Changes in Soil Physical Properties and Soybean Productivity under Preparatory Tillage Systems in Virgin Vertisols of Central India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SK designed and conducted the experiment trial and performed the statistical analysis under the guidance of author MRD. Author SK wrote the first draft of the manuscript and managed the literature searches with the help of authors MRD and PK. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Preparatory tillage, undoubtedly, is one of the most crucial practices that alter soil physical attributes and also affect crop growth and yield. In this sense, this experiment was designed to evaluate the effect of various preparatory tillage systems on soil physical properties and soybean productivity thereby find out a suitable tillage combination for *vertisol* of Vidarbha region of central India. The experiment was laid out in a randomized block design with eight tillage treatments and three replicates. Experimental results revealed that soil physical properties and productivity of

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soybean differed significantly under different preparatory tillage system and zero tillage. Further data revealed that conventional tillage treatment T_8 (1ploughing + 2 tyne harrow + blade harrow) and T_7 (1 Ploughing + 1 Tyne Harrow + 1 Rotavator) significantly improved the soil physical properties (infiltration rate, bulk density, porosity, soil moisture content) and grain yield (2378 and 2268 kg ha^{-1}, respectively). Moreover zero tillage treatment T_1 and shallow tillage treatments (1Blade Harrow + 1Rotavator and 1Tyne Harrow + 1 Rotavator) did not show any significant improvement in soil physical properties and grain yield of soybean.

1. INTRODUCTION

"Soybean (*Glycine max*) is one of the most important crops globally, valued for its high protein content and versatility in various agricultural systems. It is a significant source of edible oil, protein for animal feed, and contributes to soil fertility through nitrogen fixation. In India, the area under soybean cultivation was 10.762 million hectares which produced 93.06 lakh metric ton with productivity of 865 kg ha^{-1}, whereas in Maharashtra, the area under cultivation was 3.736 million hectares which produced 39.42 lakh metric ton soybean grains with productivity of 1055 kg/ha in the year of 2019-20" [1]. "Nowadays, there is a great concern for food security and environmental conservation because it is anticipated that agricultural food production should increase by at least 70% before 2050 to sustain food security for the increasing population" [2,3]. "Limited scope in further expansion of global land area necessitates the adoption of efficient and appropriate tillage systems to achieve food safety practices for sustainable food production" [4,5,6,7,8]. "However, intensive use of resources is often associated with several environmental impacts and also leads to soil erosion" [9,10]. "Choice of soil tillage is strategic for sustainable agricultural because of its significant impact on soil properties" [11]. "Therefore, it is of prime importance to use such preparatory tillage systems that offer high crop yields and, at the same time, preserve soil, water, and biodiversity" [2,12].

"The ability of plants to assess minerals and water from the soil is depends on their capacity to develop profuse root systems" [13,14,2]. "The success of soybean cultivars relies largely on agronomic practices such as tillage, which profoundly influences soil physical properties and, consequently, crop productivity.Preparatory tillage is a primary field operation (plowing, harrowing, or digging) that has been important part of most agricultural systems throughout the

years" [15]. "Tillage practices can be categorized into conventional tillage, reduced tillage, and no-till, each with its distinct impact on soil physical properties and crop productivity. The black cotton vertisol of Vidarbha region have the tendencies towards swelling and shrinkage so it required a high energy input to disrupt hardpan layer and thus to encourage root development and increased drought tolerance" [11,16-19].

"Tillage practices play a crucial role in shaping soil physical properties and influencing soybean productivity. For instance, improved soil structure and moisture retention with appropriate tillage systems create favorable conditions for root growth and nutrient uptake, ultimately enhancing soybean yield and quality. Furthermore, the conservation of soil organic matter in reduced tillage and no-till systems promotes long-term soil fertility and resilience to environmental stresses. In contrast, the detrimental effects of tillage on soil physical properties can hinder soybean growth, leading to reduced yields and increased production costs. Farmers of *Vidarbha* region are most commonly follow deep tillage (deep ploughing) once in three years, followed by the clod crushing operation" [20]. "Most of times, majority of farmers prepare their field just by one tyne cultivator and one blade harrow for soybean cultivation" [20]. Therefore, the objective of this study was to assess the impact of various preparatory tillage systems on various soil physical properties of *vertisols*, along with development of an appropriate technology to improve that helps to improve soil properties thereby its productivity, especially with reference to semi-arid climate of *Vidarbha* region.

2. METHODOLOGY

2.1 Location and Climatic Condition

The experiment was conducted during *Kharif* season of 2016-17 on more than seven years uncultivated field at the Agronomy research farm of Dr. Panjabrao Deshmukh Krishi Vidyapeeth

Akola, situated at the latitude of 22°42' North and longitude of 77°02' East and 281.12 meter above the mean sea level. The climate of the region is semiarid and the determination of mechanical and chemical composition of the soil revealed that the soil of experimental field was silty clay in texture with low in available nitrogen (191.25 kg ha^{-1}), moderate in phosphorus (16.12 kg ha^{-1}) and high amount of potassium (323.72 kg ha^{-1}), having pH value of 7.3(about to normal). The rainy days during the crop season were 45 having 832.9 mm rainfall. Though rainfall was adequate but its distribution during the crop growing period was quite uneven. As per the recorded data, there was a rainless period during the 24, 29, and 33rd meteorological weeks (MW). During the crop growing season the minimum and maximum temperature ranged between 28.1°C during 28th MW to 41.4°C during 22th MW. The minimum temperature varied from 16.5°C during 42th MW to 29.9°C during 22th MW.

2.2 Treatment Planning

In order to investigate the effect of various preparatory tillage systems the experiment was laid out Randomized Block design (RBD) with eight treatments having three replications. The tillage treatments comprising with T_1 - Zero tillage + Pre and Post emergence application of Herbicides (ZT), T_2 - 1 Rotavator + 1 PE Herbicide Application + 1 PoE Herbicide Application (HR), T_3 - 1 Blade Harrow + 1Rotavator (BR), T_4 - 1 Tyne Harrow + 1 Rotavator (TR), T_5 - 1 Tyne Harrow + 1 Blade Harrow + 1 Rotavator (TBR), T_6 - 2 Tyne Harrow + 1 Blade Harrow + 1 Rotavator (TtBR), T_7 - 1 Ploughing + 1 Tyne Harrow + 1 Rotavator (PTR), T_8 - 1 Ploughing + 2 Tyne Harrow + 1 Blade Harrow (PTtB). Soybean variety JS 335 was sown on 30th June 2016 with normal spacing (row to row distance of 45 cm and plant to plant distance of 5 cm) and harvested on 18th October, 2016. Periodically observations were recorded on growth and yield contributing character of soybean to evaluate treatment effect. The plants harvested from each net plot were threshed, cleaned and grain weight plot^{-1} was recorded separately. The grain yield was then converted into yield per hectare (kg ha^{-1}). Observations related to physical properties of soils were recorded as discussed below.

2.3 Infilration Rate

Double ring infiltrometer (Michael 1999) was used for measurement of infiltration because of its reliability and accuracy. Outer cylinder with diameter 60 cm and inner cylinder with diameter 30 cm having 25 cm height, point gauge for measurement of water level, and stopwatch to record the time. The cylinders were installed 10 cm deep in the soil. Care was taken to maintain the same installation depth for different tillage treatments under study. Water level in cylinder was recorded with the help of point gauge. The stopwatch and point gauge were used to record the predetermined time interval and water level respectively. Observations were continued till the infiltration rate approached a constant rate.

2.4 Moisture Content

Moisture was estimated by 'GIRL soil profile moisture meter' made by Dataflow System Pty Ltd, New Zealand from the depth of 0-10,10-20 and 20-30 cm. Moisture meter was consisting of a sensor, central probe (1 m length) and a data saver. For measuring the moisture in the field, soil access tubes were inserted in the ground up to 50 cm depth. The moisture was measured directly by inserting the sensor into the access tube. It takes reading automatically after every 30 second. The readings were recorded in data logger. The recordings were converted to 0-10 cm, 10-20 cm and 20-30 cm depth in graphical format and in numerical values. Finally, the values were averaged from each spot to get the representative reading for the depth of 0-30 cm.

2.5 Bulk Density of Soil

For determination of bulk density, the core sampler method (Blake and Hartge, 1986) was used to collect the undisturbed soil samples. The standard core sampler with height and diameter of 200 mm and 80 mm respectively, was used. Three numbers of samples were drawn from each experimental plot at the interval of 20 days. The undisturbed core samples were then oven dried at 105^{0}C for about 24-48 hours, till the constant weight was obtained. The bulk density was calculated by using the following formula.

$$\text{Bulk density} = \frac{Weight\ of\ ovendry\ soil}{Volume\ of\ soil}$$

Volume of the soil is the inner volume of the core sampler, which was calculated by $\pi r^2 h$, where, r is the radius and h is the height of the core.

2.6 Porosity of Soil

The porosity of soil mass is the ratio of volume of the voids to the total volume of given soil mass (Singh 1980). The porosity of soil was determined from the relation of dry bulk density and particle density. The relation between the dry bulk density and porosity is.

$$\text{Porosity (\%)} = [1 - \frac{Bulk\ density}{Particle\ density} X\ 100]$$

Where, particle density of soil = 2.65 g cm^{-3}

3. RESULTS AND DISCUSSION

3.1 Infiltration Rate

The rate of infiltration is determined by soil-water characteristics including ease of entry of water in soil, storage capacity and transmission rate through the soil. The data obtained from study are presented in Table 1 revealed that the rate of infiltration increased, as magnitude of tillage increased and mean values decreased to a higher extent at harvest (6.43 cm hr^{-1}) when compared to its initial status (7.93 cm hr^{-1}). The data further reveals momentous effect of various tillage practices over IR. At the time of sowing; lowest IR was recorded with the zero tillage treatment T_1 (7.21 cm hr^{-1}) followed by shallow tillage treatments of T_2 (7.64 cm hr^{-1}) and BR (7.58 cm hr^{-1}), while it remains statically similar with each other. However, maximum improvement in IR at sowing was observed with tillage treatment T_8 (8.60 cm hr^{-1}). It was closely followed by treatments T_7 and T_6 with respective IR values of 8.52 and 8.03 cm hr^{-1}, all being statistically similar with each other. There was moderate increase in IR values in medium tillage treatments of T_4 (7.94 cm hr^{-1}) and T_5 (7.89 cm hr^{-1}). As far as IR at the time of harvest is concerned, though the IR values were lower than that of sowing; at all the treatments. At this stage; maximum improvement in IR was noted with deep tillage treatment of T_8 by registering the value of 7.20 cm hr^{-1}. However, it was closely followed by treatments T_7 (7.09 cm hr^{-1}) and T_6 (6.83 cm hr^{-1}), all being statistically non significant with each other. It was interesting that maximum reduction in IR values at harvest compared to sowing was noted in T_3 and T_2 tillage treatments with respective values of 5.42 and 5.74 cm hr^{-1}.

The higher values of rate of infiltration with treatments consisting of deep tillage could be attributed to less compaction, higher mean weight diameter, lower bulk density and higher soil porosity. Ahuchaogu et al. [21] also recorded significantly higher rate of infiltration with plough+ harrow tillage (24 mm/hr) treatment. It also indicates that the probable subsurface compaction through the high speed rotavator cultivation can be minimized by ploughing the soil either through MB plough or tyne harrow, just prior to rotavator operation. The lower rate of infiltration in treatments T_2 and T_3 suggests inferior physical properties at the upper soil surface.

3.2 Soil Moisture Content at the Depth of 0-30 cm

Depth of 0-30 cm is considered as the most important for root proliferation in soybean. The data in respect of soil moisture content presented in Table 2 indicate that there was no significant difference in moisture content at 20 DAS and at harvest because of receiving sufficient effective rainfall during that stage. The difference among various tillage practices (from 19.11% to 23.48%) in conserving the moisture can clearly be seen at 60 DAS as there was least amount of rains received during this period. Thus, from the data of 40, 60 and 80 DAS, it can be inferred that deep tillage practice consistently improved the status of soil moisture not only under adequate rainfall condition but also under the condition of inadequate receipt of rainfall. This significant improvement in water conservation with T_7 and T_8 may be attributed to loosening of soil to a higher depth coupled with increased porosity and higher mean weight diameter. The soil compaction below the operational depth of rotavator and blade harrow in case of treatments T_3 and T_2 may have resulted in less percolation of water up to the depth of 30 cm; reflecting in lowest availability of soil moisture (19.11 and 19.19%, respectively at 60 DAS) for the plant growth. The lowest moisture content was recorded with shallow tillage treatment of T_3 at 40 (30.49%), 60 (19.11%) and 80 DAS (24.08%). Treatment T_1 (ZT) stored more water as compared to shallow tillage treatments of T_3 and T_2 at all growth stages of crop. The medium tillage treatments (T_4, T_5 and T_6) stored more water than T_1, T_2 and T_3 but lesser than T_8 and T_7.

Table 1. Rate of infiltration as affected by various tillage practices

Treatment	Initial and Final Rate of Infiltration (cm hr^{-1})	
	At sowing	At harvest
T$_1$ (ZT)	7.21	6.00
T$_2$ (HR)	7.64	5.74
T$_3$ (BR)	7.58	5.42
T$_4$ (TR)	7.94	6.67
T$_5$ (TBR)	7.89	6.46
T$_6$ (TtBR)	8.03	6.83
T$_7$ (PTR)	8.52	7.09
T$_8$ (PTtB)	8.60	7.20
SE (m)+	0.186	0.127
CD at 5%	0.581	0.397
GM	7.93	6.43

Table 2. Effect of tillage treatments on soil moisture content at 0-30 cm depth

| Treatment	Periodical Soil moisture content (%) at the depth of 0-30 cm				
	20 DAS	40 DAS	60 DAS	80 DAS	At harvest
T$_1$ (ZT)	35.44	31.27	19.27	25.85	33.42
T$_2$ (HR)	34.27	31.17	19.19	25.13	33.17
T$_3$ (BR)	34.15	30.49	19.11	24.08	33.75
T$_4$ (TR)	34.56	33.17	21.16	27.64	34.55
T$_5$ (TBR)	34.87	33.48	21.19	28.15	34.64
T$_6$ (TtBR)	35.76	33.64	21.77	29.08	34.08
T$_7$ (PTR)	34.91	33.81	23.17	29.58	34.46
T$_8$ (PTtB)	35.73	33.73	23.48	29.54	34.28
SE (m)+	0.551	0.345	0.409	0.456	0.476
CD at 5%	NS	1.035	1.227	1.369	NS
GM	34.96	32.60	21.04	27.38	34.04
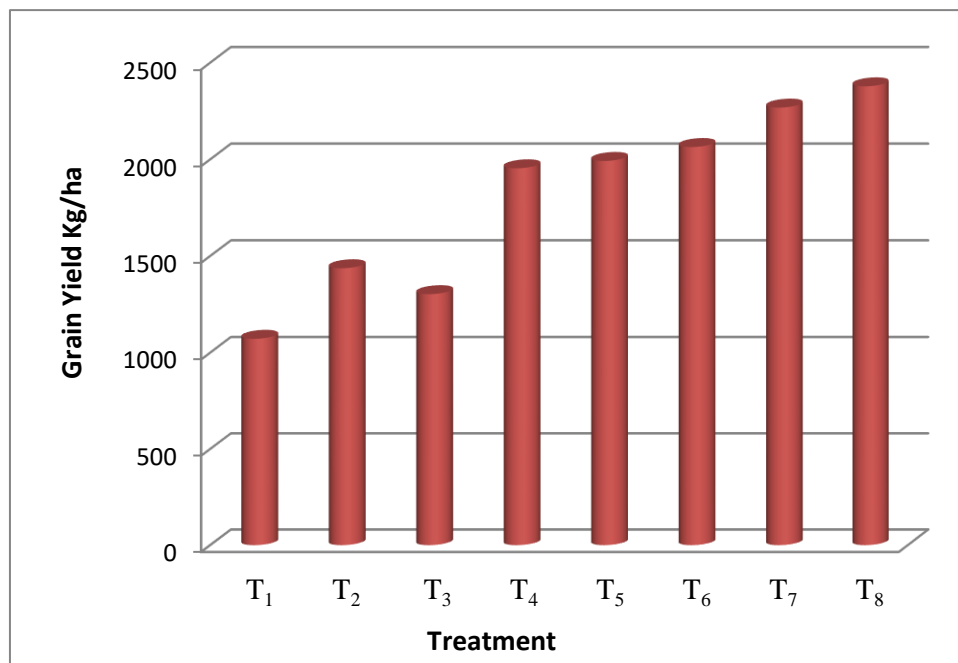
Fig. 1. Grain yield of soybean as affected by various tillage practices

Table 3. Bulk density of soil at the depth of 0-15 cm as affected by various tillage practices

Treatment	Periodical bulk density (Mg m^{-3}) at the depth of 0-15 cm				
	20 DAS	40 DAS	60 DAS	80 DAS	At harvest
T_1 (ZT)	1.16	1.22	1.38	1.34	1.29
T_2 (HR)	1.16	1.21	1.36	1.31	1.27
T_3 (BR)	1.18	1.24	1.40	1.36	1.31
T_4 (TR)	1.13	1.14	1.31	1.25	1.25
T_5 (TBR)	1.15	1.16	1.32	1.27	1.26
T_6 (TtBR)	1.12	1.14	1.29	1.24	1.22
T_7 (PTR)	1.11	1.12	1.24	1.18	1.22
T_8 (PTtB)	1.11	1.11	1.24	1.19	1.20
SE (m)$\pm$	0.01	0.01	0.01	0.01	0.01
CD at 5%	0.02	0.03	0.04	0.04	0.02
GM	1.14	1.17	1.32	1.27	1.25
Initial	1.34				

Table 4. Porosity of soil at the depth of 0-15 cm as affected by various tillage practices

Treatment	Periodical soil porosity (%) at the depth of 0-15 cm				
	20 DAS	40 DAS	60 DAS	80 DAS	At harvest
T_1 (ZT)	56.06	53.79	47.73	49.24	51.14
T_2 (HR)	56.06	54.17	48.48	50.38	51.89
T_3 (BR)	55.30	53.03	46.97	48.48	50.38
T_4 (TR)	57.20	56.81	50.38	52.65	52.65
T_5 (TBR)	56.44	56.06	50.00	51.89	52.27
T_6 (TtBR)	57.58	56.81	51.14	53.03	53.79
T_7 (PTR)	57.95	57.58	53.03	55.30	53.79
T_8 (PTtB)	57.95	57.95	53.03	54.92	54.55
SE (m)$\pm$	0.08	0.11	0.12	0.14	0.08
CD at 5%	0.24	0.33	0.37	0.42	0.24
GM	56.82	55.78	50.10	51.99	52.56
Initial	50.57				

It is well known that the degree of tillage operations highly affects the soil moisture content at various depth, even though the soil is having same physical properties. It might be due to the amount of moisture the soil retains under a given condition is closely related to porosity and size of voids as well as properties of the soil particles. The soil moisture is modified by tillage through particle to particle contact and porosity of the soil. Barua et al. [22] reported significant reduction in soil moisture with the reduction in depth of operation. Similar observations were recorded in their investigation by Karuma et al. [23] and Meidani [24].

3.3 Bulk Density of Soil at the Depth of 0-15 cm

A thoughtful perception of the data presented in Table 3 revealed that bulk density (D_b) consistently increased with subsequent depth; and in general it also increased from sowing to till harvest of the crop, however, during the period of present investigation, it again somewhat decreased after 60 DAS because of presence of more water at 80 DAS and at harvest as compared to 60 DAS. The initial value of D_b was 1.34 Mg m^{-3} and it was significantly changed with different tillage treatments. At 20 DAS, significant improvement in values of D_b was noticed with deep tillage treatments of T_8 and T_7, where its values were 1.11 Mg m^{-3} in both the treatments. As the depth of tillage decreased, as in case of T_4, T_5 and T_6, the soil compaction seems to be increased to a tune of 1.13, 1.15 and 1.12 Mg m^{-3}, respectively as compared to deep tillage operation (T_8 and T_7). Lowest improvement in the values of D_b was noticed with zero (1.16 Mg m^{-3}) and shallow tillage treatments T2 (1.16 Mg m^{-3}) & T3 (1.18 Mg m^{-3}). At 40 DAS, the values of D_b somewhat increased in all treatments except at T_8, where it recorded same value (1.11 Mg m^{-3}) of D_b as observed at 20 DAS. Significantly highest D_b value was reported in treatment T_3 (1.24 Mg m^{-3}) that was statistically similar with treatments of T_1 (Zero tillage) and T_2. Similar

trend was noticed at 60 DAS, 80 DAS and at harvest, where treatments T_6 and T_7 reported lowest values of D_b and maximum D_b value reported with treatment of T_3. It is noteworthy to mention that, the values of D_b were consistently lower (1.20 and 1.22 Mg m^{-3}) at the time of harvest with treatments T_8 and T_7, respectively, being statistically similar with each other. Thus, the effect of deep ploughing followed by tyne harrow, blade harrow/rotavator seems to be more long lasting for improving the soil bulk density as against the operation of rotavator either sole or with blade harrow and zero tillage.

It is well known that bulk density affects almost all the physical properties of soil i.e. infiltration, hydraulic conductivity, available water capacity, soil porosity and rooting depth/restrictions, which have great influence on plant growth and development. Bulk density can be changed by management practices that affect soil structure and porosity like tillage practices. De Moraes et al. [25] after two decades of experimentation observed that conventional tillage (CT) resulted in soil pulverization at 0–0.10 m depth, leading to lower D_b and higher macroporosity compared to the other soil tillage systems. Similar treatment differences were confirmed earlier by Ozpinar [26], Kahlon [27], Khan et al. [28], Meidani [24], Parvin et al. [29] and Alizadeh and Allameh [30].

3.4 Porosity of Soil

At 20 DAS, deep tillage treatments (T_7 and T_8) significantly improved soil porosity (57.95 % each) as compared to initial value of 50.57%. Significantly lowest porosity (55.30%) was registered with treatment T_3; followed by treatments T_2 (56.06%) and T_1 (56.06%). Moderate tillage treatments T_4 and T_5 recorded the porosity value in the range of 56.44 to 57.20 per cent, being statistically similar to each other. Similar pattern of treatment differences were observed at 40 and 60 DAS. However, at 80 DAS, treatment T_7 recorded significantly highest value (55.30%) of porosity. It was closely followed by treatment T_8 (54.92%). At harvest, deep tillage treatment T_8 reported to be significantly superior in respect of porosity value (54.55% and closely followed by treatments of T_7 and T_6 with common value of 53.79%. It appears from the results, that the depth of tillage has a pronounced effect on porosity. Reduction in bulk density, improvement in mean weight diameter and reduced soil strength with treatment T8 may fortuitously enhanced soil physical properties including porosity. Conversely, rototill and blade

harrow treatments of T_3 and T_2 did not improved the status of P_t at the depth of 0-15 cm, likely due to subsequent soil compaction resulting from reduced soil moisture content. Polat et al. [31] also observed higher BD and lower porosity with rotary-tiller and roller treatments as compared to other moderately deep tillage methods. Similar results were confirmed by Ozpinar and Cay [32], Polat et al. [31], Ozpinar, S., [26], Meena et al. (2011), Kahlon [27], Khan et al. [28], and Parvin et al. [29].

3.5 Grain Yield

The results (Fig. 1) revealed that use of deep treatments T_8 and T_7 recorded significantly highest seed yield 2378 kg and 2268 kg ha^{-1}, respectively and on other side zero tillage treatment (T_1), produced lowest grain yield (1072 kg ha^{-1}). It is noteworthy to mention that moderate tillage treatment T_4 (1954 kg ha^{-1}), T_5 (1992 kg ha^{-1}) and T_6 (2064 ka ha^{-1}) being statistically similar with each other, also found superior over zero and shallow tillage treatments. The adequate plant growth with deep tillage treatments (T_8 and T_7) may be due to prolific root growth, thereby enhanced absorption of minerals to nourish aerial plant part, and thereby higher production of photosynthates and metabolites, its efficient diversion towards the reproductive organs, resulting in higher gain yield [20]. The lower gain yield with zero tillage and shallow tillage treatments could be due to the lower values of plant growth and yield contributing characters. Meshram et al. [33], Alizadeh and Allameh [30], Gholami et al. [34], Ud Din *et al.* [35], Khedkar and Deshmukh [20], reported the highest seed yield in deep tillage treatment of mouldboard plough plus rotavator [36].

4. CONCLUSION

Data of experiment opined that deep tillage treatments T_8 (PTtB) and T_7 (PTR) recorded significant improvement in the soil physical properties and grain yield of soybean. Treatment T_8 noted highest infiltration rate, porosity, moisture content and lowest bulk density, which was followed by treatment T_7. On the other hand lowest improvement in above mentioned parameters was noticed with no till (T_1) and shallow tillage treatments. (T_2 and T_3). Based on the results of the current investigation and aforesaid interpretation, it could be concluded that conventional tillage practice of 1Ploughing + 1tyne harrow + rotavator (T_8) operation was found to be the most feasible preparatory tillage

system under the condition of *Vidarbha* region of Maharashtra as compared to No tillage or shallow tillage.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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