Agricultural Journal 8 (5): 217-221, 2013
ISSN: 1816-9155

Puddling Effects on the Shear Parameters of Paddy Field Soil

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Abstract: The effects of puddling intensity on shear strength, internal friction angle and cohesion were evaluated in a paddy field experiment. The treatments were Non-Puddled (NP), puddled by one pass (P1) and three passes (P3) of a rototiller. Shear parameters were measured at three soil depths in all treatments. Also, the relationships between hydraulic conductivity with internal friction angle and cohesion were developed. Results showed that the effect of puddling intensity on the shear parameters was significant ($p<0.01$). Puddling decreased the internal friction angle from 0.87° in NP to 0.25° and 0.21° in P1 and P3, respectively. Puddling by one pass of rototiller decreased the shear strength of soil by about 72% whereas puddling from one to three passes decreased the shear strength by 17%. The decrease in cohesion by one pass of puddler was about 73% whereas subsequent puddling to three passes decreased the cohesion by 78%. The regression equations developed to relate the soil cohesion and internal friction angle of soil with hydraulic conductivity varied linearly and had determination coefficients of 0.68 and 0.65, respectively.

Key words: Shear strength, internal friction angle, cohesion, hydraulic conductivity, puddling

INTRODUCTION

The conventional method of tillage and planting for rice production in Iran is wet tillage (puddling). A value for shear strength is essential to predict the load support capacity (Imhoff *et al*., 2004) and traction required to pull farm implements (McKyes, 1985). It is also used as a measure for soil credibility (Mohanty *et al*., 2004) and resistance to seedling emergence and root growth (Marsh and Rixon, 1991). Soil shear strength measurement has been used to compare changes in soil mechanical strength in ploughed and direct-drilled soils (Sharma and de Datta, 1985). Blanco-Canqui *et al*. (2005) stated that besides the vertical compressibility, knowledge of shear strength dynamics is crucial to explain the mechanical behavior and structural sustainability of agricultural soils. Mohanty *et al*. (2004) evaluated three puddling intensities (un-puddled, one and eight passes) on the shear strength. Their result showed that soil shear strength decreased with puddling and this reduction increased in higher intensities. Also, increasing in depth increased the soil strength in all three levels of puddling. Awadhwal and Singh (1992) investigated the puddling effects on mechanical characteristics of wet loam soil. They reported that the value of shear strength decreased with increasing levels of puddling. The higher intensity of puddling is favour for increasing moisture of soil.

Puddling can also produce a more open structure and hence decrease shear strength. Puddling or working soil above saturation moisture during rice cultivation eliminates most macro pores which transmit water. The remaining macro pores are partially filled by dispersed fine particles (Rezaei *et al*., 2012) resulting in drastic reduction in hydraulic conductivity. The extent reduction in hydraulic conductivity depends on puddling intensity and among other factors. The puddled soil maintained 25% more water than un-puddled soil (Kukal and Aggrawal, 2003).

Kukal and Aggarwal (2003) reported that puddling with eliminated macro pores that transmitted water and increase micro pores create an open and loose structure in the soil that have low hydraulic conductivity. The gradual settlement of dispersed particles suspended and organic matter in solution created a soft mud over a plough pan, caused decrease in hydraulic conductivity (Mouazen *et al*., 2002).

Ringrose-Voase *et al*. (2000) suggested that low hydraulic conductivity limited the upwards supply of water for evaporation so that evaporation from the soil

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surface decreased. Kukal and Sidhu (2004) reported that increasing of puddling intensity from 1-4 passes decreased the hydraulic conductivity by 30%.

The objective of this study was to determine the effect of soil puddling intensity on the soil shear strength, internal friction angle and cohesion at three depths. Also, the regression equations were developed to relate the soil cohesion and internal friction angel with soil hydraulic conductivity.

MATERIALS AND METHODS

Measurements were conducted in an experimental paddy field of 30×50 m plot under three puddling intensity; zero, one and three passes of rototiller at three depths (0-10, 10-20, 20-30 cm). The field was located at Sari Agricultural University, Mazandaran, Iran. The soil was transformed into flooding state and puddled by a rototiller having a depth of cut adjusted to 15 cm. At the start of each puddling operation the soil shear parameters and hydraulic conductivity were measured. Then, the soil was puddled to one and three passes of puddler and above mentioned parameters were measured. The treatments were replicated three times and experiment was laid out in a random block design.

The shear tests, using a two-piece shear box of square cross section were performed on three undisturbed samples. The 4 normal stresses of 10, 15, 20 and 25 kPa were used. The shear displacement rate was 1 mm min^{-1}. The relative displacement versus shear force was plotted and the soil shear parameters were estimated based on the Mohr-Coulomb criterion. Estimates of soil cohesion (c) and internal friction angle (φ) were calculated from Eq. 1:

$$\tau = C + \sigma \tan \varphi \quad (1)$$

Saturated hydraulic conductivities of soil at three replications were determined by falling-head method. Subsoil samples were taken from 10-30 cm in depth, sample cylinders were 7.55 cm in height and 3.25 cm in diameter. The muddy layer samples were collected with a container and drained (Aimrun *et al*., 2004).

Analysis of variance was used to test the puddling intensity and depth effects on shear strength, internal friction angle and cohesion. Treatments means were compared using the least significant difference procedure and Duncan's multiple range tests at the 5% probability level. Statistical software of SAS was used.

RESULTS

The results indicated that puddling intensity, depth and the interaction effect on the shear parameters were significant (Table 1). Shear strength strongly decreased from NP to P1 and P3 by 74 and 78%, respectively (Fig. 1). Also, no significant difference was observed between P1 and P3 treatments. The mean value of shear strength decreased from 12.6-10.4 kPa when puddling intensity increased from P1 to P3. The shear strength value increased with increasing soil layer depth. The lowest and highest amounts of shear strength were observed in the treatments of P3 at depth of 0-10 cm and NP at the depth of 20-30 cm, respectively (Table 2).

Effect of puddling intensity on internal friction angle was significant (Table 1). An increase in puddling intensity from NP to P1 and P3 decreased internal friction angle about 71 and 67%, respectively. Mean comparison indicated that internal friction angle was significant ($p<0.05$) between levels of puddling intensity. The interaction effect of puddling and depth on the internal friction angle was significant ($p<0.05$). The maximum and

Table 1: Analysis of variance related to shear strength, cohesion and internal friction angle

Source of variations	dp	Shear strength (kPa)	Cohesion (kPa)	Internal friction angle (°)
Puddling intensity	2	3699.544^{**}	1040.466^{**}	1.305^{**}
Depth (cm)	2	871.052^{**}	256.902^{**}	0.371^{**}
puddling x depth	4	79.663^{**}	20.856^{**}	0.021^{**}
Error	18	4.770	0.003	0.001

*, **Significant at 5 and 1% probability level, respectively

Table 2: Interaction effect of puddling intensity and depth on shear strength

	Shear strength (kpa)		
Depth (cm)	NP	P1	P3
0-10	42^{a}	0^{d}	0^{dg}
10-20	47^{b}	11^{e}	7.7^{h}
20-30	51^{c}	26.81^{f}	23.44^{i}

Table 3: Interaction effect of puddling intensity and depth on internal friction angle

	Internal friction angle (°)		
Depth (cm)	NP	P1	P3
0-10	0.71^{a}	0^{c}	0^{cf}
10-20	0.93^{b}	0.24^{d}	0.17^{dg}
20-30	0.98^{b}	0.53^{e}	0.48^{eh}

NP = Non Puddle; P1 = Puddled by one pass; P3 = Puddled by three passes; Similar letters in each column and row have no significant difference

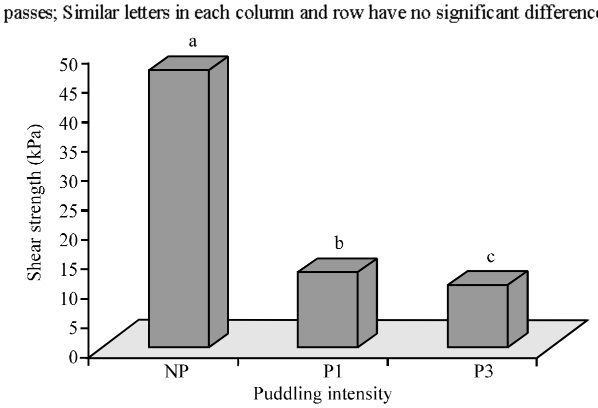

Fig. 1: Effect of puddling intensity on shear strength

minimum internal friction angles were obtained for NP at 20-30 cm depth and for P3 at 0-10 cm depth, respectively (Table 3, Fig. 2). Also, internal friction angle increased with increasing in depth and it was intense for higher intensity of puddling (Fig. 3).

According to Table 1, puddling intensity significantly ($p<0.01$) affected the soil cohesion. The values of the cohesion in unpuddled as well as freshly puddled soil at two levels of puddling and three depths are given in Table 4. Figure 4 showed that the cohesion significantly reduced after puddling by one pass (P1) and three passes (P3). Also, the difference between treatments P1 and P3 was significant ($p<0.01$). There is an increase in cohesion with depth for all treatments (Table 4).

The regression equation was developed to relate the soil cohesion and angel of friction of soil with hydraulic conductivity varied linearly and had determination coefficients of 0.68 and 0.65, respectively (Fig. 3 and 5).

DISCUSSION

The mean value of shear strength was 46.6, 12.6 and 10.38 kPa corresponding to NP, P1 and P3, respectively. The change in soil shear strength among P1 and P3 was significant (Fig. 1). The highest reduction in shear strength took place during one pass of puddler and that the subsequent passes (three passes) reduced the shear strength by 17%. Awadhwal and Sing (1992) strength took place during one pass of the puddler and reported that the first level of puddling (two passes of puddler) decreased the shear yield strength of soil by about 71% whereas puddling to higher levels decreased the soil strength by 83.4, 86.6 and 88% corresponding to three, four and six passes of the puddler. The shear strength of puddled soil is lower due to loosening and softening of the paddled layer. The shear strength in the 0-10 cm surface layer for P1 and P3 was near zero and this may be due to saturated soil condition and loose particles created by puddling. In puddled layer increasing the depth of soil increased the shear strength. This trend may be because of the progressive of heavier particles at thelowerpart of the puddled layer. Other researchers have

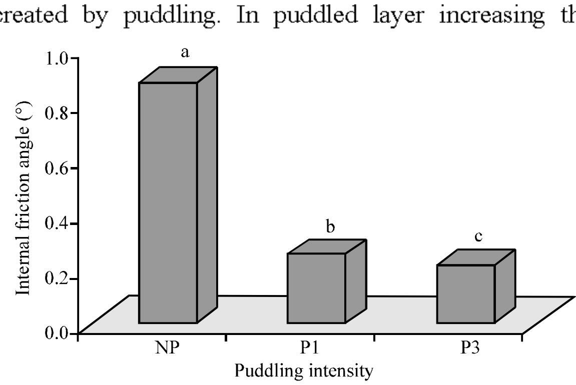

Fig. 2: Effect of puddling intensity on internal friction angle

Table 4: Interaction effect of puddling intensity and depth on Cohesion

	Cohesion (kpa)		
Depth (cm)	NP	P1	P3
0-10	22.64[a]	0.00[c]	0.00[cf]
10-20	23.52[a]	4.95[d]	3.34[dg]
20-30	27.10[b]	14.30[e]	12.40[ek]

NP = Non Puddle; P1 = Puddled by one pass; P3 = Puddled by three passes; Similar letters in each column and row have no significant difference

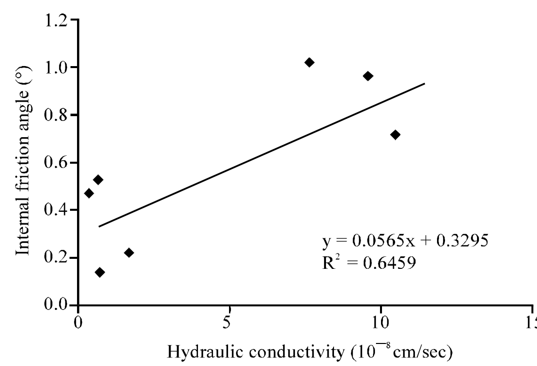

Fig. 3: The relationship between hydraulic conductivity and internal friction angle

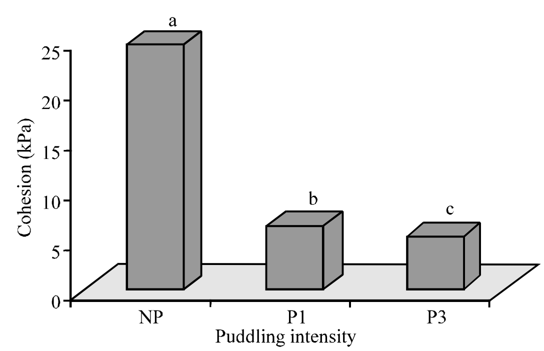

Fig. 4: Effect of puddling intensity on cohesion

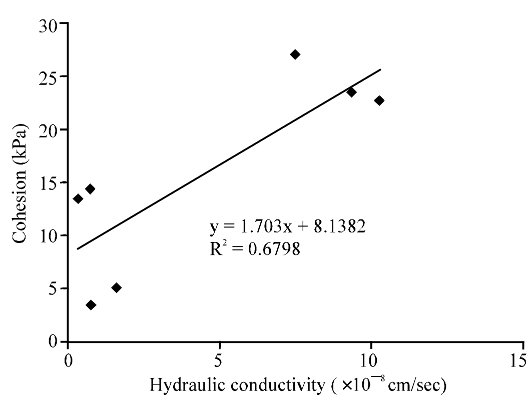

Fig. 5: The relationship between hydraulic conductivity and cohesion

also reported that shear strength decreases with puddling and increases with depth (Mouazen, 2002; Nearing *et al*., 1991). Increasing shear strength in the deeper layers (20-30) from the soil surface after puddling probably is due to soil compaction by tillage implements and tractor wheels. Puddling destroys soil aggregates and lowers bulk density due to the generation of open structure. Consequently, the shear strength is considerably reduced and a low shear strength layer is formed. There is a strong relationship between shear strength and bulk density for the lowland paddy soils (Aimrun *et al*., 2004). This would result in an increase in water repellency and a decrease in matric suction (Goebel *et al*., 2007). The decrease in matric suction resulted in a decrease in effective stress and the cohesive component of the soil shear strength.

Puddling intensity significantly ($p<0.01$) affected the internal friction angle (Table 1). It was observed that the internal friction angle of un-puddled soil before the process of tilling saturated soil was 0.87°. After puddling with a rotary puddler, the value of internal friction angle was measured and obtained 0.25° and 0.21° for one and three passes, respectively. The internal friction angle decreased by 16% when puddling intensity increased from P1 to P3 (Fig. 2). The interaction effect of depth and puddling intensity on the internal friction angle was significant (Table 1). The internal friction angle for unpuddled soil was about 3-4 times higher than that for puddled soil and it significantly decreased after puddling. The internal friction angle values after one and three passes of puddler were 0 and at the depth of 0-10 cm and decreased to 0.53 and 0.48 at the depth of 20-30, respectively (Table 3). During the puddling operation, the upper soil layer (0-10 cm) is loosened and the pore volume increased, resulting in a decrease in bulk density (Painuli, 2000). The deeper layer (20-30 cm) due to the compaction by implements and settle heavy particles of soil had a high bulk density. Soil bulk density decreased after puddling but increased with depth.

Figure 3 shows an increase in the hydraulic conductivity with increasing in internal friction angle. Puddling destroys soil aggregates, reduces macrospores and increases microspore volume. Consequently, the hydraulic conductivity is considerably reduced and a low hydraulic conductivity layer is formed (Rezaei *et al*., 2012). There is a strong relationship between hydraulic conductivity and macro porosity for the lowland paddy soils (Aimrun *et al*., 2004). Greater volume of pores in the paddled soil is occupied by fine pores which causes a decrease in soil hydraulic conductivity (Hemmat and Taki, 2003).

The cohesion in non-puddled soil was highest which puddling caused a significant decrease in cohesion (Fig. 4). Higher level of puddling created more suspended material by its churning action which decreased the hydraulic conductivity (Rezaei *et al*., 2012). The regression equations developed to relate the soil cohesion with hydraulic conductivity indicated that the cohesion varied linearly with hydraulic conductivity and had a determination coefficient of 0.68 (Fig. 5). Effective stress generated by the matrices suction increased soil c-value where continuity of water films around the particles was preserved. In granular soils, decreasing moisture content resulted in diminished continuity in water films, decreasing c and reduced contribution of the matric suction to c (Schjonning and Rasmussen, 2000). The effect of moisture content on soil c reported in this research is in agreement with those obtained by Mouazen (2002). They reported that the soil c increased with decreasing moisture content.

CONCLUSION

- Puddling had a significant effect in decreasing soil shear strength, cohesion and internal friction angle
- Increasing in depth increased soil shear strength, cohesion and internal friction angle. The shear strength of un-puddled soil was 46.66 Kpa and after puddling with a rotary puddler, it reduced to 12.6 and 10.38 kPa for one and three passes, respectively. The cohesion after puddling reduced about 18% by one and three passes of puddler than that of non-puddled soil. The decrease in internal friction angle by one and three passes was about 16%
- Puddling is need only to the required level that improved growth rice and will also deteriorate less the soil physical condition as compared to more intense puddling. Low levels of puddling due to reduce energy efficiency, degradation of soil structure and labour and work preparing land for rice is more appropriate
- There is a linear relationship between hydraulic conductivity with cohesion and internal friction angel

ACKNOWLEDGEMENT

The researchers appreciate the Research Council of Sari Agricultural University for providing research fund.

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