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Research article

Dynamics of soil penetration resistance, moisture depletion pattern and crop productivity determined by mechanized cultivation and lifesaving irrigation in zero till blackgram

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ABSTRACT

Rice fallow black gram is grown under the residual moisture situation as a relay crop in heavy texture montmorillonite clay soil under zero till condition. Since the crop is raised during post monsoon season, the crop often experiences terminal stress due to limited water availability and no rainfall. Surface irrigation in montmorillonite clay soil is determent to pulse crop as inundation causes wilting. Therefore, zero tilled rice fallow black gram has to be supplemented with micro irrigation at flowering stage (35 days after sowing) to alleviate moisture stress and to increase the productivity as well. Hence micro farm pond in a corner of one ha field was created to harvest the rain water during monsoon season and the same was utilized to supplement the crop with lifesaving irrigation through mobile sprinkler at flowering stage for the crop grown under conservation agriculture. Soil cracking is also the common phenomena of montmorillonite clay soil where evaporations losses would be more through crack surfaces. The present study was therefore conducted to study the changes in the soil physical properties, crop establishment and productivity in conjunction with mechanized sowing and harvest and supplemental mobile sprinkler irrigation. Sowing of black gram by broadcasting 10 days prior to the manual harvest of rice, manual drawn single row seed drill after the machine harvest of rice and sowing by broadcasting at 4 days prior to machine harvest of rice was experimented separately and in combination with lifesaving irrigation. Results indicated that the number of wheel passes and lifesaving irrigation had a very strong impact on soil penetration resistance and soil moisture. Combined harvester followed by no till seed drill increased the soil penetration resistance in all the layers (0–5 cm, 5–10 cm and 10–15 cm). Two passes of wheel increased the mean soil penetration resistance from 407 KPa to 502 KPa. The soil penetration resistance (0–5 cm) at harvest shown that black gram sown by manual broadcasting 10 days prior to manual harvest of paddy supplemented with life irrigation on 30 DAS reduced the soil penetration resistance from 690 Kpa to 500 Kpa, 740 Kpa to 600 Kpa and 760 Kpa to 620 Kpa respectively at 0–5 cm, 5–10 cm and 10–15 cm layer. In general, moisture depletion rate was rapid in the surface layer of 0–5 cm as compared to other layers of 5–10 cm and 10–15 cm up to 30 DAS (Flowering stage). The moisture content and the soil penetration resistance had an inverse relationship. The soil penetration resistance also had an inverse relationship with the root length in which the root length lowers as the soil penetration resistance increases. The soil crack measured at 60 DAS was deeper with no till seed drill (width of 3.94 cm and depth of 13.67 cm) which was mainly due to surface layer compaction. The

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relative water content, specific leaf weight and chlorophyll content were significantly improved through the supplemental irrigation given on 30 DAS irrespective of crop establishment methods. The results further indicated that compaction of ploughed layer in the moist soil due to combined harvester and no till seed drill had a negative impact on yield (457 kg ha^{-1}), which was improved by 19.03 per cent due to increased soil moisture with supplemental irrigation. The mean yield increase across different treatments due to supplemental lifesaving irrigation through mobile sprinkler was 20.4 per cent.

1. Introduction

Relay cropping is a traditional cropping system which is done by broadcasting the seeds of short duration pulses or oilseed crops in standing paddy field at the time of harvest. In Cauvery Delta Zone of Tamil Nadu, India relay cropping of black gram (*Vigna mungo* (L.) Hepper) is a unique system where sprouted seeds of black gram are broadcasted in standing rice crop 7–10 days prior to its harvest and grown under no-tillage conditions using the residual moisture and nutrients in the soil [1].

Though the relay cropping of rice-pulse has been practiced from time immemorial in the Cauvery delta zone of Tamil Nadu, the productivity of pulses is very low due to adoption of poor crop management practices. Unlike irrigated pulses, the improved production or protection technologies will not be followed by the farmers as the crop is considered to be incentive crop after the harvest of rice crop. Reference [2] reported that due to above said reasons the yield of rice fallow pulses is low due to the various biotic and abiotic stress and non-adoption of technologies. As far as rice fallow black gram concerned, the crop is totally grown under residual moisture content and as a result, soil and water plays a pivotal role in determining the yield. Since irrigation is withdrawn 10–15 days before the harvest of rice crop, the moisture content in the soil declines rapidly with advancement of crop period. Especially from the second fortnight of February due to rise in temperature, the crop faces drought during flowering and pod formation stages which eventually resulted in poor yield of black gram. In order to evade the terminal moisture stress in rice fallow black gram, supplemental irrigation would be useful at 30–35 DAS (Pre flowering) to augment the yield [3]. In montmorillonite expanding clay, surface irrigation is determent to the crop as inundation of water leads to wilting of the crop. Hence portable or mobile sprinkler irrigation would be a better choice of supplemental lifesaving irrigation to avoid terminal drought. But water availability during the post monsoon period is the major concern. Lifesaving supplemental irrigations through mobile sprinklers with the use of harvested water could be a viable strategy to increase the productivity in rice fallow situations [3].

A shallow ditch of 2 m deep with 2:1 slope or 1:1 slope constructed in a corner of the field to harvest rainfall runoff served as a source of supplemental irrigation (4–6 cm) to avoid terminal stress in rainfed rice crop. The rain water harvested in the on-farm reservoir could be used as either supplemental irrigation or even for land preparation for the timely sowing of rainfed rice crop. The water stored in the reservoir may also provide 2 or three supplemental irrigations [4].

Maintenance of adequate plant population is a prerequisite to maximize returns from rice fallow pulse cultivation. The practice of broadcasting black gram seeds 7–10 days prior to harvest of rice crop after the final irrigation at a waxy soil condition is being adopted in the Cauvery delta region conventionally [5]. Sub optimal population and uneven plant density are the common constraints associated with broadcasting of black gram seeds in standing crop of rice. The trampling effect of wheels on field traverse while employing combine harvester damages the establishing pulse crops. With wider adoption of mechanized harvesting, it has emerged as a major abiotic stress in rice fallow cultivation. Though mechanized cultivation is advantageous in crop production nowadays, surface soil compaction (crusting) and sub surface soil compaction (Hard pan) are an emerging problem in crop production. Especially in wet land condition, employing combined harvester in the deep clay soils resulted in more vertical stress due to heavy wheel loads. Vertical stress on the subsoil layers is on increasing mode with increase in the use of farm machineries in recent day [6].

Soil compaction is commonly known to be caused by different tillage methods, use of either power operated or bullock drawn machineries for puddling, transplanting, intercultural operations and surface [7]. To quantify the vertical stress in terms of degree of compaction especially in adoption of no tillage immediately after employing combine harvester, measurement of soil penetration resistance (SPR) to quantify the soil quality and to identify the layers with increased degree of compaction would be a meaningful approach [8]. Reference [9] also indicated that soil penetration resistance, a function of several mechanical properties of soil provides a rapid method to characterize the variability of soil strength or compaction within the soil profile in different layers.

The studies on soil compaction have indicated that soil compaction changes soil structure, increases bulk density and penetrometer resistance, reduces soil aeration, decreases water infiltration, reduces hydraulic conductivity [10]. The degree of soil compaction is determined by soil mechanical impedance, wheel passes and soil moisture content. Soil penetrometer is generally used to estimate the mechanical resistance of soil [11]. The correlation between soil strength and root growth is well explained by the penetration resistance studies [12]. A decrease in macropores and increase in micropores are associated with increase in bulk density which ultimately affects the soil hydraulic properties and the ability of soil to shrink and soil water conductance [13]. Increase in bulk density was also reported to decrease the number of nodules [14]. The reduced root length, elongation and decreased nutrient availability and uptake under compacted soils were the reasons for low crop yield. The soil compaction causes yield loss from 5 to 90 % depending upon the number of passes by the heavy vehicles [15]. Though soil cracks were said to be reduce the soil erosion and enhance the soil moisture reserves, the movement of water during the post rainy season especially in the extended dry seasons in the soil cracks is very crucial as evaporations losses would be more through crack surfaces [16]. The present experiment was hence conducted to study the changes in the dynamism of soil penetration resistance, moisture depletion rate, crop establishment and productivity in conjunction with mechanized sowing and harvest and supplemental irrigation.

2. Material and methods

2.1. Site description

This study was conducted for four years during the post rainy seasons of 2014–15, 2015–16, 2016–17 and 2017–18 (Dec–March) at Tamil Nadu Rice Research Institute, Aduthurai (11°01′N, 79°48′E, 19.5 m a.s.l.), Tamil Nadu, India. The study area is characterized by a tropical climate with distinct wet and dry seasons with annual rainfall of 1169.4 mm. The amounts of annual rainfall during the study year were 1237.2, 1292.4, 530.1 and 1488 mm in 2014, 2015, 2016 and 2017 respectively. The total precipitation during the South West Monsoon (June–September) in 2014, 2015, 2016 and 2017 was 239.2, 232.2, 221.3 and 529.6 mm respectively and the amounts of rainfall during the North East Monsoon (October–December) were 776.8, 878.8, 195.0 and 750.6 mm, respectively in 2016–2017 and 2017–2018 (Fig. 1.). However, the rainfall during the study period of January–March was nil during all the four years.

The region is characterized by a sub-tropical climate with a hot dry summer (March–June), and extended wet period from September to February. The mean annual rainfall is about 1176 mm, majority of which was received during North East Monsoon. The mean annual maximum and minimum temperatures were 33.3 °C and 23.5 °C. The mean annual relative humidity was 89 per cent. The mean wind velocity and bright sunshine hours were 5.2 kmph and 6.7 h day^{-1}.

2.2. Experimental design and treatments

Field experiments were conducted for 4 years during the post rainy season of 2014–15, 2015–16, 2016–17 and 2017–18 (January–March) at Tamil Nadu Rice Research Institute, Aduthurai, India. (11°01′N, 79°48′E, 19.5 m altitude) with six treatments. The treatments were replicated four times.

The field experiment has been commenced with the sowing of black gram (ADT-3 variety) during the month of January after the long duration paddy crop (CR 1009 variety). Sowing by manual broadcasting as per the ‘traditional method’ was done ten days prior to the manual harvest of paddy (T_1). A manual drawn single row seed drill (IIPR prototype) was employed to place the seeds after the harvest of rice (Harvesting with a chain type combine harvester) with an inter row spacing of one foot apart (T_2). The sowing was taken up immediately after the harvest of paddy to avoid soil moisture loss. Seeds fell continuously into a V shaped furrow (7.5 cm depth) opened by the disc type wheel of the seed drill. In another treatment (T_3), sowing by broadcasting at 3–4 days prior to harvest of paddy (Harvesting with a chain type combine harvester) were also experimented. Lifesaving irrigation with portable mobile sprinkler was combined with T_1 (T_4), T_2 (T_5) and T_3 (T_6).

A pond was dug at a dimension of 15 m × 6 m ×2 m (L x B x H) in a corner nearby the experimental field with an objective of harvesting the rain water during the North East monsoon. Subsequently the stored water in the pond was utilized for irrigating the pulse crop through mobile sprinkler at critical stage (flowering – 35 days after sowing). Thus, even after the cessation of North East Monsoon in the month of December, the water harvested and stored in the farm pond was used to irrigate with mobile sprinkler so as to mitigate the moisture stress at flowering stage in the month of February. The full storage capacity of the pond is 2,10,000 L. The average stored water depth after the cessation of North East Monsoon was 1.65 m (1,73,250 L). The average water availability in the pond at the time of flowering was 1,05,000 L of water. The mobile sprinkle discharge rate per minutes was 80 L. The water requirement/ha to irrigate through mobile sprinkler for a depth of 10 mm is 1,00,000 L. The water availability at the time of flowering was sufficient to irrigate at a depth of 10 mm during all the four years of study.

Soil of the experimental site was montmorillonitic, isohyperthermic, *Udorthentic Chromusterts* of heavy clay texture with a pH 7.8, low in organic carbon (0.15 %) and medium in available nitrogen (288 kg ha^{-1}), high in available phosphorus (35 kg ha^{-1}) and medium in available potassium (376 kg ha^{-1}). The soil bulk density was determined with undisturbed soil samples using the cutting

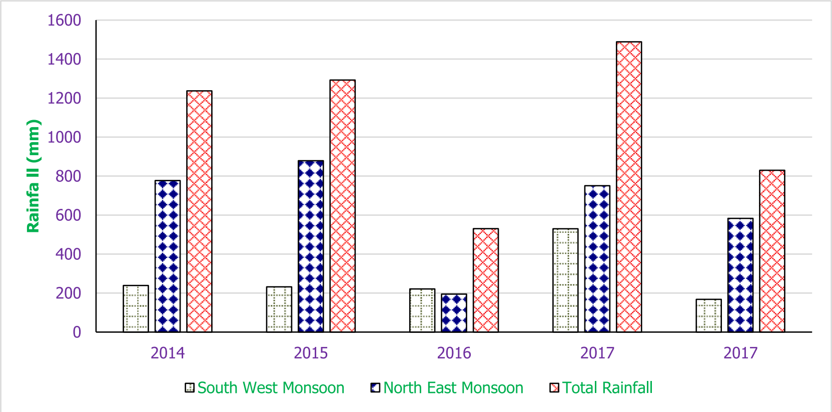


Fig. 1. Rainfall (mm) during the cropping seasons.

ring method (Li et al., 2012) and the mean bulk density of the soil was 1.26 g cm^{-3}. The black gram seeds of ADT 3 variety were used as a test crop. In a plot size of 10.0 m × 4.0 m, 33 rows of black gram and 400 plants per row were maintained by dibbling seeds at a spacing of 30 cm × 10 cm. The early post-emergence herbicide quizalofop ethyl was sprayed at 50 g a.i. ha^{-1} on 15 DAS to keep the experimental plot weed free and clean.

2.3. Sample measurements and data analysis

2.3.1. Soil moisture

Assessments on soil profile moisture depletion were commenced with HH2 moisture meter (Delta-T Devices Ltd., Cambridge, UK) at 0–5, 5–10 and 10–15 cm layers at weekly intervals throughout the cropping period.

2.3.2. Soil penetration resistance

The sampling was performed with Hand penetrometer Eijkelkamp, minimal design (measuring at each point, reaching up to 1.0 m depth. with an accuracy of 1000 Kpa to measure the penetration resistance in each treatment randomly in six points at three depths (0–5, 5–10 and 10–15 cm). At each sampling points, the measurements were made with constant speed at different soil depths. The soil penetration resistance in each treatment is the mean of the six measurements in each depth.

2.3.3. Soil crack

The soil crack in terms of width and depth was measured by using a flexible measuring steel ruler in five randomly marked area of 1 m × 1 m in each treatment. The depth of the crack was measured by inserting the ruler down the crack and it was gently wiggled until it reaches the lowest point. The width of the crack was measured perpendicular to the crack walls. Since the depth of the crack measurement may not be realistic due to obstruction of small clods, the volume of the crack was measured by pouring the river sand in the crack and amount of sand required to fill the crack was taken as volume of the crack in litres.

2.3.4. SPAD meter

The SPAD-502 chlorophyll meter (SPAD-502 Minolta Camera Co., Ltd., Japan), a rapid, non-destructive and hand held spectral device was used for estimating leaf chlorophyll content. SPAD values of the four fully expanded uppermost leaves were determined on 30 and 45 DAS and the results are reported as SPAD units. Ten randomly selected plants from each plot were measured in the field.

2.4. Growth and yield attributes

The data on growth and yield attributes were observed at the time of harvest randomly from ten plants from the same five plants in each treatment. The seed yields were measured as total yield per plot and transformed to kg ha^{-1}. The crop was harvested on 65 days after sowing.

2.4.1. Number of effective nodules and nodule dry weight

Five plants per treatment were randomly uprooted on 30 and 45 DAS for counting the number of effective root nodules per plant and root nodules dry weight study as well. Plants from each treatment were uprooted from the soil along with the ball of earth without any disturbance to the roots. The roots of each plant were gently washed in water. After removing the soil from the roots, the nodules were separated from the roots. After the detachment of root nodules, the nodules were examined for the presence of leg-hemoglobin to estimate the number of effective nodules per plant. The nodule dry weight was obtained by over drying the nodules at 80 °C. The total number of effective nodules and dry weight of nodules were measured in all the treatments and mean value was arrived [17].

2.4.2. Relative water content

The relative water content (RWC) expresses the water content in per cent at a given time as related to the water content at full turgor and describes the degree of water saturation in plant leaves. The RWC was measured by using the formula suggested by Ref. [18].

$$\text{Relative Water Content (RWC)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

2.4.3. Specific leaf weight (SLW)

Specific Leaf Weight (SLW) is one of the few morphological characteristics of plants that shows large changes over the course of a single day. Specific leaf weight (SLW) was calculated by using the formula of Amanullah [19] and expressed as mg/cm^2.

$$\text{Specific leaf weight (SLW)} = \frac{\text{Leaf dry weight per plant}}{\text{Leaf area per plant}}$$

2.5. Statistical analyses

Analysis of variance (ANOVA) was used to detect the significance of treatment effects on different parameters studied. Least significant difference (LSD) was used to separate the mean, whenever the treatment means were significantly different. In general, differences are reported at the 5% probability level [20]. Combined analysis of variance was performed after homogeneity test for error variances by using Bartlett's tests (Snedecor and Cochran 1983). For diagrams and regression analysis [21], Microsoft Excel 2010 was used.

Because the results were similar across the four experimental years seasons, pooled mean values of the four-year data for each season were presented in tables and figures.

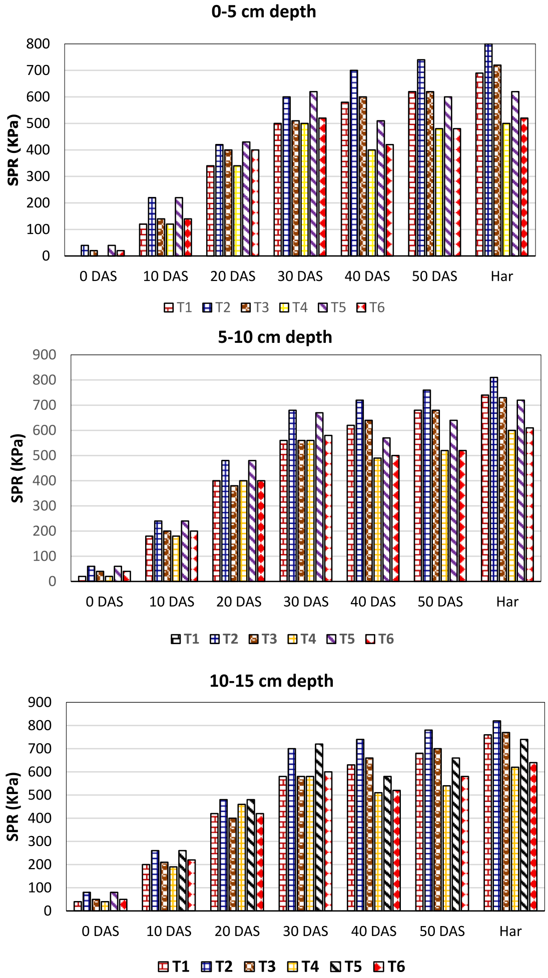
3. Results

3.1. *Soil penetration resistance*

The different crop establishment methods had a great influence on soil penetration resistance irrespective of the soil layers (Fig. 2).

In general, the soil penetration resistance was on increasing trend with advancement in the crop period. However, the soil penetration resistance diminished markedly after the lifesaving irrigation given through mobile sprinkler at the time of flowering on 30 DAS, which has been evidently seen from the data on soil penetration resistance observed on 40 DAS. Though the penetration resistance was decreased on 40 DAS, it tends to increase subsequently up to the harvest of black gram in all the sowing methods of black gram.

The wheel passes of harvester and seed drill (Two passes) significantly increased the soil penetration resistance at all the stages of observation irrespective of the layers. The soil penetration resistance was almost zero at 0–5 cm layer with the farmers practice of sowing black gram 10 days prior to manual harvest of rice crop (No pass) and at 5–10 cm and 10–15 cm layers, it was only 20 and 40


0-5 cm depth

5-10 cm depth

10-15 cm depth

Fig. 2. Soil Penetration Resistance as influenced by mechanization and lifesaving irrigation. T_1 – Manual broadcasting of seeds 10 days prior to the manual harvest of paddy. T_2 – No till seed drill after the machine harvest of paddy. T_3 – Manual broadcasting of seeds 4 days prior to the machine harvest of paddy. T_4–T_{1+} Lifesaving irrigation. T_5–T_{2+} Lifesaving irrigation T_6–T_{3+} Lifesaving irrigation.

mpa respectively. In the modified sowing time of 4 days before the machine harvest of rice crop (Single pass), the soil penetration resistance at the time of sowing was 20, 40 and 60 (KPa) at 0–5, 5–10 and 10–15 cm soil layers respectively. Seed drill sown black gram after the machine harvest of rice crop (Two passes of wheel) had higher soil penetration resistance 40, 60 and 80 (KPa) at 0–5, 5–10 and 10–15 cm soil layer at the time of sowing as compared to other methods at all the stages of observation. Similarly, the soil penetration resistance at the time of harvest was also highest with the seed drill sown black gram at all the layers (720, 760 and 770 KPa) at 0–5, 5–10 and 10–15 cm soil layers. Whereas life irrigation given at the time of flowering stage (30 DAS) no till seed drill sown black gram after the machine harvest of rice profoundly influenced the soil penetration resistance at harvest (680,720 and 740 KPa at 0–5, 5–10 and 10–15 cm soil layers), which was almost equivalent to the soil penetration resistance observed on 30 DAS.

Taking soil moisture as dependent variables and SPR as an independent variable, results from simple regressions indicated that variations in soil moisture content was significantly related to the variation in SPR. The variation in soil moisture content was inversely

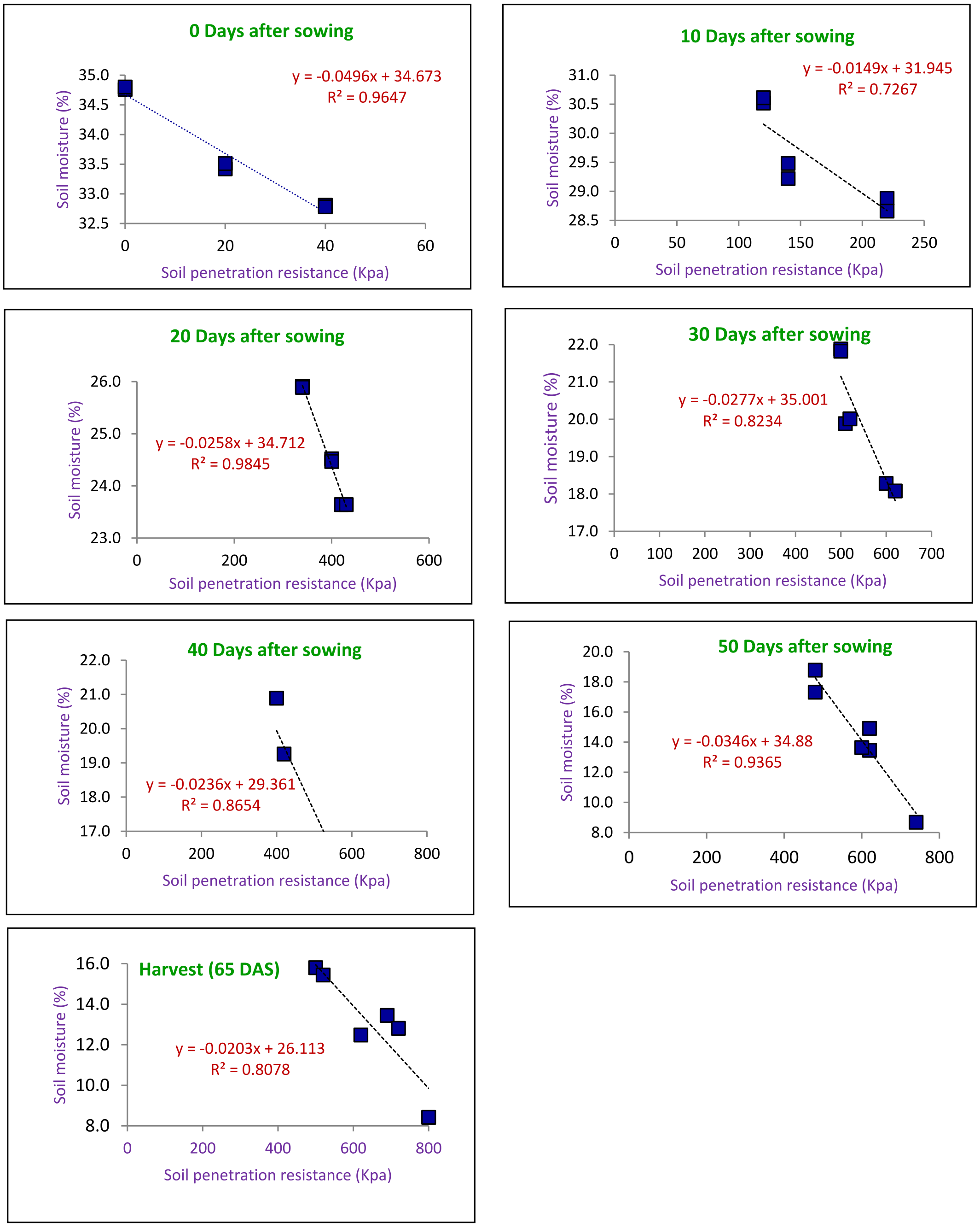


Fig. 3. Relationship between soil penetration resistance (KPa) and soil moisture content (%) during different crop period.

related to SPR. (Fig. 3). Based on R^2 value at 5% level of significance, the fitted equation was found to be significant. The linear relationship between soil moisture content and SPR was 96.4 % at 0 DAS, while it was around 80 percent at the time of harvest. The regression analysis further indicated that the relationship between soil moisture content and SPR was significantly increased at 50 DAS which was due to the supplemental life irrigation given on 30 DAS.

3.2. *Soil cracking (cm)*

The rice fallow pulse was grown in the soils of fine, montmorillonitic, isohyperthermic, *Udorthentic Chromusterts* with heavy clay texture in the entire Cauvery Delta Zone of Tamil Nadu, India. These soils become shrink when flooded and begun to crack on drying. The soil crack and depth were greatly influenced by the number of wheel passes (Fig. 4). In the different black gram establishment systems, black gram sown with seed drill under no till condition (two passes) exhibited deeper soil crack with a width of 3.94 cm and depth of 13.67 cm as compared to other sowing methods. Though the width and depth of the crack in the farmers practice of sowing black gram 10 days before manual harvest of rice crop (No pass) was more as compared to black gram sown 4 days before the harvest of rice crop (Single pass), the volume of the sand required to fill the crack was lesser than the other treatments.

3.3. *Bulk density (g/cc)*

The ratio of the mass of dry solids to the bulk volume of the soil is greatly influenced by the different crop establishment methods of black gram and supplemental irrigation. In general, the variation in the bulk density ranged from 1.28 g/cc to 1.42 g/cc at 0–5 cm layer with no pass, single and two passes of wheel in no till soil at 0 DAS. While it was 1.36 g/cc to 1.52 g/cc at 5–10 cm layer (Table 1).

The measured values indicated that black gram sown with seed drill after the machine harvest of rice (two passes) significantly increased the bulk density at 0–5 cm and 5–10 cm layer by 20.1 and 6.9 per cent over broadcasting of black gram manually before the manual harvest of black gram (No wheel traffic). However, the bulk density was not greatly influenced at 10–15 cm layer due to the wheel passes of seed drill and harvester.

The supplemental lifesaving irrigation given on 30 DAS had a significant influence on bulk density at 0–5 cm and it ranged from 1.28 g/cc to 1.58 at 0–5 cm. The wheel traffic of harvester and the furrow opened at optimum moisture by the seed drill did not respond positively to the supplemental irrigation through mobile sprinkler, where the bulk density increased due to the water droplets from the sprinkler system. However, in no pass, the bulk density of the soil decreased due to mobile sprinkler irrigation from 1.32 g/cc to 1.28 g/cc at 0–5 cm layer though supplemental irrigation did not increase the bulk density at 5–10 and 10–15 cm layers.

3.4. *Soil moisture depletion pattern*

The assessment of soil profile moisture depletion was commenced with gravimetric method of taking soil cores at 0–5 cm, 5–10 cm and 10–15 cm (Fig. 5) at 10 days interval from sowing of black gram sowing to harvest. The mean moisture percentage at the time of sowing black gram (10 days before the harvest of rice crop) was 34.78 % in 0–5 cm layer, 33.80 % in 5–10 cm layer and 33.67 % in 10–15 cm layer. Whereas moisture percentage at the.

time of sowing black gram (4 days before the harvest of rice crop) was 33.48 % in 0–5 cm layer, 32.23 % in 5–10 cm depth and 32.16 % in 10–15 cm layer. However, the moisture percentage observed in black gram sown with seed drill after the harvest of the rice crop was 32.81 % in 0–5 cm layer, 31.02 % in 5–10 cm layer and 31.22 % in 10–15 cm layer. The data further revealed that, irrespective of the layer, black gram sown 10 days before the manual harvest of paddy (No wheel pass) had the highest soil moisture content at different crop periods as compared to other treatments. The moisture content observed at the time of flowering before lifesaving irrigation (30 DAS) ranged from 18.08 to 21.88 % in 0–5 cm layer, 19.68–23.68 % in 5–10 cm layer and 20.11–24.68 % in 10–15 cm layer across the treatments. The variation in the moisture content across the treatments were significant after the lifesaving

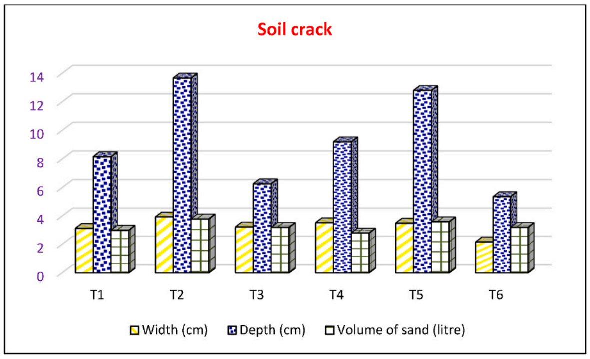


Fig. 4. Soil cracks changes due to mechanization and lifesaving irrigation. T_1 – Manual broadcasting of seeds 10 days prior to the manual harvest of paddy. T_2 – No till seed drill after the machine harvest of paddy. T_3 – Manual broadcasting of seeds 4 days prior to the machine harvest of paddy. T_4–T_{1+} Lifesaving irrigation. T_5–T_{2+} Lifesaving irrigation T_6–T_{3+} Lifesaving irrigation.

Table 1
Trends of Soil bulk density (g/cc) in different layer due to mechanization and lifesaving irrigation.

Treatments	Soil Bulk Density (g/cc)								
	0–5 cm			5–10 cm			10–15 cm		
	0 DAS	30 DAS	60 DAS	0 DAS	30 DAS	60 DAS	0 DAS	30 DAS	60 DAS
T_1 – Broadcasting 10 days prior to manual harvest of paddy (No pass)	1.28	1.30	1.32	1.36	1.44	1.46	1.38	1.46	1.48
T_2 – No till seed drill on the day of paddy harvested by combine harvester (Two pass)	1.42	1.54	1.60	1.48	1.54	1.58	1.52	1.54	1.55
T_3 – Broadcasting 4 days prior to harvest of paddy by combine harvester (Single pass)	1.32	1.34	1.38	1.42	1.44	1.46	1.45	1.46	1.46
T_4–T_1 + Lifesaving irrigation with mobile sprinkler	1.28	1.26	1.32	1.36	1.42	1.44	1.38	1.46	1.44
T_5–T_2 + Lifesaving irrigation with mobile sprinkler	1.42	1.58	1.58	1.52	1.52	1.56	1.52	1.54	1.54
T_6–T_3 + Lifesaving irrigation with mobile sprinkler	1.32	1.34	1.36	1.42	1.42	1.46	1.42	1.44	1.46
LSD (0.05)	0.06	0.05	0.05	0.04	0.05	0.05	0.06	0.06	0.05

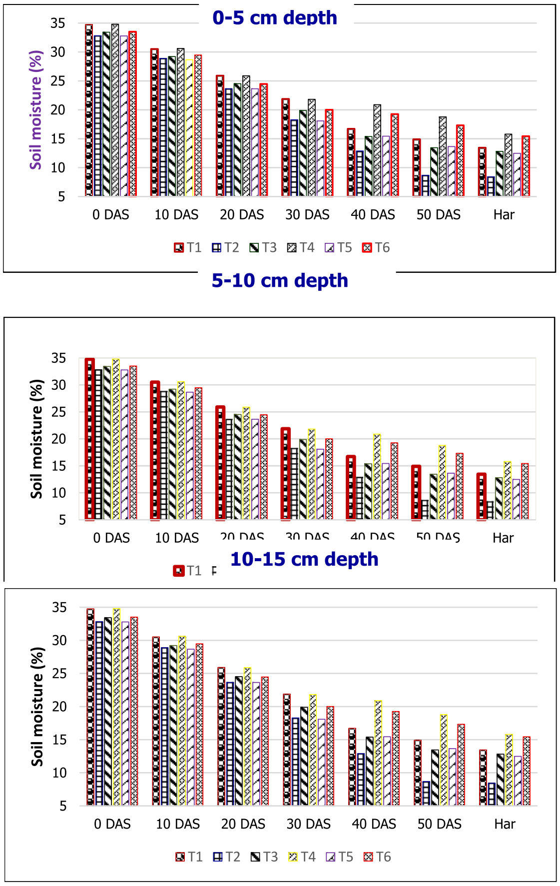


Fig. 5. Soil moisture depletion pattern as influenced by different treatments. T_1 – Manual broadcasting of seeds 10 days prior to the manual harvest of paddy. T_2 – No till seed drill after the machine harvest of paddy. T_3 – Manual broadcasting of seeds 4 days prior to the machine harvest of paddy. Lifesaving irrigation with mobile sprinkler was combined with T_1 (T_4), T_2 (T_5) and T_3 (T_6).

irrigation given on 30 DAS. The values of moisture content observed at 40 DAS indicated that the moisture content observed on 30 DAS was not depleted significantly due to the lifesaving irrigation. The moisture level observed 10 days after the supplemental irrigation given on 30 DAS at 0–5 cm layer indicated that the soil moisture depletion rate with blackgram sown 10 days prior to manual harvest of rice crop (No pass) was only to a tune of less than 1 % (from 21.82 to 20.89 %) as compared to 5.1 % loss in black gram sown 10 days prior to the harvest of rice crop without any lifesaving irrigation (21.88 %–16.72 %). Irrespective of the lifesaving irrigation and different layers, the lowest soil moisture level was observed with the treatment of black gram sown after the harvest of the rice crop with IIPR seed drill (Two passes). The lifesaving irrigation given at flowering stage (30 DAS) did not have any profound influence on the moisture content in the 5–10 cm and 10–15 cm layer in all the crop establishment methods.

Significant and strong relationship between bulk density and soil water content was observed at different soil layers and time of observation (Table 2). The bulk density of expanding clayey is mostly determined by the soil water content, which has been evidently seen in the R^2 value. The bulk density increased with increase in soil water content and vice versa. In the linear relationship, the intercept predicts the bulk density at maximum soil moisture and slope is an indication of changes in bulk density due to soil moisture.

3.5. Crop physiological parameters

The physiological parameters like Relative water content (RWC), Specific leaf weight (SLW) and Chlorophyll content (SPAD value) observed on 30 DAS were not greatly influenced by the different crop establishment methods due to increase in the duration of moisture stress (Table 3). However, the observation taken on 45 DAS after the lifesaving irrigation given at flowering stage (30 DAS) indicated significant variation in the above physiological parameters.

Specific leaf weight (SLW) varied between 7.04 and 7.66 g/cm^2 at 30 DAS in different methods of black gram sowing. Whereas the relative water content ranged from 81.44 % to 85.91 %. The SPAD values across the treatments were 32.6–37.07. Sowing of black gram 10 days before manual harvest of rice crop (No pass) had higher level of RWC (85.91 %), SLW (7.62 g/cm^2) and SPAD value (36.93) at 30 DAS. However, the supplemental lifesaving irrigation through mobile sprinkler given on 30 DAS significantly increased the values of SLW, RWC and SPAD over the non-irrigated treatments. Sowing of black gram 10 days before the manual harvest of rice crop followed by supplemental lifesaving irrigation through mobile sprinkler on 30 DAS had the higher values though it was onpar with sowing of black gram 4 days before the mechanical harvest of rice crop (Single pass) followed by supplemental irrigation.

3.6. Nodule count and dry weight

Nodulation is considerably affected by the physical properties of heavy soil and soil moisture. Similar to the trend of physiological parameters, nodule count and nodules dry weight were also highly influenced by different crop establishment methods at 30 DAS (Table 4). Sowing of blackgram 10 days before the manual harvest of rice crop (No pass) registered a higher number of nodules and nodule dry weight (23.67 and 0.17 g) at 30 DAS. Sowing of black gramwith seed drill after the harvest of rice crop (Two passes of wheel) resulted in poor development of root nodules and nodule weight as well (23.67 and 0.17 g). The supplemental irrigation given on 30 DAS did not have a profound influence on number of root nodules and dry weight on 45 DAS.

Though the number of nodules and dry weight (17.44 and 0.11 g) were higher with sowing of blackgram 10 days before the manual harvest of rice crop (no pass) followed by supplemental lifesaving irrigation through mobile sprinkler on 30 DAS, the number of nodules and dry weight (0.17 and 0.11 g) were comparable with sowing of black gram4 days before the machine harvest of rice crop (Two passes) followed by supplemental lifesaving irrigation through mobile sprinkler on 30 DAS.

3.7. Root length (cm) and root dry weight (g)

Similar to the physiological parameters, different sowing methods black gramhad significant influence on root length and weight at 30 DAS (Table 5). Sowing of black gram10 days before the manual harvest of rice crop (No wheel pass) resulted in highest root length of 6.93 cm and root dry weight of 0.073 g at 30 DAS as compared to two passes in no till seed drill (5.87 cm and 0.058 g). However, sowing of black gram10 days before the manual harvest of rice crop followed by supplemental irrigation through mobile sprinkler registered highest root length (8.76 cm) and root dry weight (0.092 g) at 40 DAS.

3.8. Yield attributes and seed yield

The growth and yield attributes were significantly influenced by crop establishment techniques (Table 6). The data on plant density at 10 DAS indicated that no till seed drill (Two passes) had the highest plant density of 42 plants/m^2 as compared to sowing of black gram10 days before the manual harvest of rice crop (32 plants/m^2). Sowing of black gram4 days before the machine harvest of rice crop resulted in reduced plant population (28 plants/m^2). However, the plant population was not significantly differed at the time of harvest. Though the plant density was highest with no till seed drill at 10 DAS, the population was drastically reduced to two third at the time of harvest.

Black grambroadcasted 10 days before the manual harvest of rice crop (No pass) had more no. of pods/plant (20), seeds/pod (6.0),

Table 2

Regression between soil moisture content and bulk density at different layers.

Layer/DAS	0 DAS				30 DAS				Harvest (65 DAS)			
	a	b	R^2	F sig	a	B	R^2	F sig	a	b	R^2	F sig
0–5 cm	3.525	−0.064	0.909	0.01	2.907	−0.075	0.935	0.01	1.935	F sig	0.803	0.06
5–10 cm	3.049	−0.050	0.961	0.02	2.019	−0.025	0.809	0.06	1.815	−0.023	0.995	0.01
10–15 cm	3.084	−0.050	0.971	0.01	1.934	−0.020	0.777	0.07	1.724	−0.016	0.950	0.01

* Level of significance = $p < 0.05$.

Table 3
Crop physiological parameters of black gram as affected by different wheel passes.

Treatments	Relative water content (%)		Specific leaf weight (g/cm^2)		Chlorophyll content (SPAD value)	
	30 DAS	40 DAS	30 DAS	40 DAS	30 DAS	40 DAS
T_1 – Broadcasting 10 days prior to manual harvest of paddy (No pass)	85.91	80.27	7.62	7.05	36.93	35.67
T_2 – No till seed drill on the day of paddy harvested by combine harvester (Two pass)	81.44	77.78	7.07	6.44	32.70	30.17
T_3 – Broadcasting 4 days prior to harvest of paddy by combine harvester (Single pass)	83.88	78.52	7.22	6.66	34.20	32.17
T_4–T_1 + Lifesaving irrigation with mobile sprinkler	85.86	84.95	7.66	7.51	37.17	38.27
T_5–T_2 + Lifesaving irrigation with mobile sprinkler	81.47	79.15	7.04	6.53	32.60	32.62
T_6–T_3 + Lifesaving irrigation with mobile sprinkler	83.68	80.14	7.26	6.96	34.51	34.22
LSD (0.05)	1.06	1.05	0.25	0.21	2.28	0.81

Table 4
Nodule count and nodule dry weight (g/plant) as affected by different treatments.

Treatments	Nodules/plant		Nodule dry weight (g)	
	30 DAS	45 DAS	30 DAS	45 DAS
T_1 – Broadcasting 10 days prior to manual harvest of paddy (No pass)	21.52	15.77	0.188	0.146
T_2 – No till seed drill on the day of paddy harvested by combine harvester (Two pass)	16.72	12.89	0.155	0.128
T_3 – Broadcasting 4 days prior to harvest of paddy by combine harvester (Single pass)	17.73	13.22	0.168	0.133
T_4–T_1 + Lifesaving irrigation with mobile sprinkler	21.17	16.84	0.184	0.16
T_5–T_2 + Lifesaving irrigation with mobile sprinkler	16.84	13.08	0.154	0.128
T_6–T_3 + Lifesaving irrigation with mobile sprinkler	17.65	14.66	0.167	0.142
LSD (0.05)	2.14	1.09	0.011	0.010

Table 5
Root length (cm) and root dry weight (g/plant) as affected by different treatments.

Treatments	Root length (cm)		Root dry weight (g/plant)	
	30 DAS	40 DAS	30 DAS	40 DAS
T_1 – Broadcasting −10 days prior to manual harvest of paddy (No pass)	6.98	7.39	0.081	0.082
T_2 – No till seed drill on the day of paddy harvested by combine harvester (Two pass)	5.87	6.03	0.058	0.064
T_3 – Broadcasting 4 days prior to harvest of paddy by combine harvester (Single pass)	6.22	6.83	0.064	0.072
T_4–T_1 + Lifesaving irrigation with mobile sprinkler	6.94	8.76	0.079	0.092
T_5–T_2 + Lifesaving irrigation with mobile sprinkler	5.93	6.76	0.058	0.068
T_6–T_3 + Lifesaving irrigation with mobile sprinkler	6.13	7.63	0.063	0.076
LSD (0.05)	0.014	0.027	0.004	0.005

Table 6
Growth and Yield attributes and seed yield (kg/ha) as influenced by mechanization and lifesaving irrigation.

Treatments	Plant population/m^2		Plant height at harvest (cm)	No. of pods/plant	No. of seeds/pod	100 seed weight (g)	Yield (kg/ha)
	10 DAS	Harvest					
T_1 – Broadcasting 10 days prior to manual harvest of paddy (No pass)	31	28	29.3	20	6.0	4.97	656
T_2 – No till seed drill on the day of paddy harvested by combine harvester (Two pass)	42	30	25.3	15	5.8	4.55	457
T_3 – Broadcasting 4 days prior to harvest of paddy by combine harvester (Single pass)	30	26	24.8	17	6.0	4.94	568
T_4–T_1 + Lifesaving irrigation with mobile sprinkler	31	28	28.2	24	6.6	4.98	786
T_5–T_2 + Lifesaving irrigation with mobile sprinkler	42	33	25.9	17	5.8	4.62	544
T_6–T_3 + Lifesaving irrigation with mobile sprinkler	30	31	28.4	20	6.4	4.98	690
LSD (0.05)	4	NS	NS	2	NS	0.1	112

higher 100 seed weight (4.97 g) and grain yield (656 kg ha^{-1}) as compared to no till seed drill (Two passes). The yield improvement over seed drill sown black gram (two passes) was 30.4 %. The critical importance of the supplemental irrigation at flowering stage is to bridge dry spells, especially to subsidise the terminal stress risks in relay cropping. Significant yield improvement was observed with supplemental irrigation given at the time of flowering (30 DAS) irrespective of the sowing methods. The mean yield increase across the different treatments due to mobile sprinkler irrigation at flowering stage was 16.8 per cent over the non-irrigated treatments. Black gram broadcasted 10 days before the manual harvest of rice crop (no pass) followed by supplemental irrigation resulted in a yield increase of 30.7 per cent as compared to black gramsown with seed drill after the machine harvest of the rice (Two passes) with supplemental irrigation.

4. Discussion

4.1. Soil penetration resistance

Soil penetration resistance (SPR) is an important parameter of soil strength, which is considered as an indicator for soil compaction that determines the root growth and crop yield [22]. Mechanized crop cultivation is of great growing concern as wheel traffic due to employment of transplanter and harvester emerges as potential threat to the subsoil structure, which is irreversible and ultimately lead to harmful soil compaction [23]. In no till soil, zero tillage could be characterized by soil penetration resistance [24]. Soil penetration resistance (SPR) has been used by several researchers to quantify the soil quality and to identify the layers with increased degree of compaction [8].

The experiment was carried out in zero till black gram which was grown as a relay crop after rice. In no till soil, additional compaction with a reduced total porosity is commonly observed due to denser top soil [25]. The soil penetration resistance was found to be greater in zero tillage as compared to conventional tillage [26]. The SPR was nil at 0–5 cm layer on the day of black gram sown 10 days before the manual harvest of rice crop which was due to optimal moisture in the rice field. However, there was an increase in the SPR when the black gram was sown 4 days before the harvest of rice to facilitate machine harvest of paddy which was mainly due to depletion of soil moisture in the surface. In the present study, the soil penetration resistance was higher with black gram seed sown with seed drill after the harvest of rice with combined harvester. The wheel passes of combine harvester and black gram seed drill would have created soil compaction and deaccelerate the root growth and water availability in deeper soil layers. The results are largely in accordance with changes in soil strength that the vertical loads of wheels had caused greater stress in the soil and dense top layer.

Irrespective of the treatments, significant reduction in the soil penetration resistance (0–5 cm layer) at 45 DAS was found after the supplemental irrigation given at flowering stage through mobile sprinkler. The SPR observed was 400 Kpa at 0–5 cm layer where black gram was sown 10 days before the manual harvest of rice crop followed by supplemental irrigation as against the non-irrigated (580 Kpa). The findings indicated that sprinkler water droplets did not create any soil compaction in the surface soils (0–5 cm layer) of all the three methods of black gram sowing. This is in contrary to earlier findings that sprinkler water droplets energy increased the surface sealing (soil compaction) and reduced aggregate stability [27,28]. The earlier findings may be hold good in soils where the crop would have irrigated through the crop and not as a supplemental irrigation once.

The number of passes of agricultural machinery creates mechanical resistance in the surfaces of soil and thick layers of soil under plough pan due to soil compaction [29]. In the present study, the use of combine harvester for rice harvest and seed drill for black gram sowing has created the higher soil penetration resistance of 620 Kpa at 45 DAS after the supplemental irrigation at flowering stage. In the seed drill, seeds fell continuously into a V shaped furrow opened by the disc type wheel of the seed drill. The depth of the V shaped furrow opened while sowing was about 7.5 cm and even up to 15 cm depth where the soil moisture was excess. Hence the seed drill employed on heavy soils with optimum moisture content after the harvest of rice crop might have increased the soil mechanical impedance. Earlier [30] also reported that use of heavy agricultural machinery, often on soils with high moisture content, it increased significantly the risk of soil compaction.

The vertical load of agricultural machinery creates soil compaction which is evidently seen in the increase of bulk density or decrease in porosity of soil [7]. Bulk density is also variable due to wheel compaction, tillage management and biological activity. The bulk density always had a positive relationship with soil penetration resistance and negative relationship with soil moisture [31]. The results of the present experiment also indicated that the values of bulk density increased with soil penetrating resistance. The bulk density was highest with black gram sown with seed drill and employment of combine harvester for the harvest of rice where the number of wheel passes was more. The heavy machinery traffic (Wheel passes of seed drill and combine harvester) would have resulted in mechanical compaction and ultimately increased the bulk density. Similarly, Ref. [32] observed increase in bulk density due to soil compaction caused by heavy agricultural machinery.

[33] also observed that wheel traffic caused an increase in soil bulk density though wheels are loaded in flooded condition. In the present study also, when the harvester and seed drill was employed, the soil moisture was optimum. Hence the bulk density was more due to the wheel passes. However supplemental mobile sprinkler irrigation given on 30 DAS eased way the soil compaction to a small extent which was reflected in the values of bulk density observed at 45 DAS. The continued compaction would have decreased the water content up to 30 DAS and the increased moisture content through the supplemental irrigation resulted in reduced values of bulk density. The moisture entered between the clay lattices would have increased the volume and as a result the bulk density at surface level was reduced. A steady increase in bulk density with decrease in moisture content was already reported by Ref. [34]. Conversely gradual increase in bulk density with an increase in soil moisture content was already documented by Ref. [33]. Reference [15] noted increase in bulk density and penetration resistance within no-till.

4.2. Soil moisture pattern

Surface soil compaction created in no till soil due to the puddled condition in the preceding rice crop and sub surface soil compaction due to wheel traffic of harvester and seed drill had played a major role in determining the depletion pattern of soil moisture. Soil crusting due to the breakdown of surface soil aggregates and hard pan due to puddling and wheel passes had restricted the water and soil entry [35].

In conventional relay cropping system, black gram was sown manually 10 days before the harvest of rice crop, where the soil condition was waxy. The black gram was broadcasted and hence there was absolutely no vertical loading on soil while sowing the black gram. The rice was also harvested manually and the black gram was at 2–3 leaf stage while harvesting of rice was completed. This would be the major reason for the slower depletion rate of soil moisture under the conventional cropping system as compared to sowing of black gram manually 4 days before the mechanical harvest of rice and black sown with seed drill on the day of harvest of rice with combine harvester. The time delay of 10 days between black gram sown manually before the harvest crop and black gram sown with seed drill after the harvest of rice crop created huge variation in soil moisture. The purpose of relay cropping by utilizing the residual moisture was partially fulfilled as the moisture content at the time of black gram sowing after the harvest of rice was 5.6, 8.22 and 7.27 percent lesser respectively at 0–5 cm, 5–10 cm and 10–15 cm layer as compared to black gram sown 10 days before the harvest of rice crop. Further the V shape furrow opened during sowing of black gram with seed drill exposed the top soil completely and would have disintegrated the soil aggregates. This deleterious effect might have rapidly depleted the soil moisture in the subsequent stages when compared to other methods of sowing. The surface soil compaction caused by the combined harvester through ground contact pressure and sub soil compaction due to the axle load of seed drill would have damaged the soil structure and as a result of soil compaction, the moisture retention capacity was reduced, which has been seen in the soil moisture depletion rate throughout the crop period. The results are in accordance with the observation of [36] that soil compaction and wheel traffic decrease the moisture retention capacity and hydraulic conductivity.

In order to avoid further drying of surface soil and depletion of soil moisture, mobile sprinkler irrigation was given at flowering stage (35 DAS). The soil moisture data recorded at 40 DAS revealed that though the soil moisture was not increased dramatically, the supplemental irrigation given was able to maintain almost the same soil moisture content at 0–5 cm layer that of 30 DAS in black gram broadcasted 10 days before the manual harvest of rice and 4 days before the machine harvest of rice crop. However, the soil moisture content did not improve with seed drill sown black gram. The wheel traffic of harvester and seed drill would have also decreased the water infiltration rate when supplemental irrigation was given. Reference [36] also in an opinion that the compacted soil profile contains small pores in the upper layer, which leads to higher evaporation loss and poor moisture retention. Further increase in soil penetration resistance and reduced water uptake due to drying of top soil was also documented by Ref. [37]. Reference [38] also showed that the infiltration rate was significantly reduced due to wheel traffic, which eventually reduced the soil moisture retention capacity. As the crop was raised under no till condition irrespective of the sowing methods, the lifesaving irrigation did not alter the soil moisture content in 5–10 cm and 10–15 cm. The supplemental irrigation was given once at flowering stage was only 10 mm which would not have infiltrated the deeper layers of the soil. Soil compaction and reduced infiltration due to energy of sprinkler droplets was earlier reported by Ref. [28].

4.3. Soil crack

Soil type is another factor that determines the soil compaction through influencing the soil aggregates. The present study was conducted in clayey soil where montmorillonite is the dominant mineral. Swelling phenomena is common in clayey soil due to the formation of diffuse double layer and flocculation. The soil shrinks when dry with deep wide cracks and swell moistened. Due to continuous moisture loss in the clay soil, shrinkage ends up with cracks due to generation soil suction [39]. Tillage methods and organic amendments could alter the Soil cracking patterns [16].

The changes in soil strength due to wheel traffic of combine harvester and as well seed drill in the present study increased the width and depth by 7.9 and 25.8 per cent over the manual sowing and harvest. The maximum cracking area under no tillage system was earlier observed by Ref. [40]. Though [40] reported that higher compaction of soil results in lower shrinkage and cracks of soil, the furrow opened to a depth of 7.5 cm at optimum soil moisture during the operation of seed drill might have resulted in deeper crack and volume. The data on soil cracking volume further indicated that, though the width and depth of soil cracks was higher in blackgram sown manually 10 days before the manual harvest of rice as compared to blackgram sown manually 4 days before the machine harvest of rice crop, the volume of sand required to fill the cracks was highest blackgram sown manually 4 days before the machine harvest of rice crop due to the soil compaction and plough pan created due to the wheel passes of combine harvester. Reference [41] also observed greater loss of water through bypass flow due to higher crack width and crack volume as a result of soil compaction. Soil shrinking ability and hydraulic conductivity has been reported to be affected by increased bulk density [13].

4.4. Root growth

Penetration resistance is one among the four physical barriers that limits the development root and plant growth. The pressure needed to be exerted to drive the root cap into the soil in the elongation zone is largely controlled by the soil penetration resistance [42]. Mechanical compaction of soil increased the soil bulk density which modify the root configuration and root-soil interactions [43].

The root length and root dry weight varied greatly with soil penetration resistance and bulk density. Irrespective of the treatments, the supplemental irrigation given on 30 DAS significantly reduced the penetration resistance at 40 DAS, which was exhibited in the corresponding increase in the root length and root weight as well. Black gram sown 10 days before the harvest of rice crop in a waxy soil condition would have increased the elongation of root due to minimal penetration resistance in the early stages. The increase in soil penetration resistance from mpa to mpa in seed drill sown blackgram reduced root length by 49% and root dry weight 25%. In the soils of blackgram sown with seed drill after the machine harvest of rice, the lesser moisture content would have resulted in poor elongation of roots due to increased soil penetration resistance. The soil moisture content always had a negative relationship with soil penetration resistance and as a result increased soil penetration resistance severely reduced the root and plant growth [44] due to lack of oxygen and by accumulation of toxins [45]. The reduction in soil water content and increase in bulk density would have restricted the root penetration of root due to low strength of soil. The use of machineries had increased the soil penetration resistance and bulk density and a result, restricted root growth and soil moisture content was noticed [46]. Reference [31] also reported that higher bulk density affects the root distribution and biomass due to soil compaction.

4.5. Root nodules

The nitrogen fixation efficiency in leguminous crop is affected by root nodule development. Mechanized cultivation in the modern Agriculture often results in risk of soil compaction due to use of heavy machineries for sowing and harvest. Compaction causes phenomenal changes in the soil environmental characteristics that affects root nodulation especially in clay soils by virtue of its greater resistance to air movement by the formation of impermeable layer [45]. The number of nodules per plant was significantly higher with black gram sown 10 days before the manual harvest of rice crop. Normally the nodules initiate at ten days after sowing in black gram. When compared to other method of sowing, black gram sown in this method had sufficient moisture in the soil and better microclimatic condition, which would have helped in producing a greater number of effective nodules and nodule dry weight at 30 DAS. The higher penetration resistance and lower moisture content in seed drill sown blackgram resulted in a reduction of root nodules/plant by 22.30 per cent and dry weight by 17.30 per cent. Reference [47] observed significant reductions in the number of nodules due to soil compaction. However, in the present study, though the number of nodules/plant nodules was lesser in soil with more penetration resistance due to more of wheel passes, the per nodule weight was larger as compared to soil with less penetration resistance. The mean per nodule weight was 9.20 mg and 9.38 mg respectively at 30 and 45 DAS in seed drill sown black gram after the machine harvest of rice as compared to manually sown black gram 10 days before the manual harvest of rice crop (8.71 mg and 9.37 mg). Similarly, Ref. [48] also reported that though the number of nodules per plant is reduced in compacted soil, the size of the nodules was bigger than the nodules observed in non-compacted soil.

The effective nodulation and nitrogen fixation in pulses is greatly affected by soil moisture and optimum soil moisture is required for nodule formation [49]. The supplemental irrigation given through mobile sprinkler on 30 DAS significantly increased the nodule number/plant and dry weight. Increase in the soil moisture would have enhanced the physiological and photosynthetic activities and finally improved the number of root nodules [50]. Increase in soil moisture up to 50 per cent increased the nodule formation and nodule dry weight [51]. Ceasing of nodulation in the absence of irrigation was earlier reported by Ref. [52]. In general, the data on number of nodules at 45 DAS shown decline trend in all the methods of blackgram sowing. Rapid depletion of soil moisture content led to soil compaction would have restricted the production of nodules in the later stages. In addition, normally nodulation in pulses starts at 9 DAS, reaches the peak at 50 per cent flowering stage and starts to decline after 45 DAS due to spontaneous regeneration in pulses [53]. A progressive increase in the number of nodules per plant was only up to the vegetative phase and started to decline in the flowering phase.

4.6. Physiological parameters

The soil penetration resistance due to soil compaction limits the root growth and subsequently physiological performance of the crop. The decrease in soil moisture due to soil penetration resistance and bulk density in the compacted soil retarded the physiological activities [54]. The relative water content at 30 DAS was significantly reduced by 5.2 per cent in the seed drill sown blackgram, which might be due to low stomatal conductance because of increased soil penetration resistance and bulk density at 30 DAS, as the crop was sown after the harvest of rice crop. During the stress period, stomatal closure reduces the relative water content [55].

The soil moisture content had a direct influence on the relative water content at 30 DAS as the crop was grown under residual moisture condition without any irrigation. The leaf RWC was significantly improved on 40 DAS when the crop was given supplemental irrigation and the per cent of increase in relative water content at 40 DAS with the supplemental irrigation was 3.2 over non-irrigated. The RWC reduction also caused a considerable decrease in the total leaf area which was evidently seen in the specific leaf weight. The reduced water supply from the soil would have reduced the photosynthetic activity due to low stomatal conductance. Similar reduction in relative water content and specific leaf weight was earlier reported by Ref. [56]. Thus, soil compaction which led to poor soil inhibited various physiological activities [55].

The restricted root growth due to soil compaction in seed drill sown blackgram after the machine harvest of rice crop had reduced the root demand for photosynthetic substances, which eventually reflected in the values of SPAD meter. The stomatal conductance was reported to be decreased due to high bulk density in the compacted soil, which in turn alter the transfer capacity of electron and chlorophyll content [57]. The chlorophyll content was significantly lowered in the compacted soil which was due to poor N uptake by the restricted growth of roots. Thus, the photosynthetic efficiency of a crop is limited by the scant chlorophyll content [54].

4.7. Yield

Soil compaction that hinders root growth, nutrient uptake and yield reduction are the major concern of farm mechanization [10]. The number of wheel passes and poor soil management creates impermeable layers especially by the puddling operation. Though impermeable layer improves water retention capacity, it restricts water and nutrient cycles. Many authors have reported that the subsoil compaction has negatively influenced the soil physical conditions, which substantially decreased crop yield. However, Ref. [58] showed that moderate compaction had no effect on crop yield or can increase yield. Reference [59] stated that moderate soil compaction favours seedling emergence, root growth and moisture and nutrient uptake.

The traditional practice of broadcasting blackgram in the standing crop rice as relay crop by utilizing the residual moisture and nutrients improves the soil environment, conserve soil resources, save time and energy. Plant density per unit area is very important in determining the yield of any crop. In the present study, the initial plant population observed at 10 DAS and as well as at harvest was highest with blackgram sown with seed drill after the harvest of rice crop. The seed placement was not optimum in the seed drill and dropping of seeds were more than the required population per unit area. The crowded population resulted in interplant competition, as a result the plants grew tall with fewer branches and number of pods per plant. Earlier, Ref. [60] reported higher population per unit area causes mutual shading which reduced the photosynthetic efficiency and finally the crop yield. In addition to the above more plant population per unit area had also depleted more of soil moisture which ultimately resulted in poor yield attributes and yield. Reference [22] also observed that Soil penetration resistance (SPR) in the compacted soils restricts the crop root growth and water uptake and finally led to yield reduction.

Supplemental lifesaving irrigation generally increases the crop yield in all the crops. The mobile sprinkler irrigation system normally maximizes the water use efficiency especially under water stress condition. This kind of lifesaving supplemental irrigation is regarded as that is deficit irrigation [61]. The lifesaving irrigation through mobile sprinkler at the flowering stage had eased away the soil penetration resistance to some extent, halted the soil moisture depletion, improved the physiological activities, root growth, yield attributes and yield. The supplemental irrigation given between jointing and anthesis had significantly increased the grain yield, WUE and HI in wheat [62,63]. Reference [64] also obtained similar yield with deficit irrigation to that of well-irrigated crops due to better root growth and elongation which maintained relative water content.

5. Conclusion

The soil compaction under mechanized cultivation in no till black gram had a significant effect on soil penetration resistance, bulk density and soil moisture depletion pattern. The results of the experiment indicated increased the soil penetration resistance, bulk density and volume of soil crack due to the mechanized harvest of rice and seed drill sown black gram. The soil penetration resistance and bulk density had an inverse relationship with the soil moisture content and as a result poor root growth and root dry wight was observed with two passes of wheel (Machine harvest and seed drill) as compared to single (machine harvest) and no pass (manual harvest). Supplemental lifesaving irrigation given at flowering stage had a profound influence on soil properties and crop growth irrespective of the wheel traffic. Two passes of wheel in the soil under optimum moisture condition created more compaction and had a negative impact on crop growth and yield. Though broadcasting of black gram seeds 10 days before the manual harvest of rice along with lifesaving irrigation on 30 DAS significantly increased the pod yield of black gram under zero till condition as compared to seed drill sown method of crop establishment after the machine harvest of rice, broadcasting of black gram seeds 4 days before the machine harvest of rice along with lifesaving irrigation may be recommended to obtain comparable yield of blackgram.

CRediT authorship contribution statement

Subrahmaniyan Kasirajan: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **T. Parthipan:** Methodology, Investigation, Formal analysis, Data curation. **S. Elamathy:** Formal analysis. **G. Senthil Kumar:** Investigation. **M. Rajavel:** Methodology, Investigation, Formal analysis, Data curation. **P. Veeramani:** Software, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: SUBRAHMANIYAN KASIRAJAN reports administrative support, statistical analysis, and travel were provided by Tamil Nadu Agricultural University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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