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Effects of puddling intensity on the in-situ engineering properties of paddy field soil

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Abstract

Puddling may have an effect on the physical and mechanical properties of soil. Puddling intensity (the number of puddler passes) to a required level has always been a challenge for many farmers. Field experiments were conducted to determine the effect of puddling on the hydraulic conductivity, bulk density and penetration resistance at three depths (0-10, 10-20 and 20-30 cm). The treatments were puddling by one pass (P1) and three passes (P3) of a tractor-drawn rototiller and no-puddling (NP). The treatments were replicated three times and experiment was laid out in a randomized block design. Results showed that puddling caused a significant reduction ($p<0.01$) in soil hydraulic conductivity, bulk density and penetration resistance. Hydraulic conductivity decreased from 5.36 cm h^{-1} in NP to 1.12 and 0.78 cm h^{-1} in P1 and P3, respectively. The first level of puddling (one pass of puddler) decreased the penetration resistance of soil by about 53%, whereas puddling to higher levels decreased the penetration resistance by 15% corresponding to three passes of the puddler. The decrease in bulk density by one pass of puddler was about 6%, whereas subsequent puddling to three passes decreased the bulk density by 3%. Increasing in depth increased bulk density and penetration resistance but decreased hydraulic conductivity. Puddling only to the required level will deteriorate less the soil physical condition as compared to more intense puddling.

Keywords: hydraulic conductivity, bulk density, penetration resistance, puddling.

Introduction

The total cultivated area of paddy in Iran was about 550 ($\times 10^3$ ha) in 2010 (FAO, 2010). More than 75% of paddy fields are located in Northern provinces of Mazandaran and Gilan (Ministry of Agriculture, 2010). Puddling is the only operation for land preparation and generally refers to breaking down soil aggregates at near saturation into ultimate soil particles. It involves cultivation of the soil after it has been softened by flooding for several days and creates a layer of soft mud which often overlies a dense plough pan. Awadhwal and Singh (1992) reported that decreasing soil strength to facilitate transplanting of rice is one of the main objectives of puddling. Saito and Kawaguchi (1971) showed that the upper puddled layer is composed of fine particles, the middle layer is thin and porous and the lowest layer is massive without particle differentiation. Generally, farmers have a tendency to create a very fine puddle that actually may not be required. Puddling influences soil physical, mechanical and chemical properties which in turn influence rice growth. Bulk density may increase or decrease depending on soil structural statue before puddling. The effect of puddling on bulk density depends on soil aggregation before puddling. Sharma et al. (2005) reported that puddling caused a significant increase in bulk density, which increased further by rice harvesting. Puddling can also produce a more open structure, and hence decrease bulk density. Bajpapi and Tripathi (2000) reported that puddling significantly reduced the soil bulk density at depth of 0-6 cm. Kukal and Aggarwal (2002) reported that puddling created an open and loose structure in the soil that has low hydraulic conductivity. Sharma et al. (2005) compared hydraulic conductivity of unpuddled soil for clay and clay loam soil. Hydraulic conductivity decreased from 0.637 to 0.133 cm h^{-1} in a clay loam soil whereas, in clay soil hydraulic conductivity reduced non-significantly over non-puddled soil (from 0.10 to 0.08 cm h^{-1}). Ringrose-Voase et al. (2002) suggested that low hydraulic conductivity limited the upwards supply of water for evaporation so that evaporation from the soil surface decreased. Kukal and Aggarwal (2002) reported that hydraulic conductivity of the sandy loam soil of the puddled layer decreased with increasing puddling intensity (0.064 cm h^{-1} with medium-puddling to 0.009 cm h^{-1} with high-puddling). Kukal and Sidhu (2004) reported that increasing of puddling intensity from one to four passes decreased the hydraulic conductivity by 30%. The penetration resistance is greatly reduced by puddling and increased with depth. In general, puddling decreased soil strength in the puddled layer. Penetration resistance decreased with moisture content and increased with bulk density. Mohanty et al. (2004) evaluated three puddling intensities (unpuddled, one and eight passes of puddler) on the penetration resistance. Their result showed that penetration resistance decreased with puddling and this reduction increased in higher intensities. Also, increasing in depth increased the soil penetration resistance 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 cone index decreased with increasing levels of puddling. The objective of this study was to determine the effect of soil puddling intensity on the soil bulk density, hydraulic conductivity and penetration resistance at three depths.

Results and Discussion

Hydraulic conductivity

The results of field experiments indicated that puddling intensity had a significant effect ($p<0.01$) on the hydraulic conductivity (Table 1). It was observed that the hydraulic conductivity of un-puddled soil before the process of tilling saturated soil was 5.36 cm h^{-1}. After puddling with a rotary puddler, the value of hydraulic conductivity was obtained 1.12 and 0.78 cm h^{-1} for one and three passes, respectively. The hydraulic conductivity decreased by 29% when puddling intensity increased from P1 to P3 (Fig. 1). Kukal and Sidhu (2004) reported that four puddling operations decreased hydraulic conductivity of soil by 30% from that with one puddling operation. Similar trends for hydraulic conductivity were observed for one, two, three, four and five passes of rotary puddler by Shrivastava and Datta (2006). 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. There is a strong relationship between hydraulic conductivity and macro porosity for the lowland paddy soils (Aimrun et al., 2004). Table 2 shows the interaction effects of depth and puddling intensity on the hydraulic conductivity. The hydraulic conductivity value decreased with increasing in soil depth. The lowest and highest amounts of hydraulic conductivity were observed in the treatments of P3 at depth of 20-30 cm and NP at the depth of 0-10 cm, respectively. The hydraulic conductivity values after one and three passes of puddler were 1.8×10^{-3} and 1.3×10^{-3} cm h^{-1} at the depth of 0-10 cm and decreased to 0.43×10^{-3} and 0.3×10^{-3} cm h^{-1} at the depth of 20-30 cm, respectively (Table 2). During the puddling operation the upper soil layer (0-10 cm) is loosened and the pore volume increased, resulting in an increase in hydraulic conductivity. The deeper layer (20-30 cm) due to the compaction by implements had a lower hydraulic conductivity. Puddling has been reported to decrease hydraulic conductivity of puddle layer (0-10 cm) of sandy loam soil from 0.064 cm h^{-1} in unpuddled to 0.015 cm h^{-1} with medium puddling and 0.009 cm h^{-1} with high puddling (Kukal and Agrawal, 2002). When a soil is puddled, the aggregates are broken down into small particles. These materials settle gradually after puddling and block the pores at the soil surface. The hydraulic conductivity of the soil profile is controlled by the blocked soil surface. Thus, it appears that the hydraulic conductivity of puddled soil is controlled mostly by the top layer of particles. Higher level of puddling creates more suspended material by its churning action, which decreased the hydraulic conductivity (Kukal and Sindhu, 2004).

Bulk density

Effect of puddling intensity on soil bulk density was significant (Table 1). Puddling caused a significant reduction in soil bulk density (Fig. 2). An increase in puddling intensity from NP to P1 and P3 decreased bulk density about 10 and 15%, respectively. Mean comparison indicated that bulk density was significant ($p<0.05$) between levels of puddling intensity. The decrease in bulk density by one pass of puddler was about 6%, whereas subsequent puddling to three passes decreased the bulk density by 3%. Puddling caused loosening and softening of soil and hence bulk density decreased with increasing levels of puddling. The decrease in bulk density by puddling has also been reported by some researchers (Mohanty et al., 2004; Sharma and DeDatta, 1985). They reported that puddling destroys aggregates, increases porosity and it can produce a more open structure, and hence decrease bulk density. Table 1 showed that the interaction effect of puddling and depth on bulk density was significant ($p<0.05$). The maximum and minimum bulk densities were obtained for NP at 20-30 cm depth and for P3 at 0-10 cm depth, respectively (Table 3). Also, bulk density increased with increasing in depth and it was intense for higher intensity of puddling. The values of the bulk density in unpuddled as well as freshly puddled soil at two levels of puddling and three depths are given in Table 3. The soil bulk density decreased with puddling intensity at all three depths of the study. However, P3 did not significantly decreased soil bulk density any further, compared to P1 than that NP. This may be attributed to maximum changes in the structure of P3 than P1 and NP. Therefore, reduced-puddling (P1) was sufficient to decrease the bulk density on soil surface. The bulk density increased due to increase in depth at any puddling intensity and it was intense for higher intensity of puddling (Table 3). It could be due to puddling operation on upper layer of the soil. This result is in agreement with the finding by Ringrose-Voase et al. (2002). They reported that soil bulk density decreased after puddling but increased with depth.

Penetration resistance

Table 1 showed that puddling intensity significantly ($p<0.01$) affected the soil penetration resistance. The reduction in penetration resistance was significant after puddling by one pass (P1) and three passes (P3), while no significant difference was observed between P1 and P3 treatments (Fig 3). The mean value of penetration resistance was 1.8, 0.7 and 0.6 Mpa corresponding to NP, P1 and P3, respectively. The first level of puddling (one pass of puddler) decreased the penetration resistance of soil by about 53%, whereas puddling to higher levels decreased the penetration resistance by 60% corresponding to three passes of the puddler. These results imply that the highest reduction in penetration resistance took place during one pass of the puddler, and that the subsequent passes (three passes) reduced the penetration resistance by 14%. The penetration resistance of puddled soil is lower due to loosening and softening of the paddled layer. The decrease in penetration resistance by puddling has also been reported by some researchers (Awadhwal and Singh, 1992; Hemmat and Taki, 2003; Painuli, 2000). There is an increase in penetration resistance with depth for all treatments (Fig. 4). The change in soil penetration resistance among P1 and P3 was not significant. Figure 4 showed that difference in penetration resistance with depth up to 15 cm for P1 and P3 was not significant while it considerably increased after depth of 15 cm. This trend may be because of the progressive settlement of heavier particles at the lower part of the puddled layer. The penetration resistance in the 0-5 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. Also, below 15 cm penetration resistance changed with depth faster for NP and after this depth, the increase was slow. In puddled layer increasing the depth of soil increased the penetration resistance. Other researchers have also reported that penetration resistance decreases with puddling and increases with depth (Mohanty et al., 2004; Painuli, 2000). Increasing resistance to penetration in the deeper layers (20-30) from the soil surface after puddling

Table 1. Analysis of variance related to hydraulic conductivity, bulk density and penetration resistance.

Source of variation	df	Bulk density (g cm^{-3})	Penetration resistance (Mpa)	Hydraulic conductivity (cm h^{-1})
puddling	2	0.135**	3.09**	59.78**
depth(cm)	2	0.274*	3.89*	18.86**
puddling×depth	4	0.028*	0.239*	6.96*
error	18	0.006	0.001	0.01

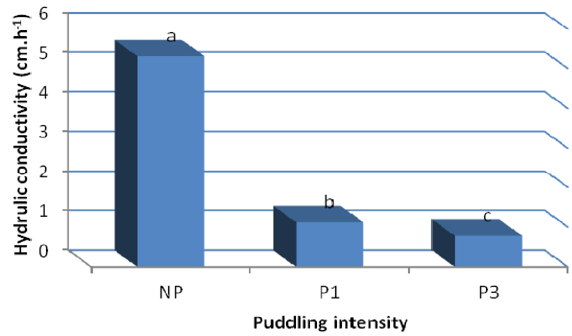

Fig 1. Effect of puddling intensity on the hydraulic conductivity.

Table 2. Interaction effect of puddling intensity and depth on hydraulic conductivity.

Depth (cm)	Hydraulic conductivity (cm h^{-1})		
	NP	P1	P3
0-10	8.5	1.8	1.3
10-20	5.58	1.14	0.75
20-30	2.1	0.43	0.3

NP= non puddle P1= Puddled by one pass P3= Puddled by three passes.

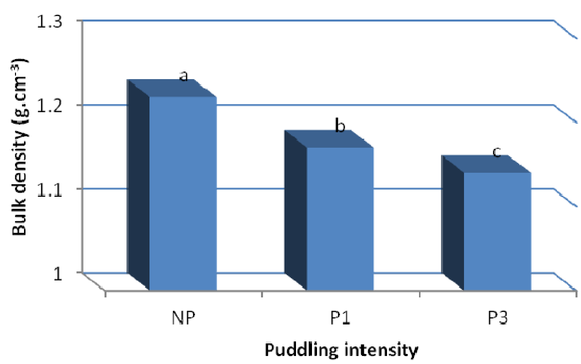

Fig 2. Effect of puddling intensity on the bulk density.

probably is due to soil compaction by tillage implements and tractor wheels.

Materials and Methods

Experimental site

Experiments were conducted on a loamy-clay soil containing 7.2% sand, 40%silt and 50% clay, during June 2011 at the rice research field of Sari Agricultural University, Mazandaran, Iran. The average of rainfall during first 6 months was 34.5 mm and average of temperature was 24.2 ºC. The average of relative humidity of air during first 6 months was 81.1%. The soil was transformed into flooding state and puddled by a rototiller having a depth of cut adjusted to 15 cm. The soil was puddle to two levels with one and three passes of the puddler. Then, the process of flattering was done by wooden plank. At the start of each puddling operation the soil bulk density, hydraulic conductivity and penetration resistance were measured. The experiment consisted of non-puddled (NP) and puddled treatments including one pass of tractor-drawn rototiller (P1) and three passes of tractor-drawn rototiller (P3). Hydraulic conductivity, bulk density and penetration resistance were measured at three depths (0-10, 10- 20 and 20-30 cm). The treatments were replicated three times and experiment was laid out in a randomized block design. The plot size under each treatment was 50 m×10 m.

Measurements

Measurements were made for soil parameters such as bulk density, hydraulic conductivity and penetration resistance. Bulk density was sampled using soil cores (6 cm in diameter

Table 3. Interaction effect of puddling intensity and depth on bulk density.

Depth (cm)	Bulk density (g cm^{-3})		
	NP	P1	P3
0-10	1.19	1.11	1.08
10-20	1.23	1.17	1.13
20-30	1.3	1.25	1.17

NP= non puddle P1= Puddled by one pass P3= Puddled by three passes.

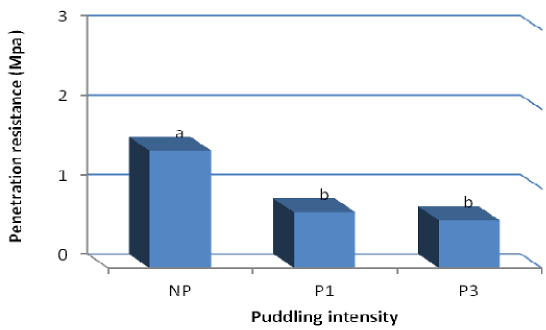

Fig 3. Effect of puddling intensity on the penetration resistance.

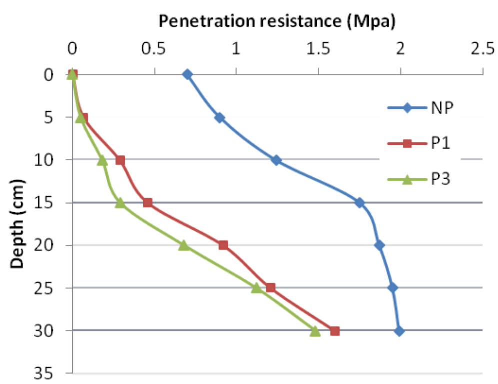

Fig 4. Interaction effect of puddling intensity and depth on the penetration resistance.

and 5 cm in height) from depth intervals 0-10, 10-20 and 20-30 cm .The samples were transferred to the laboratory and oven dried at 105 ºC for 72 h and the bulk density was calculated. The penetration resistance was measured using a hand held penetrometer model SL138 (Compact Ltd., England) with cone angle of 30 degrees and the cross section of the cone 0.5 in^2. Saturated hydraulic conductivities of soil at three replications were determined by falling-head method. Subsoil samples were taken from 10 to 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).

Statistical analysis

The data were analysed using the standard procedure of randomized block design. An analysis of variance was carried out, and means were analyzed by Duncan's multiple range tests at the 5% probability level. Statistical software of SPSS and MSTATC were used.

Conclusion

Soil hydraulic conductivity, penetration resistance and bulk density decreased due to puddling. Increasing in depth increased bulk density and penetration resistance but decreased hydraulic conductivity. The hydraulic conductivity of un-puddled soil was 5.36 cm h^{-1} and after puddling with a rotary puddler, it reduced to 1.12 and 0.78 cm h^{-1} for one and three passes, respectively. The penetration resistance after puddling reduced about 60% by one and three passes of puddler than that of non-puddled soil. The decrease in bulk density by one and three passes was about 6%. 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.

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