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Infiltration and Bypass Flow of Cracking Puddled Soils

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Abstract: A study of infiltration and bypass flow was conducted in a wet soil bin with three different soils treatments (sandy loam, clay loam and clay soil) to determine the swelling behaviour of cracking puddled soils by watering and its impact on bypass flow. Infiltration rate for the soils was recorded after puddling the soils. Then the puddled soils were allowed to dry for a period of up to 15 days. After that the plots were rewetted in order to observe the swelling and bypass behaviour of cracked soils. From this study it is observed that the infiltration rates of puddled soils were very low (0.03-0.05 mm h^{-1}) mainly due to the puddling effect. The study indicates that cracks on puddled soils at 15th day's of drying are effectively irreversible. The maximum bypass flow was recorded for the clay loam soil. During the first day, the flow rate was extremely high at 313 mm h^{-1}. But this higher rate gradually reduced from the second day and onwards. The bypass flow rate for the clay loam and clay soil was almost same. The study reveals that it is not possible to swell up shrinkage cracks on puddled soils by watering alone. Re-working of the soil is necessary to seal the cracks.

Key words: Bypass flow, infiltration, cracking, puddled soils, shrinkage-swelling

INTRODUCTION

Today more than 90% of the worlds irrigated land is irrigated by surface irrigation (Kay, 1986). Most of this land has swelling clay soils (Waller and Wallender, 1991). Shrinkage cracks that develop during drying of swelling soil strongly influence the infiltration rate. When shrinkage cracks are open to the surface, the potential infiltration rate is extremely large. Depending on the degree of cracking, some fraction of the water added to the soil surface flows down through cracks and goes to waste as bypass flow. Pandey and Pandey (1982) mentioned that a large proportion of the water added to the soil surface flows through the soil cracks as bypass flow and only a small fraction of it actually passes through the soil capillary pores and profile. Puddling is considered to be a pre-requisite for successful rice production. Puddling reduces the non-capillary pore spaces, resulting in closer packing of soil particles (Wopereis *et al.*, 1994). But when a puddled soils dries, it usually becomes hard and dense (Reid and Parkinson, 1984). Hence, there is a higher probability of cracking on puddled soils.

Therefore, knowledge of shrinkage properties as well as swelling of paddies is of great importance for efficient water management and irrigation scheduling for rice in areas with a limited water resource. At present, there are few studies about swelling of shrunken paddy soils. Therefore, a study was undertaken with the object to investigate the swelling potential of dry puddled soils to increase the application efficiency by reducing the bypass flow.

MATERIALS AND METHODS

The study was conducted in a wet soil bin and consisted of three soils treatments: T_1 = Sandy loam (13% clay); T_2 = Clay loam (28% clay); T_3 = Clay soil (58% clay) in order to determine the influence of different clay contents on shrinking and swelling behaviour of puddled soils and their impact on bypass flow. The treatments were arranged in a completely randomized design (CRD) with three replications. The 20 x 1.5 x 1.5 m bin is made of rendered bricks and is sealed at the bottom. The roof of the bin area is protected from the rain by a plastic sheet. Nine plots were installed in the bin, each 1 x 1m and were surrounded by plastic lawn edging.

Three soils having different textural make-up were collected and proper drying of the soil, clods were broken into small pieces. Then the soil was spread out on the plots according to a randomized layout. The soils were wetted for three days and puddled by trampling. Initially, a uniform 150 mm puddled layer was provided in each plot. Infiltration rate of puddled soils were determined by double ring infiltrometer and flooding methods. The puddled layer overlaid a porous plastic geo-textile, beneath which a 500 mm coarse sand layer was used to facilitate good drainage, which may represent in-situ interlinked crack performance. Two puncture tensiometers and mercury tensiometers were used in each plot to measure soil moisture status, one at 10 mm and another at 100 mm depth. A rolling metallic trolley at the top of the bin side-wall was set up as a benchmark and this could be moved to each plot. On this benchmark measuring scales were attached which could be moved along the bar to take readings of water surface during an infiltration test and one dimensional soil surface elevation (vertical shrinkage) after watering.

The shrinkage behaviour was recorded for a period of 15 days. The plots were rewetted after recording the crack dimensions in order to observe swelling time and its behaviour. The study of watering was continued for a period of five days. Each rewatering consisted of 40 litres of water, which poured instantaneously on each plot. Elapsed time of bypass flow was recorded as the time from watering to when the ponding water disappeared from the surface. Again water was applied as before and it was continued for 5-7 h daily to measure the bypass flow rate. Bypass flow rate is defined as the volume of free water passed through macropores in a unit time. Crack dimensions of the plots were measured every day before and after watering. Photographs were taken to observe the visual change of cracks as swelling.

RESULTS AND DISCUSSION

Infiltration rate of the puddled soils: The infiltration rate of puddled soils was determined at the beginning of the experiment using a double ring infiltrometer and a flooding method. As can be seen from the Table 1, almost the same results were obtained by the two methods for a particular soil. In both the methods the standard deviation for each treatment was low. Among the three soils, the clay soil showed less infiltration rate (0.03-0.04 mm h^{-1}). On the other hand, a slightly higher rate of infiltration (0.05 mm h^{-1}) was observed in the sandy loam soil. In general, the infiltration rate was very low for all the study soils due to the puddling effect. Bouma (1984) supported the finding and he reported that the intrinsic low infiltration was mainly due to compaction or puddling of the soil surface layer. From this study it can be concluded that puddling resulted in almost impermeable soil and it tremendously reduces the percolation losses.

Shrinkage behaviour of puddled soils: It is observed from the Table 2 study that the soil moisture content ($\theta v\%$) at 10 mm depth was lower (19.7%) for the sandy loam followed by the clay loam soil (33.7%) than 100 mm depth. The maximum moisture content (48.7%) was recorded for the clay soil. In general, higher moisture content was recorded at 100 mm depth as expected. The difference between the moisture content of the two layers (10 mm and 100 mm depth) of the soils was about 6%. The total number of cracks was slightly higher in the sandy loam than the clay soil. But the average length of cracks was higher in the clay soil. The range of these parameters is shown in parenthesis. On the other hand, the average width and depth of the cracks were higher in the clay loam soil. Consequently, the average total surface area, % of cracks area over the surface and the volume of cracks were higher for the clay loam soil than for the other two soils. At the latter stages of drying, different sizes of polygonal blocks were formed which were mainly orthogonal in shape. The estimation of moisture content of the study soils at the 15th day's of drying was determined based on the water release characteristic curve of the particular soil. From this observation it is found that the clay loam and clay soils remained around field capacity even at the 15th day's of drying.

Table 1: Infiltration rate (mm h^{-1}) of puddled soils by two different methods

	Infiltration rate (mm h^{-1})			
Soil type	Double ring[a] infiltrometer	Standard deviation	Flooding[b] method	Standard deviation
Sandy loam	0.05	0.037	0.05	0.012
Clay loam	0.04	0.026	0.04	0.016
Clay soil	0.04	0.032	0.03	0.004

[a] = Average of three sets [b] = Average of three replications

In comparison, the number of cracks was higher in the sandy loam and the clay loam soil, probably due to less cohesion compared to the clay soil. Crack surface area was high in the clay loam soil mainly due to their greater length and width.

Volume of bypass water versus time required: The total amount of water (l) applied and bypass through the cracks of each plot at different five days are shown in Fig.1. In each time a measured 40 litres of water was poured instantaneously on each plot and the time required for disappearance of ponding water from the surface was recorded. This procedure was continued for 5-7 h every day as before. From this study it is observed that during the first day, an average of 98.3 (l), 538.3 (l) and 598.3 (l) water was required to pour on each plot of the sandy loam, clay loam and clay soil respectively with the above procedure. But all the standing water disappeared from the surface in a few h (3-5 h) and it passed through the cracks to the under laying sand layer of the soil bin. This indicates that a large volume of irrigation water will be lost from the cracking field without swelling up the cracks. This finding agrees with the findings of Beven and Germann (1982).

During this five days period, a total of 190 (l), 1395 (l) and 1548 (l) water was required in each plot of the sandy loam, clay loam and clay soil, respectively. The maximum

Table 2: Shrinkage behaviour of puddled soils at 15th days of drying (Trial-1)

Cracking parameters	Sandy[a] loam	Sd	Clay[a] loam	Sd	Clay[a] soil	Sd
Soil moisture (Θv%)						
10 mm	19.7	0.94	33.7	3.29	48.7	0.47
100 mm	26.3	3.39	40.0	1.63	54.3	1.88
Number of cracks[b]	28.0	4.92	25.7	0.47	17.3	2.05
Length of cracks (cm)	30.2 (5-95)	1.52	26.9 (10-78)	1.02	34.4 (5-95)	3.18
Width of cracks (cm)	0.5 (0.1-1.1)	0.00	1.0 (0.3-2.0)	0.12	0.9 (0.2-1.8)	0.12
Depth of cracks (cm)	5.2 (1.0-11.0)	0.62	8.6 (1.0-11.0)	0.67 (2.0-12.0)	7.7	0.90
Surface area (cm^2)	639.5	44.39	1684.9	377.91	744.3	232.6
% of crack area	4.8	0.77	11.3	1.45	7.4	1.9
Crack volume (cm^3)	3358.3	581.64	8742.9	836.37	6308.0	976.1

[a] = Average of three replications [b] = All individual cracks on the 1 x 1m plot surface Sd = Standard deviation
Figure in the parenthesis is the range of those parameters

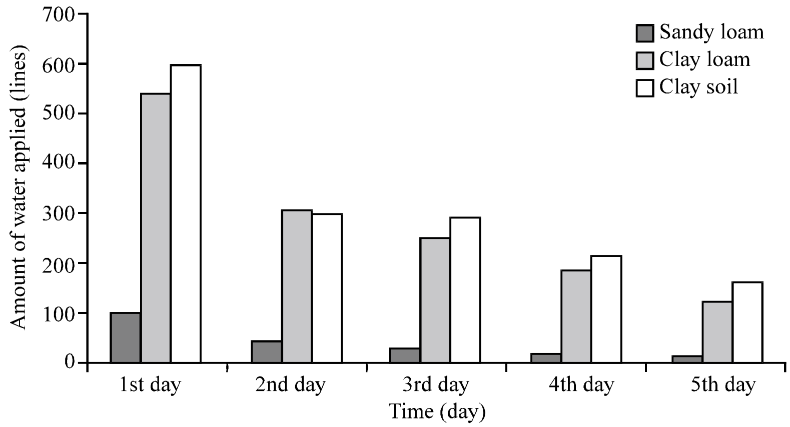

Fig. 1: Water bypass versus time

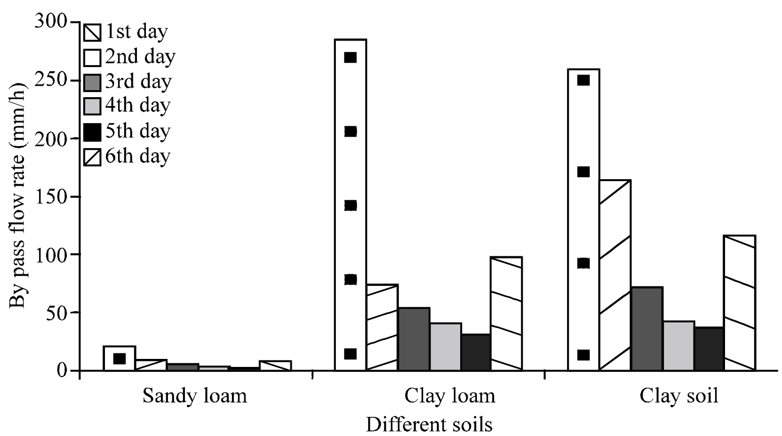

Fig. 2: Bypass flow rate on different days

amount of water was required for the clay soil followed by the clay loam mainly due to its high crack volume and area. Moreover, there was no slaking effect in clay soil as with the sandy loam due to its strong cementation of aggregates. Therefore, the above findings indicate that the soil-water behaviour of cracking puddled soil is very important and it differs from non cracking soils in respect of bypass flow. In all cases the first application of water disappeared very rapidly, after which the time for disappearance gradually increased. The study reveals that cracking puddled soils need a longer time of continuous ponding for closing up of the cracks even at an early stage of cracking. In this regard, McIntyre *et al.* (1982) reported that the swelling of a rice soil was almost completed after 150 days of continuous ponding, though the swelling proceeded rapidly up to 75 days. Which indicate that a prolonged ponding is needed for complete closing of dry paddy cracks and it is not possible in irrigation areas with limited water resource.

The statistical analysis indicates that the difference among the treatments is highly significant at the 1% level of probability. The coefficient of variances (CV) is 7.7, 18.8 and 16.9% for the 1st, 3rd and 5th day of swelling analysis, respectively. It is evident from the results that the amount of bypass flow of the sandy loam is significantly different from the clay loam and the clay throughout the study period. But the bypass flow of the clay loam did not differ significantly from the clay soil.

Rate of bypass flow: It can be seen from the Fig. 2 that the flow rate was low for the sandy loam soil. At the beginning the rate was 20 mm h^{-1} and it gradually reduced to 5e mm h^{-1} when it reached the 5th day. The maximum flow rate for all treatments was recorded for the clay loam soil. During the first day the flow rate was extremely high (313 mm h^{-1}). On the second day it sharply declined (94 mm h^{-1}) and then it gradually reduced. The bypass flow rate in the clay soil was not significantly different than the clay loam soil. The bypass flow rate in the clay soil decreased slowly and this trend was maintained up to the 5th day. However, the average bypass flow rate for the clay loam and the clay soil was almost the same. The initial higher rates of bypass flow (Fig. 2) indicate the possibility of total loss of irrigation water if it is applied at this stage without any control measure.

From this study it is observed that the bypass flow rate was low in sandy loam mainly due to its lower crack surface area and volume (Table 2). Moreover, slaking under the water application on the surface layer was more prominent in the sandy loam during watering because of its lower clay content; this resulted in soil particles being washed to the bottom of the cracks. In addition, closing of crack tips as swelling may be another reason for reducing bypass flow. The slaking effect was not observed in the clay loam and the clay soil mainly due to their higher cohesion force. The result in a decreasing trend of bypass flow in clay loam and clay soil on the following days of watering may be due to close of crack tips by swelling.

The study indicates that the puddled soils especially clay loam and clay should not be allowed to dry for a long time (15 days) before irrigation. Otherwise almost all the irrigation water will be lost as bypass flow through the cracks of puddled layer. Wopereis *et al.* (1994) supported the finding and further reported that the cracking can break the plowpan and water can easily reach the subsoil.

Swelling behaviour of puddled soils: From this study it is observed that there is little or no change of crack dimensions after watering except for the sandy loam soil. The change in the sandy loam may be due to the slaking effect, which is mentioned earlier. The crack surface area was high at the 15th day of drying (about 5-10 mm wide for the three soils). As a result, nearly the whole volume of applied water was lost as bypass flow in a short time. Crack width and surface elevation of the plots were measured every day before and after watering. From these measurements it is observed that there was no swelling or change of crack dimension and surface elevation during this study period though a large amount of water passed through the cracks. The study indicates that puddled soils crack irreversibly when dried for 15 days. As a result, there is no evidence of swelling effect even for the clay soil. This may have been due to insufficient and discontinuous wetting of the puddled soils. The study indicates that irrigation water should be applied before 15th day of drying by considering crack width to reduce bypass flow.

The study reveals that it is not feasible to swell up the shrinkage cracks of puddled soils by watering alone and it needs some physical soil management to close up the cracks. Therefore, an optimum irrigation interval by considering crack dimensions especially crack width and moisture content of puddled soils with a proper soil management is necessary to increase the water use efficiency by reducing bypass flow.

When puddled soils are dried, crack form on them and separate the surface into small blocks of different sizes and shapes. The blocks further shrink and cement while losing moisture. Degrees of cementation depend on the depletion of accumulated moisture. Consequently, the cracks of puddled soils become almost irreversible in this experiment at 15 days of drying. As a result, almost the whole volume of applied water is lost though the cracks without any swelling of the soils. Therefore, the study indicates that it is not possible to increase the water retention capacity of the puddled soil by swelling up the cracks during irrigation, especially with limited water resource. An appropriate soil management with irrigation may help to increase the irrigation efficiency of cracking puddled soils.

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