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Effect of Establishment Methods and Moisture Regimes on Physical Properties of Soil in a Rice Field under Deep Water Table Conditions of Uttarakhand

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A B S T R A C T

Introduction of new agricultural technology created growing realization of soil physical properties limiting crop production. However, soil physical changes and their impact on crop production are less easily realized because of their exceedingly complex and dynamic nature. Since the nature and arrangement of aggregates in soils could be expected to have a profound influence on pore space, which in turn would govern air and water relations, wide use has been made of aggregate analyses to evaluate spot physical conditions. Experience has sown that it is difficult to interpret these analyses in terms of behaviour on soils. The great difficulty arises from the fact that a given soil permeability can be obtained with an infinity of combinations of different sized aggregates. Rice (*Oryza sativa* L.) cultivation is due to special conditions of land preparation affect on physical characteristics of soil such as bulk density, infiltration rate, hydraulic conductivity, penetration resistance etc. In this present investigation effect of two establishments viz. direct seeded and manual puddling and three soil moisture regimes viz. on one day after disappearance of ponded water (1DADPW), I_2 (3DADPW) and I_3 (5 DADPW) on some physical properties of sandy loam soil grown with rice (*Oryza sativa* L.) c.v. Pant Dhan-12 at four dates viz. D_1 (26 May), D_2 (10 June), D_3 (25 June) and D_4 (10 July) during *kharif* seasons of 2016 and 2017. Results indicated that the magnitude of mean bulk density at surface and sub-surface was found 1.71 and 1.57 Mg m^{-3} at 30 days after sowing (DAS) and 1.75 and 1.62 Mg m^{-3} at harvest in direct seeded rice, however in puddled transplanted rice, bulk density was found to be 1.58 and 1.54 Mg m^{-3} at 30 DAS and 1.61 and 1.56 Mg m^{-3} at surface and subsurface, respectively. Bulk density increased from surface to sub surface may be due to the presence of fine gravels at the depth. The mean value of hydraulic conductivity (K_s) was observed as 23.63 and 24.23 cm day^{-1} at 30 DAS and 22.92 and 23.69 cm day^{-1} at harvest in direct seeded rice. Although in puddled transplanted rice plots K_s was found as 15.62 and 20.21 cm day^{-1}at 30 DAS and 15.25 and 19.60 cm day^{-1}at harvest at surface and subsurface, respectively. Data on infiltration rate (IR) indicated that mean value of IR 32.22 at 30 DAS and 31.16 mm h^{-1} at harvest in direct seeded and the mean value of IR in puddled transplanted rice it was 29.13 at 30 DAS and 27.55 mm h^{-1} at harvest at surface and subsurface, respectively. Observations on soil penetration resistance (PR) measurement indicated that the value of PR was found low for direct seeded plots compared with puddled transplanted rice plots. These results clearly indicated that IR and K_s were maximum in direct seeded rice plots compared with the values in puddled rice plots. This study confirmed that puddling can alter the physical properties of soil in rice plots for efficient water management more water can be conserved for optimizing rice yields.

Introduction

Rice (*Oryza sativa* L) is the world's most important crop and is a staple food for more than half of the world's population. It is also an important crop in India, covering 43.4 million hectares area with a total production of 110.15 million tonnes and productivity of 2.4 tonnes ha^{-1} (Anonymous 2018). In Uttarakhand state, it is cultivated mainly in *tarai* region with area, production and productivity of 0.25 M ha, 0.57 M tonnes and

2.33 tonnes per hectare, respectively (DES, 2017). The physical properties of soil are known to be of fundamental importance for plant growth, but much of the literature on the subject is qualitative or vague. Most physical phenomena have important effects on the chemical and biological soil properties and processes, and these in turn influence plant growth. Soil is a physical system and can be described in terms of bulk density, hydraulic conductivity, infilteration rate, porosity, amount of moisture and air in the soil and friability. The rice establishment methods namely, direct seeding and transplanting and differential soil moisture regimes provide different growth environment for rice mainly because of different tillage operation adopted. If productivity of crops is to be maintained, an agricultural system able to preserve a satisfactory physical condition in the soil must be developed. Fertilizer alone, or even in conjunction with improved crop varieties and measures to control pests and diseases, will not preserves productivity, if significant deterioration of physical condition occurs. Important soil physical constraints include, soil structure, bulk density, infiltration rate, water retention and movement, soil compaction, soil crust, hydraulic conductivity, soil aeration, soil temperature, penetration resistance etc. Puddling is the most common practice of rice establishment although, Puddling in rice is known to cause subsoil compaction, destroys soil structure in surface soil, and lowers permeability in the subsurface layer, resulting in restricted root penetration. Also, puddling cause late maturation of rice crop over direct seeded rice because of avoiding transplanting shock which delays rice growth, therefore, the crop mature a week to 10 days earlier and late maturation of rice crop further increases the water requirement duration of crop (Dawood *et al.,* 1971, De Datta, 1981 and Sharma *et al.,* 1995). Also sub-surface depths (0-0.06 and 0.12-0.18 m) bulk density of puddled plots was found to be higher than that of the non-puddled plot at tillering stage and the mean value was (1.62 mg m-3) and (1.59 mg m-3) in puddled and non-puddled plots, respectively (Bajpai and Tripathi, 2000). An increase in soil density below the puddled layer due to physical compaction during the puddling process (Ghildyal, 1982 and Rahman, 1991. The conventional tillage under dry conditions increased hydraulic conductivity of soils but it reduced under wet conditions which were more apparent in sandy loam and clay loam than in clayey soil (Mambani *et al.,* 1989). Puddling considerably reduced hydraulic conductivity throughout the rice season. It was 5.68 and 3.25 times higher at surface and sub-surface layer in direct seeded plots than transplanting (Hobbs *et al.,* (2002). Puddling in rice results in loss of transmission pores which significantly reduce infiltration rate (Saroch and Thakur, 1991). reported higher Infiltration under direct seeded plots was higher (0.75 and 1.81 mm hr-1) at 20 days after transplanting and harvest in comparison to transplanting plots (0.44 and 0.92 mm hr^{-1}) (Hobbs *et al.,* 2002). Infiltration rate was higher under direct drilling (1.92 mm hr^{-1}) and beushening methods (1.53 mm hr^{-1}) of rice as compared to transplanting (0.86 mm hr^{-1}) of rice cultivation (Purohit, 2003).

Materials and Methods

The experiments were conducted during two consecutive *kharif* seasons of 2016 and 2017 in C-5 plot, at N. E. Borlaug Crop Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar (29^o N latitude, 79^o 30` E longitude and 243.84 meter above the mean sea level), district Udham Singh Nagar, Uttarakhand, India. The climate of region is Humid Sub-Tropical the region is characterized with hot and dry summer. The monsoon sets during third week of June and lasts up to end of September. Soils of the region have developed from calcareous and medium to moderately coarse textured parent material under the predominant influence of grasses and vegetation with moderate to well drained conditions. The experiment was conducted 24 treatments *viz.,* four dates of sowing/transplanting-D (D_1- 26 May, D_2- 10 June, D_3- 25 June and D_4- 10 July), two establishment methods - M (M_1- Direct seeded rice and M_2- Puddled transplanted rice) and three moisture regimes - I (I_1- Irrigation on one day, I_2- three and I_3-five days after disappearance of ponded water, DADPW). In all 24 treatment combinations (4 × 2 × 3) were laid out in split-split design with rice crop cv. Pant Dhan-12 in a sandy loam soil with three replications during *kharif* seasons of 2016 and 2017. The experiment had a total of 72 plots (experimental units) of 4 m x 3 m size each. All the plots were provided with 1.0 m wide buffer space around it for avoiding seepage. The gross area for every plot was 12 m^2. Irrigation water 7.5 cm was measured with a graduated scale marked at 7.5 cm and installed in each plot. Major physical properties of soil viz. bulk density, saturated hydraulic conductivity, infiltration rate and penetration resistance of soil were measured using standard procedures during both rice growing seasons of 2016 and 2017. The Core sampler method (Blake and Hartge, 1986) was used for determining the bulk density of soil in rice plots. Hydraulic conductivity was determined by using a constant head permeameter and calculated as per (Klute and Dirksen, 1986). Infiltration rate was measured as per the method described by (Bouwer, 1986). The Penetration resistance of soil strength was measured in the field with the help of pocket penetrometer.

Results and Discussion

Bulk Density

Data pertaining to bulk density (Mg m^{-3}) of soil at two depths and intervals of rice crop is presented in Table 1. It is evident from the data that among different dates of sowing, bulk density of soil at 0-15 cm depth and 30 DAS, was non-significantly higher with D_1 and D_3 (1.66 and 1.65, respectively) during both the years while between methods of establishment, bulk density was found significantly higher with M_2 (1.72 and 1.71 during both the years, respectively). Bulk density of 0-15 cm depth soil at 30 DAS of rice crop was also found non-significantly higher with I_1 (1.67 and 1.66) over the other irrigation schedules during both the years, respectively. Bulk density of soil at 15-30 cm depth and 30 DAS of rice crop was found non-significantly affected with the dates of sowing, with highest values obtained under D_1 (1.54 and 1.56 during both the years, respectively) while the highest values were obtained under M_2 (1.57 and 1.60) over M_1 during both the years, respectively. Among irrigation schedules, bulk density was found non-significantly higher with I_1 (1.62 and 1.61 during both the years, respectively) followed by I_2. Bulk density of 0-15 cm depth soil at harvest of rice crop was found non-significantly higher with D_1 (1.70 and 1.69) and I_3 (1.71 and 1.70) among different dates of sowing and irrigation schedules during both the years, respectively.

However, Bulk density was found significantly higher with M_2 (1.76 and 1.75) between the establishment methods, during both the years, respectively. Bulk density of 15-30 cm depth soil at harvest of rice crop was found non-significantly higher at 1.61 with D_2 and D_4 among different dates of sowing. Among different Irrigation schedules, bulk density was found non-significantly higher with I_3 (1.64 and 1.61) during both the years, respectively. Bulk density was also found non-significantly higher with M_2 (1.64 and 1.61) between the establishment methods, during both the years, respectively. The overall data on bulk density of soil at different depths and intervals of rice crop revealed that bulk density was found non-significantly affected with the dates of sowing and irrigation schedules at different depths and intervals of rice crop during both the years while establishment methods was found to have significant effect on bulk density of soil at 0-15 cm only. Soil with puddled transplanted rice had higher values of bulk density over the direct seeded rice soil during both the years, which may be attributed to soil compression due to puddling practice done on the surface soil. However, sub-surface soil with puddled transplanted rice also had higher values of bulk density over the direct seeded rice but could not reach up to level of significance. Sharma *et al.,* (2005) and Rezaei *et al.,* (2012) also reported significant increase in bulk density with puddling of rice field.

Saturated hydraulic conductivity (k_s)

Data pertaining to saturated hydraulic conductivity (cm day^{-1}) of soil at different depths and intervals of rice crop is presented in Table 2. It is evident from the data that among different dates of sowing, hydraulic conductivity of soil at 0-15 cm depth and 30 DAS, was non-significantly higher with D_1 and D_4 (19.94 and 20.10, respectively) during both the years while between methods of establishment, hydraulic conductivity was found significantly higher with M_1 (23.54 and 23.72) during both the years, respectively. Hydraulic conductivity of 0-15 cm depth soil at 30 DAS of rice crop was also found non-significantly higher with I_3 (19.62) during 2016 and I_1 (20.07) during 2017 over the other irrigation schedules. Hydraulic conductivity of soil at 15-30 cm depth and 30 DAS of rice crop was found non-significantly affected with the dates of sowing, with highest values obtained under D_2 (22.42 and 22.65 during both the years, respectively) while the highest values were obtained under M_1 (24.11 and 24.35) over M_2 during both the years, respectively. Among irrigation schedules, hydraulic conductivity was found non-significantly higher with I_3 (22.34 and 22.56 during both the years, respectively) followed by I_2. Hydraulic conductivity of 0-15 cm depth soil at harvest of rice crop was found non-significantly higher with D_1 (19.43) during 2016 and D_2 (19.48) during 2017 over other dates of sowing. Among different irrigation schedules, hydraulic conductivity was found non significantly higher with I_2 (19.15) during 2016 and I_3 (19.28) during 2017.

However, hydraulic conductivity was found significantly higher with M_1 (22.86 and 22.99) between the establishment methods, during both the years, respectively. Hydraulic conductivity of 15-30 cm depth soil at harvest of rice crop was found non-significantly higher with D_4 (23.25) during 2016 and D_2 (22.11) during 2017 over other dates of sowing. Among different Irrigation schedules, hydraulic conductivity was found non-significantly higher with I_3 (21.76 and 21.98) during both the years, respectively. However, hydraulic conductivity was found significantly higher with M_1 (23.36 and 24.02) between the establishment methods, during both the years, respectively.

It is evident from these results that hydraulic conductivity was found non-significantly affected with the dates of sowing and irrigation schedules at different depths and intervals of rice crop during both the years while establishment methods was found to have significant effect on hydraulic conductivity of soil. Soil with puddled transplanted rice had higher values of hydraulic conductivity over the direct seeded rice soil during both the years, which may be attributed to ceasing of macro pores during the practice of puddling. Sharma *et al.,* (2005) and Rezaei *et al.,* (2012) also reported significant decrease in hydraulic conductivity with puddling of rice field.

Table.1 Effect of sowing dates, establishment methods and irrigation schedules on Bulk density (Mg m^{-3}) of soil with rice crop cv. Pant Dhan-12 at different intervals and soil depths during *kharif* seasons of 2016 and 2017

	Bulk density (Mg m^{-3})							
At the time of sowing	**2016**		**2017**		**2016**		**2017**	
	0-15 cm		**15-30 cm**		**0-15 cm**		**15-30 cm**	
	1.58		**1.56**		**1.58**		**1.54**	
Treatment	**30 DAS**				**At harvest**			
	0-15 cm		**15-30 cm**		**0-15 cm**		**15-30 cm**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Date of Sowing								
D_1 (26th May)	1.66	1.64	1.54	1.56	1.70	1.69	1.57	1.58
D_2 (10th June)	1.64	1.64	1.55	1.55	1.69	1.68	1.61	1.60
D_3 (25th June)	1.65	1.66	1.55	1.57	1.68	1.69	1.59	1.59
D_4 (10th July)	1.65	1.64	1.58	1.59	1.68	1.67	1.61	1.58
SEm±	0.01	0.01	0.04	0.05	0.02	0.03	0.04	0.06
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Establishment methods								
M_1 (Direct seeded rice)	1.58	1.58	1.53	1.56	1.62	1.60	1.55	1.57
M_2 (Puddled transplanted rice)	1.72	1.71	1.58	1.57	1.76	1.75	1.64	1.61
SEm±	0.01	0.01	0.04	0.06	0.03	0.03	0.08	0.07
LSD (*p*=0.05)	0.02	0.02	NS	NS	0.10	0.12	NS	NS
Irrigation Schedules								
I_1 (1 DADPW)	1.67	1.66	1.54	1.55	1.67	1.69	1.58	1.57
I_2 (3 DADPW)	1.64	1.64	1.56	1.57	1.69	1.66	1.59	1.59
I_3 (5 DADPW)	1.65	1.65	1.57	1.6	1.71	1.7	1.64	1.61
SEm±	0.01	0.01	0.02	0.03	0.02	0.03	0.01	0.02
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Table.2 Effect of sowing dates, establishment methods and irrigation schedules on hydraulic conductivity (cm day^{-1}) of soil with rice crop cv. Pant Dhan-12 at different intervals and soil depths during *kharif* seasons of 2016 and 2017

	Hydraulic conductivity (cm day^{-1})							
At the time of sowing	**2016**		**2017**		**2016**		**2017**	
	0-15 cm		**15-30 cm**		**0-15 cm**		**15-30 cm**	
	23.54		**20.32**		**23.20**		**20.68**	
Treatment	**30 DAS**				**At harvest**			
	0-15 cm		**15-30 cm**		**0-15 cm**		**15-30 cm**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Date of Sowing								
D$_1$ (26th May)	19.94	19.73	21.96	22.18	19.43	18.94	21.40	21.77
D$_2$ (10th June)	19.20	19.86	22.42	22.65	18.80	19.48	21.76	22.11
D$_3$ (25th June)	19.01	19.53	22.00	22.22	18.55	18.92	19.25	21.56
D$_4$ (10th July)	19.60	20.10	22.13	22.35	19.24	19.38	23.25	22.09
SEm±	0.75	0.92	0.61	0.33	0.84	0.65	0.82	0.63
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Establishment methods								
M$_1$ (Direct seeded rice)	23.54	23.72	24.11	24.35	22.86	22.99	23.36	24.02
M$_2$ (Puddled transplanted rice)	15.34	15.9	20.14	20.34	15.13	15.37	19.47	19.73
SEm±	1.59	1.31	0.92	0.75	1.95	1.61	0.95	1.05
LSD (*p*=0.05)	4.60	3.94	2.32	2.17	4.91	4.65	2.86	2.65
Irrigation Schedules								
I$_1$ (1 DADPW)	19.21	20.07	21.90	22.12	18.85	19.21	21.23	21.88
I$_2$ (3 DADPW)	19.49	19.62	22.15	22.37	19.15	19.05	21.26	21.79
I$_3$ (5 DADPW)	19.62	19.73	22.34	22.56	19.00	19.28	21.76	21.98
SEm±	0.85	1.02	0.92	0.56	0.53	0.85	0.67	0.23
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Table.3 Effect of sowing dates, establishment methods and irrigation schedules on Infiltration rate in soil (mm h^{-1}) of soil with rice crop cv. Pant Dhan-12 at different intervals at 30 DAS during *kharif* seasons of 2016 and 2017

	Infiltration rate in soil (mm h^{-1})			
At the time of sowing	**2016**		**2016**	
	33.52		**33.84**	
Treatment	**30 DAS**		**At harvest**	
	2016	**2017**	**2016**	**2017**
Date of Sowing				
D_1 (26th May)	30.94	31.57	27.58	30.70
D_2 (10th June)	29.79	31.78	28.16	31.34
D_3 (25th June)	29.50	31.25	27.63	30.76
D_4 (10th July)	30.41	32.16	27.79	30.94
SEm±	0.68	0.73	0.79	0.91
LSD (*p*=0.05)	NS	NS	NS	NS
Establishment methods				
M_1 (Direct seeded rice)	32.17	33.27	30.18	32.14
M_2 (Puddled transplanted rice)	28.15	30.11	25.39	29.71
SEm±	0.91	0.84	1.02	0.79
LSD (*p*=0.05)	2.63	2.12	3.07	2.39
Irrigation Schedules				
I_1 (1 DADPW)	29.81	32.11	27.50	30.61
I_2 (3 DADPW)	30.24	31.40	27.82	30.96
I_3 (5 DADPW)	30.44	31.57	28.05	31.23
SEm±	0.58	0.76	0.68	0.72
LSD (*p*=0.05)	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

Table.4 Effect of sowing dates, establishment methods and irrigation schedules on Penetration resistance (kg cm^{-2}) of soil with rice crop cv. Pant Dhan-12 at different intervals and soil depths during *kharif* seasons of 2016 and 2017

	Penetration resistance (kg cm^{-2})							
At the time of sowing	**2016**		**2017**		**2016**		**2017**	
	0-15 cm		**15-30 cm**		**0-15 cm**		**15-30 cm**	
Treatment	**30 DAS**				**At harvest**			
	0-15 cm		**15-30 cm**		**0-15 cm**		**15-30 cm**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Date of Sowing								
D_1 (26th May)	3.35	3.21	2.76	2.75	3.49	3.26	2.93	2.89
D_2 (10th June)	3.23	3.23	2.82	2.81	3.37	3.35	2.98	2.92
D_3 (25th June)	3.20	3.18	2.77	2.76	3.33	3.25	3.02	2.86
D_4 (10th July)	3.30	3.27	2.79	2.77	3.45	3.34	2.83	2.94
SEm±	0.23	0.61	0.58	0.24	0.21	0.26	0.34	0.42
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Establishment methods								
M_1 (Direct seeded rice)	2.42	2.38	2.19	2.14	2.57	2.46	2.34	2.31
M_2 (Puddled transplanted rice)	4.12	4.07	3.38	3.39	4.25	4.14	3.53	3.49
SEm±	0.51	0.43	0.21	0.34	0.53	0.41	0.35	0.26
LSD (*p*=0.05)	1.47	1.29	0.53	0.98	1.34	1.18	1.05	0.66
Irrigation Schedules								
I_1 (1 DADPW)	3.23	3.27	2.76	2.74	3.38	3.30	2.91	2.90
I_2 (3 DADPW)	3.28	3.19	2.79	2.78	3.44	3.28	2.93	2.89
I_3 (5 DADPW)	3.30	3.21	2.81	2.80	3.41	3.32	2.98	2.91
SEm±	0.12	0.23	0.19	0.34	0.43	0.26	0.38	0.42
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Infiltration rate (mm h^{-1})

Data pertaining to infiltration rate (mm h^{-1}) of soil at different intervals of rice crop is presented in Table 3. It is evident from the data that among different dates of sowing, infiltration rate of soil at 30 DAS, was non-significantly higher with D_1 (30.94) during 2016 and D_4 (32.16) during 2017 over other dates of sowing. Between methods of establishment, infiltration rate was found significantly higher with M_1 (32.17 and 33.27) during both the years, respectively.

Infiltration rate of soil at 30 DAS of rice crop was also found non-significantly higher with I_3 (30.44) during 2016 and I_1 (32.11) during 2017 over the other irrigation schedules. Infiltration rate of soil at harvest of rice crop was found non-significantly higher with D_2 (28.16 and 31.34) and I_3 (28.05 and 31.23) over different dates of sowing and irrigation schedules during both the years, respectively.

However, infiltration rate was found significantly higher with M_1 (30.18 and 32.14) between the establishment methods, during both the years, respectively. Overall data on infiltration rate of soil at different depths and intervals of rice crop revealed that hydraulic conductivity was found non-significantly affected with the dates of sowing and irrigation schedules at different depths and intervals of rice crop during both the years while establishment methods was found to have significant effect on infiltration rate of soil.

Soil with puddled transplanted rice had higher values of infiltration rate over the direct seeded rice soil during both the years, which may be attributed to ceasing of macro pores of surface soil during the practice of puddling. Sharma *et al.,* (2005) also reported significant decrease in infiltration rate with puddling of rice field.

Penetration resistance

Data pertaining to penetration resistance (kg cm^{-2}) of soil at different depths and intervals of rice crop is presented in Table 4. It is evident from the data that among different dates of sowing, penetration resistance of soil at 0-15 cm depth and 30 DAS, was non-significantly higher with D_1 (3.35) during 2016 and D_4 (3.27) during 2017. Between methods of establishment, penetration resistance was found significantly higher with M_2 (4.12 and 4.07) during both the years, respectively. Penetration resistance of 0-15 cm depth soil at 30 DAS of rice crop was also found non-significantly higher with I_3 (3.30) during 2016 and I_1 (3.27) during 2017 over the other irrigation schedules during. Penetration resistance of soil at 15-30 cm depth and 30 DAS of rice crop was found non-significantly affected with the dates of sowing, with highest values obtained under D_2 (2.82 and 2.81 during both the years, respectively) while the significantly highest values were obtained under M_2 (3.38 and 3.39) over M_1 during both the years, respectively. Among irrigation schedules, penetration resistance was found non-significantly higher with I_3 (2.81 and 2.80) during both the years, respectively.

Penetration resistance of 0-15 cm depth soil at harvest of rice crop was found non-significantly higher with D_1 (3.49) during 2016 and D_2 (3.35) during 2017 over other dates of sowing. Among different irrigation schedules, penetration resistance was found non-significantly higher with I_2 (3.44) during 2016 and I_3 (3.32) during 2017. However, penetration resistance was found significantly higher with M_2 (4.25 and 4.14) between the establishment methods, during both the years, respectively. Penetration resistance of 15-30 cm depth soil at harvest of rice crop was found non-significantly higher with D_3 (3.02) during 2016 and D_4 (2.94) during 2017 over other dates of sowing. Among different Irrigation schedules, penetration resistance was found non-significantly higher with I_3 (2.98 and 2.91) during both the years, respectively. However, penetration resistance was found significantly higher with M_2 (3.53 and 3.49) between the establishment methods, during both the years, respectively. It is clear from these results that penetration resistance was found non-significantly affected with the dates of sowing and irrigation schedules at different depths and intervals of rice crop during both the years while establishment methods was found to have significant effect on penetration resistance of soil. Soil with puddled transplanted rice had higher values of penetration resistance over the direct seeded rice soil during both the years, which may be attributed to more compaction due to the practice of puddling. Rezaei *et al.,* (2012) also reported significant increase in penetration resistance with puddling of rice field.

Soil moistures in rice crop sown on different dates had less effect on studied physical properties. However, puddling in rice crop significantly increased bulk density and penetration resistance while decreased infiltration rate and hydraulic conductivity that lead to better water retention on the soil surface and ultimately reduced number of irrigations. So it can be concluded that in a sandy loam soil with very deep water table, practising puddling modifies soil physical parameters favourably for better rice yields.

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