT	50.56	52.07	51.32	48.30	45.28
CvT	51.32	53.20	52.83	50.94	47.16
SS+CvT	52.07	53.58	53.58	51.69	48.67
STT	50.18	52.83	52.07	49.81	45.66
STB	50.94	52.45	52.45	50.18	46.79
SE(m) ±	0.25	0.29	0.19	0.35	0.28
CD at 5%	0.76	0.89	0.61	1.08	0.88

Effect of tillage practices on porosity percent at the depth of 15-30 cm

At the depth of 15-30cm, the per cent porosity (Table 5) was found to be decreased among all the tillage treatments when compared with upper soil layer. At the time of sowing significantly higher porosity (44.52%) was recorded with deep tillage (SS+CvT) which was at par with conventional tillage (CvT) (43.77%). Significantly lowest porosity (43.08%) was recorded in treatment conservation tillage (CnT) which was found to be at par with treatments shallow tillage by tractor (STT) (42.64%) and shallow tillage bullock (STB) (43.03%). Similar trend of porosity was recorded when observed at 30,60 and 90 DAS. At the time of harvest the porosity was significantly higher in treatment very deep tillage (SS+CvT) and it was followed by conventional tillage (CvT), the porosity was recorded to the tune of 39.62 per cent. Significantly lowest porosity was recorded by treatments CnT and STT (37.73% and 37.74%) respectively. Hence, it can be inferred from the above data that the effect of sub soiling persisted to the depth of 30 cm as recorded at all the crop growth stages. Whereas, the lower value of porosity in conservation tillage (CnT) and shallow tillage by bullock (STT) may be attributed to the reduced tillage causing greater soil compaction at the depth of 15-30 cm. Similar results was reported by the Abdullah *et al.*, (2008) [1] studied the relation between crop growing and soil tillage treatment are play important role in agricultural production.

Table 5: Porosity of soil at 15-30 cm depth as affected by various tillage practices

Treatment	Porosity (%)				
	At Sowing	30 DAS	60 DAS	90 DAS	At harvest
CnT	43.01	43.77	43.77	41.88	37.73
CvT	43.77	45.66	45.28	43.77	39.62
SS+CvT	44.52	46.03	46.03	44.90	40.75
STT	42.64	45.28	44.52	42.64	37.73
STB	43.39	44.90	44.90	43.01	38.86
SE(m) ±	0.36	0.16	0.27	0.17	0.13
CD at 5%	1.11	0.46	0.83	0.54	0.49

Effect of tillage treatments on hydraulic conductivity of the soil at the depth of 0-15 cm

The hydraulic conductivity (Table 6) before sowing revealed that, the deep tillage practice very deep tillage (SS+CvT) was recorded significantly highest hydraulic conductivity (0.74 cm hr^{-1}) followed by treatments conventional tillage (CvT) and shallow tillage bullock (STB) with hydraulic conductivity values of 0.65 to 0.61 cm hr^{-1} respectively being at par with each other. The very shallow treatments shallow tillage by tractor (STT) and conservation tillage (CnT), being at par with each other and recorded the hydraulic conductivity to the tune of 0.57 and 0.52 cm hr^{-1} respectively. At harvest the overall hydraulic conductivity values decreased markedly. At this period the hydraulic conductivity found to be significantly superior in deep tillage practices (CvT + SS) (0.58 cm hr^{-1}). It was followed by treatments conventional tillage (CvT) and shallow tillage by bullock practices (STB), being at par with each other, recording the values of hydraulic conductivity in the range of 0.49 and 0.47 cm hr^{-1}repectively. The lowest hydraulic conductivity was found in treatment conservation tillage (CnT) (0.37 cm hr^{-1}) which was at par with treatment shallow tillage by tractor (STT) (0.42 cm hr^{-1}). The movement of water through soil profile is largely dependent on the change in soil volume which ultimately depends upon the reorientation of soil particles and displacement of molecules between particles. The structural arrangement of particles is highly influenced by soil manipulation practices. The higher degree of soil manipulation changes the state of soil compaction by rearranging the particles and changing the volume of soil voids. Hence, in case of treatment very deep tillage (CvT + SS), the higher soil porosity and lower soil might have caused a marked increase in the hydraulic conductivity. Due to reduced tillage in treatment conservation tillage (CnT), caused minimum change in the volume of voids resulting in increased soil compaction and decreased hydraulic conductivity. Similar results were observed by Hirekurbar *et al*. (1991) [13] studied the effect of soil compaction on hydraulic conductivity of Vertisol and observed that the bulk density increased with decrease in hydraulic conductivity.

Table 6: Hydraulic conductivity of soil at 0-15 cm depth as affected by various tillage practices.

Treatments	Hydraulic conductivity (cm hr^{-1})	
	Initial	At harvest
CnT	0.52	0.37
CvT	0.65	0.49
SS+CvT	0.74	0.58
STT	0.57	0.42
STB	0.61	0.46
SE(m) ±	0.005	0.007
CD at 5%	0.016	0.022

Effect of tillage treatment on penetration resistance at 5 cm depth

The penetration resistance values were recorded to be significantly lowest in very deep tillage practices (Table 7). It was up to 113 kPa at the time of sowing and gradually increased up to 276 kPa in treatment SS+CvT. It was followed by conventional tillage which recorded the penetration resistance values in range of 139 kPa to 387 kPa. The highest resistance to soil penetration was recorded in conservation tillage. In this treatment the value of penetration resistance were found in the range of 254 kPa to 427 kPa. The other two tillage practices viz; shallow tillage by tractor and shallow tillage by bullock were found to be intermediates in respect of penetration resistance values. The decrease in penetration resistance values may be ascribed to increased soil porosity and decreased soil bulk density under deep tillage practice. The higher bulk density and lower porosity might be responsible for higher penetration resistance value under conservation tillage. Similar results observed by Kumar *et al.*, (2006) studied soil cone index estimation for different tillage systems.

Table 7: Penetration Resistance (kPa) in depth 5 cm as affected by various tillage practices.

Treatment	Penetration Resistance (kPa)							
	At Sowing	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At Harvest
CnT	254	333	345	358	286	319	364	428
CvT	139	231	243	298	198	222	343	387
SS+CvT	113	214	236	267	136	190	273	277
STT	234	316	329	356	267	294	370	403
STB	224	307	316	324	257	273	367	379
SE (m) ±	1.49	0.63	0.52	0.30	0.51	0.43	0.50	0.54
CD at 5%	4.61	1.94	1.61	0.93	1.59	1.34	1.70	1.66

Effect of tillage treatment on penetration resistance at 10 cm depth

The penetration resistance was decreased significantly (Table 8) with deep tillage practices followed by conventional tillage at all the stages of observation under study. In this treatment the penetration resistance increased from 234 kPa to 362 kPa, in response to the better soil tilth and improved status of moisture. It was followed by conventional tillage practices with penetration resistance values ranging from 311 to 524 kPa. The shallow tillage by tractor and shallow tillage by bullock also recorded moderate values for soil penetration resistance. The highest penetration resistance values in the range of 455 to 707 kPa were found with conservation tillage which indicates the higher strength of soil for root penetration. Being the most critical soil depth for root penetration, it is desirable to have lower penetration values at this depth. Treatment SS+CvT and treatment CvT being deeply ploughed soils, recorded the lower values of penetration resistance when compared with other tillage treatments. Similar results recorded by Rashidi *et al.*, (2007) [16] studied and reported that significant effect of different tillage treatments on soil penetration resistance was also found during the years of study.

Table 8: Penetration resistance at 10 cm depth as affected by various tillage practices.

	Penetration resistance (kPa)							
Treatment	**At Sowing**	**15 DAS**	**30 DAS**	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**	**At Harvest**
CnT	455	523	527	538	464	492	625	708
CvT	311	417	435	462	342	381	498	524
SS+CvT	234	305	319	331	253	296	355	363
STT	342	469	494	510	410	453	530	543
STB	339	339	483	494	405	433	511	537
SE(m) ±	0.39	0.89	0.47	0.77	0.68	0.67	8.88	10.84
CD at 5%	1.22	2.74	1.45	2.39	2.09	2.08	27.35	33.39

Effect of tillage treatment on penetration resistance at of 15 cm depth

Though the values of penetration resistance (Table 9) increased among all tillage treatments at the depth of 15 cm, still very deep tillage recorded its statically superior by keeping the lower values of penetration resistance when compared with other treatments. In these tillage treatments the penetration resistance was recorded in range of 377 kPa to 527 kPa during the stages of observation under study. It was followed by treatment with values of penetration resistance in the range of 460 kPa to 637 kPa. The shallow tillage treatments by tractor and by bullock recorded intermediate values for soil penetration resistance ranging from 687 kPa to 953 kPa was found in conservation tillage. The shallow tillage treatments (STT) and (STB) recorded intermediate values for soil penetration resistance. Significantly highest soil penetration resistance ranging from 687 kPa to 953 kPa was found in conservation tillage. Similar results were recorded by Yavuzcan *et al*., (2002) [19] they studied the effect of three different tillage systems viz; conventional tillage (ploughing down to 23 cm followed by disc harrowing down to 12 cm and combine harrowing down to 8 cm), reduced tillage (horizontal rotary tiller — rotary harrow combination down to a depth of 13 cm) and reduced tillage (vertical rotary tiller — rotary harrow combination down to a depth of 13 cm).

Table 9: Penetration resistance in depth 15 cm as affected by various tillage practices

Treatment	Penetration resistance (kPa)							
	At Sowing	**15 DAS**	**30 DAS**	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**	**At Harvest**
CnT	687	789	796	811	748	771	862	954
CvT	460	552	567	598	504	528	611	638
SS+CvT	377	436	448	463	706	427	494	528
STT	576	628	651	678	588	598	704	720
STB	535	584	609	628	537	565	646	754
SE(m) ±	0.54	0.68	0.81	0.89	0.33	0.53	0.61	0.56

Effect of tillage treatment on penetration resistance (kPa) at 20 cm depth

Significantly highest soil penetration resistance ranging from 906 kPa to 1064 kPa was recorded under conservation tillage treatment (Table 10). The penetration resistance was increased as the days of sowing may be due to effect of cropping and manipulation of soil during the course of experimentation. This may be due to increased porosity resulted less penetration resistance as compared to other tillage practices. It was followed by treatment STT by recording somewhat lower values of penetration resistance. Significantly lowest values of soil penetration resistance in range of 472 kPa to 622 kPa was observed in treatment SS+CvT which were followed by treatment CvT. Similar results were observed by Yavuzcan (2000) [20], studied the effect of seven different tillage systems and reported that the compaction status of the soil generally changed with loosening of soil during tillage.

Table 10: Penetration resistance in depth 20 cm as affected by various tillage practices.

Treatment	Penetration resistance (kPa)							
	At Sowing	**15 DAS**	**30 DAS**	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**	**At Harvest**
CnT	906	956	997	1011	911	935	1042	1064
CvT	584	688	696	710	613	651	721	735
SS+CvT	472	512	527	541	490	496	584	622
STT	713	786	818	821	751	770	834	885
STB	694	774	786	801	743	757	826	848
SE(m) ±	0.92	0.96	0.6	0.9	0.86	0.96	0.59	0.84
CD at 5%	2.85	2.96	1.86	2.77	2.65	2.95	1.84	2.6

Effect of tillage treatment on penetration resistance at depth of 25 cm.

At this depth also, deep tillage practices (SS+CvT) maintained its superior by keeping the lower values when compared with other tillage treatments. In this treatment the range of soil penetration resistance (Table 11) recorded in between 568 kPa to 739 kPa from sowing to harvest of the crop. It was followed by conventional tillage with soil penetration values ranging from 669 kPa to 853 kPa. Significantly highest penetration resistance values (1014 kPa to1253 kPa) were recorded in conservation tillage practices. Shallow tillage by tractor (STT) and shallow tillage by bullock (STB) registered the intermediate values of soil penetration resistance. Recording of consistently lower values of soil penetration resistance with deep and very deep tillage treatments (CvT and SS+CvT) might have been due to increased moisture content, increased soil porosity and decreased soil bulk density values. Therefore, the root penetration of soybean crop might have been improved with these tillage treatments. The conservation tillage treatments (Cnt) could not performed better due to its higher degree of soil compaction resulting from very shallow tillage operations. Similar results observed by Borghei *et al*., (2008) [3] stated that cotton is highly susceptible to soil compaction. Subsoiling effectively alleviates compaction and recovers soil productivity.

Table 11: Penetration resistance in depth 25 cm as affected by various tillage practices

Treatment	Penetration resistance (kPa)							
	At Sowing	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At harvest
CnT	1014	1067	1128	1145	1021	1039	1173	1254
CvT	670	779	808	812	745	764	837	854
SS+CvT	569	632	681	699	583	621	718	739
STT	847	917	935	963	875	884	992	1028
STB	814	881	899	911	821	835	938	970
SE(m) ±	0.38	1.03	0.40	0.82	0.74	0.55	0.65	0.77
CD at 5%	1.18	3.18	1.22	2.54	2.29	1.69	2.01	2.39

Conclusion

It can be concluded that the rainfed soybean with the package of tillage operations including one sub soiling + one ploughing +two harrowing can give the highest crop yield and improves the dry bulk density, penetration resistance, soil porosity and hydraulic conductivity of Vertisols.

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