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# Puddling Efficiency for Rice Root Growth in a Cohesive Soil

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**ABSTRAK**

Satu kajian di makmal telah dilakukan untuk menentukan keberkesanan nisbah campuran air dan agregat tanah liat kering dalam proses pengedapan menggunakan pengaduk putar pacuan motor elektrik dengan kelajuan 2000 putaran seminit. Empat nisbah campuran tanah dan air telah diuji pada tiga masa putaran pengaduk. Keputusan yang dicapai menunjukkan bahawa serakan terpantas bagi menghasilkan ketumpatan pukal basah minima 1.23 Mg/m$^3$ diperolehi pada nisbah 1.2. Nilai nisbah campuran tanah dan air yang melebihi had ini tidak mempengaruhi perubahaan nilai ketumpatan pukal basah untuk kesemua masa putaran. Nisbah yang melebihi 1.0 juga tidak menambah peratus pecahan agregat di bawah garispusat 0.5 mm. Walau bagaimanapun, pengaruh masa putaran amat berkesan terhadap pecahan agregat di bawah garispusat 0.5 mm bagi kesemua nisbah campuran air dan agregat tanah liat kering dengan input tenaga 0.084 watt-jam dan 0.168 watt-jam.

**ABSTRACT**

A laboratory study was conducted to determine the influence of water-soil ratio on the ease of puddling air-dried aggregates. Soil puddling was carried out using a rotary stirrer simulating the rotary motion of a rotary cultivator commonly used in wetland preparation. The stirrer was driven by an electric motor at a speed of 2000 rev/min. Four water-soil ratios were tested at three different stirring times. The results obtained showed that the fastest dispersion of particles resulting in a minimum wet bulk density of 1.23 Mg/m$^3$, was achieved at a water-soil ratio of 1.2. Increasing the water-soil ratio above this value did not change the wet bulk density value for all stirring times. Increasing the water-soil ratio above 1.0 did not increase the percentage of aggregate breakdown significantly for aggregates below 0.5 mm diameter. The effect of stirring time on the percentage of aggregate breakdown for aggregates below 0.5 mm diameter, however, was significant at all water-soil ratios when the input energy was 0.084 and 0.168 watt-hours.

**Keywords: Puddling efficiency, rice, root growth, cohesive soil**

## INTRODUCTION

Puddling is the vigorous working of soil after primary tillage under submerged conditions. It destroys the system of macropores in the soil and results in a minimum percentage of air-filled pores (Koenigs 1963).

This substantially increases the amount of water retained by the soil and reduces both water and nutrient loss through percolation. The current practice of puddling frequently consumes much water and energy. There is a need in many situations to reduce this. Whilst much work is documented on soil puddling, little work has related the resulting puddle to rice root growth requirements (Throne and Peterson 1950; Lyon *et al.* 1952; McGeorge 1937; Baver 1956; Beacher and Strickling 1955; Bodman and Rubin 1948; Sanchez 1973; De Datta and Kerim 1974; Taylor 1972; Chaudhary and Ghidyal 1969; Gupta and Jaggi 1979). In addition, very little information is available regarding the influence of water quantity on the degree of aggregate breakdown required to prepare the conditions desired for rice root growth. Kar *et al.* (1976) conducted a laboratory study and reported the optimum conditions in terms of soil bulk density but did not determine the optimum water quantity for preparation. They reported that rice root and shoot growth increased significantly as soil wet bulk density decreased from 1.4 to 1.0 $Mg/m^3$. Tenhave (1967), Dutt *et al.* (1986), Nichols (1976) and Agarwal *et al.* (1978) compared the performance of implements in flooded fields and determined the resultant puddle, but did not relate the findings specifically to water usage. If water requirements for puddling are to be reduced, more information is needed on the influence of water quantity on the efficiency of puddling with given puddling equipment. This paper presents the results of a fundamental study on the influence of water quantity measured in terms of water-soil ratio for a particular clay soil.

## MATERIALS AND METHODS

A Montmorillonite clay soil (65% clay) was air dried to simulate the extreme conditions experienced in the field, broken into smaller aggregates and sieved to extract aggregates in the size range 10 and 12 mm diameter. Aggregates of this diameter were selected because a smaller diameter aggregate absorbs water quickly compared to a bigger clod of the same initial moisture content as observed in earlier studies (Gumbs and Warkentin 1976). About 400 grams weight of the air-dried aggregates was mixed with measured amounts of water (gravimetric basis) in a litre beaker of known base area. The mixture was soaked for 5 minutes before puddling. In a real situation, considerable water could be lost due to percolation and evaporation before puddling could be carried out. Four water-soil ratios ranging from 0.8 to 1.4 of the oven-dry soil weight were selected.

The puddler consisted of a stirrer with four blades fitted to a motor shaft. The variable speed motor was connected to a kilowatt-hour meter which measured the input energy expressed in watt-hours required for a desired degree of puddling. This was based on the technique used by

Naphade and Ghidyal (1971). Three input energy levels of 0.042, 0.084 and 0.168 watt-hours were applied. These simulated the effects of different puddling energy inputs achievable using different types of puddling equipment.

Degree of puddling was measured in terms of the final wet bulk density and percentage of aggregate breakdown for aggregates below 0.5 mm mean weight diameter calculated according to the method of Youker and McGuinness (1957). Percentage of aggregate breakdown within the puddled soil was determined by wet sieving using the method of van Bavel (1952). After each puddling experiment, the total content of each beaker was poured into a nest of sieves, immersed in a tub of water and agitated vertically at a rate of 30 strokes per minute. The agitation was carried out for 500 strokes to separate the fine from the coarser aggregates. Material retained on each sieve was washed into a drying tin, dried at 100°C for 48 hours, and the percentage of aggregate retained calculated. The wet bulk density of the final puddle was measured by dividing the total weight of wet soil by the volume of puddled soil (without free water). The volume of puddled soil was determined after allowing the soil in the beaker to settle for 2 hours.

## RESULTS AND DISCUSSION

*Degree of Aggregate Breakdown*

Results on the percentage of aggregate breakdown are presented in Tables 1a, 1b and 1c. For an input energy of 0.042 watt-hour (*Fig. 1a*), aggregates larger than 2.0 mm diameter constituted the largest percentage of total soil at 0.8 water-soil ratio but their number decreased sharply as the ratio was increased from 0.8 to 1.0. The decline in larger aggregates with increasing water-soil ratio corresponded with an increase in percentage of soil in aggregates of all other sizes. Beyond a water-soil ratio of 1.0, there was little further change.

With an input energy of 0.084 watt-hour (*Fig. 1b*) the response to increasing water-soil ratio was similar to that of 0.042 watt-hour. The only exception in this case was that the percentage of soil in aggregates below 0.125 mm was greater than that for 0.042 watt-hour. Increasing the energy level to 0.168 watt-hour (*Fig. 1c*) had little effect on aggregates in the size ranging from 0.125 to 2.0 mm over the different water-soil ratios. Aggregates below 0.125 mm continued to increase as those above 2.0 mm declined.

An analysis of variance at 95 per cent probability level on the effect of water-soil ratio and input energy on the percentage of soil aggregates below 0.5 mm diameter showed that both factors were significant individually and in interaction with each other. The results for soil aggregates

TABLE 1
Aggregate breakdown (%)

a) Input energy = 0.042 watt-hour

| Sieve size (mm) | Water-soil ratio | | | |
|---|---|---|---|---|
| | 0.8 | 1.0 | 1.2 | 1.4 |
| > 2.0 | 49.54 (1.61) | 22.68 (1.08) | 23.59 (1.92) | 25.33 (1.33) |
| 1.0 - 2.0 | 5.34 (0.99) | 11.30 (0.59) | 10.64 (0.52) | 10.98 (0.32) |
| 0.5 - 1.0 | 4.86 (0.80) | 12.68 (1.59) | 10.70 (1.58) | 12.46 (0.87) |
| 0.25 - 0.50 | 5.79 (0.04) | 10.06 (1.25) | 11.39 (1.69) | 15.17 (1.27) |
| 0.125 - 0.25 | 2.92 (0.22) | 7.29 (0.90) | 9.68 (1.72) | 5.26 (0.25) |
| < 0.125 | 31.55 (3.31) | 35.99 (2.49) | 41.15 (2.48) | 30.80 (0.33) |

b) Input energy = 0.084 watt-hour

| Sieve size (mm) | Water-soil ratio | | | |
|---|---|---|---|---|
| | 0.8 | 1.0 | 1.2 | 1.4 |
| > 2.0 | 36.84 (1.23) | 23.77 (2.11) | 23.74 (0.63) | 20.01 (2.46) |
| 1.0 - 2.0 | 7.30 (1.05) | 11.11 (1.61) | 9.12 (1.19) | 11.41 (0.48) |
| 0.5 - 1.0 | 6.76 (0.93) | 8.09 (0.49) | 8.66 (0.46) | 11.43 (1.06) |
| 0.25 - 0.50 | 5.33 (1.30) | 13.94 (0.15) | 10.75 (0.99) | 11.38 (1.74) |
| 0.125 - 0.25 | 2.08 (0.53) | 5.58 (0.26) | 3.04 (0.96) | 5.02 (0.86) |
| < 0.125 | 41.69 (1.04) | 38.02 (1.45) | 45.30 (1.92) | 40.75 (3.05) |

c) Input energy = 0.168 watt-hour

| Sieve size (mm) | Water-soil ratio | | | |
|---|---|---|---|---|
| | 0.8 | 1.0 | 1.2 | 1.4 |
| > 2.0 | 27.95 (1.06) | 19.17 (1.66) | 20.14 (0.93) | 16.43 (0.93) |
| 1.0 - 2.0 | 10.47 (0.36) | 7.79 (0.26) | 9.70 (0.56) | 9.79 (1.21) |
| 0.5 - 1.0 | 9.35 (1.55) | 6.49 (0.44) | 7.88 (0.97) | 7.61 (0.59) |
| 0.25 - 0.50 | 7.86 (0.55) | 9.99 (0.28) | 7.29 (1.00) | 7.03 (0.89) |
| 0.125 - 0.25 | 2.37 (0.19) | 7.30 (1.06) | 2.32 (0.23) | 2.73 (0.25) |
| < 0.125 | 42.00 (1.04) | 49.16 (0.74) | 52.68 (1.35) | 56.40 (3.43) |

Figures in brackets are standard deviation values.

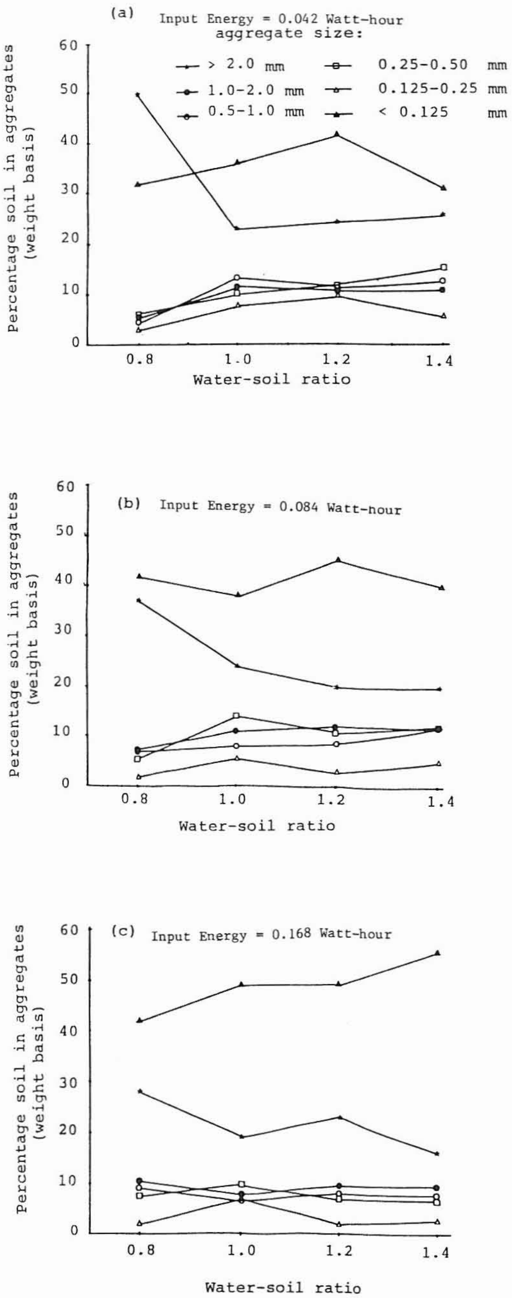


*Fig. 1. Percentage soil in aggregates following puddling at different water-soil ratios*

below 0.5 mm diameter are presented in Table 2 and shown graphically in *Fig. 2.*

*Bulk Density of Puddled Soil*

The wet bulk density values of the puddled soils are presented in Table 3 and shown in *Fig. 3* while Table 4 shows the initial water level and the level of soil after puddling. Wet bulk density values decreased steadily as the water-soil ratio was increased from 0.8 to 1.2, reaching an equilibrium state above 1.2. The response to increasing water-soil ratio with 0.084 watt-hour input energy showed a similar trend. However, in this case, the density was

TABLE 2
Percentage aggregate size ( < 0.5 mm diameter)

| Input energy (watt-hour) | Water-soil ratio | | | |
|---|---|---|---|---|
| | 0.8 | 1.0 | 1.2 | 1.4 |
| 0 | 24.53 (2.91) | 25.18 (3.09) | 24.67 (3.00) | 25.60 (0.89) |
| 0.042 | 40.26 (2.99) | 53.34 (2.86) | 62.23 (7.10) | 51.23 (1.22) |
| 0.084 | 49.10 (1.19) | 57.54 (3.69) | 59.09 (1.38) | 57.15 (3.89) |
| 0.168 | 52.24 (1.10) | 66.45 (1.06) | 62.29 (1.36) | 66.17 (2.51) |

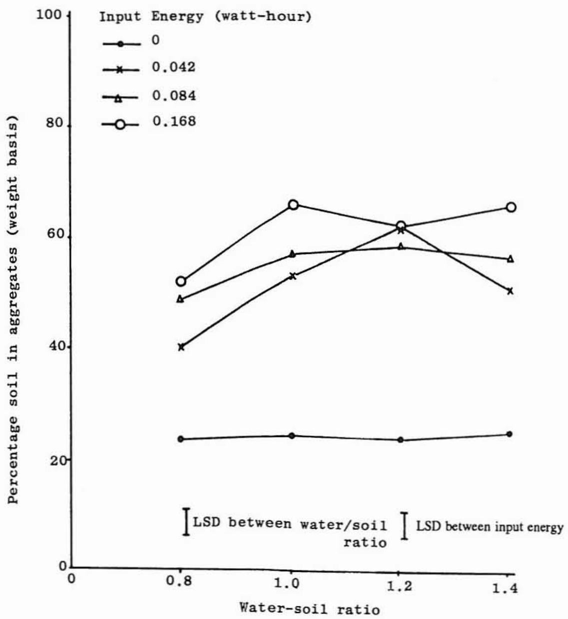


*Fig. 2. Percentage soil in aggregate against water-soil ratio for different input energy*

lower than that with 0.042 watt-hour and the difference was significant at water-soil ratios above 0.8. Increasing the input energy to 0.168 watt-hour had little effect on density beyond a water-soil ratio of 1.2. At a given water-soil ratio, increasing the input energy decreased the wet bulk density values. An analysis of variance at 95 per cent probability level on the effect of water-soil ratio and input energy on soil wet bulk density showed that both factors were significant individually and in interaction with each other.

The results of the experiment conducted show that for a given input energy, aggregate breakdown could be increased and soil wet bulk density decreased by increasing the amount of water to a certain limit, beyond which there would be little further change. Water quantities above this limit would be a waste from a puddling point of view. For a given water-soil ratio, increasing the input energy would increase the aggregate

TABLE 3
Wet bulk density values ($Mg/m^3$)

| Input energy (watt-hour) | Water-soil ratio | | | |
|---|---|---|---|---|
| | 0.8 | 1.0 | 1.2 | 1.4 |
| 0.042 | 1.49 (0.20) | 1.42 (0.02) | 1.27 (0.01) | 1.29 (0.01) |
| 0.084 | 1.48 (0.01) | !.35 (0.01) | 1.24 (0.01) | 1.26 (0.02) |
| 0.168 | 1.48 (0.01) | 1.35 (0.01) | !.23 (0.01) | 1.23 (0.03) |

TABLE 4
Initial water level and level of puddled soil for different input energy. Units are in millimetres

| Input energy (watt-hour) | Water-soil ratio | | | | |
|---|---|---|---|---|---|
| | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 |
| 0.042 | Hwater | 44.3 (0.58) | 59.7 (0.58) | 66.0 (1.00) | 73.3 (0.58) |
| | Hpuddle | 42.3 (0.59) | 46.3 (1.53) | 52.7 (0.57) | 52.0 (0.20) |
| 0.084 | Hwater | 45.0 (1.00) | 59.7 (1.50) | 66.0 (0.30) | 73.3 (0.60) |
| | Hpuddle | 44.0 (1.00) | 54.7 (1.52) | 57.7 (0.30) | 60.0 (1.00) |
| 0.168 | Hwater | 45.0 (1.00) | 59.7 (0.59) | 66.0 (1.00) | 72.7 (0.60) |
| | Hpuddle | 44.0 (1.00) | 54.7 (0.60) | 61.0 (1.00) | 66.7 (0.73) |

Base area of beaker = 11.33 $cm^2$
Hwater = height of water level
Hpuddle = height of puddled soil

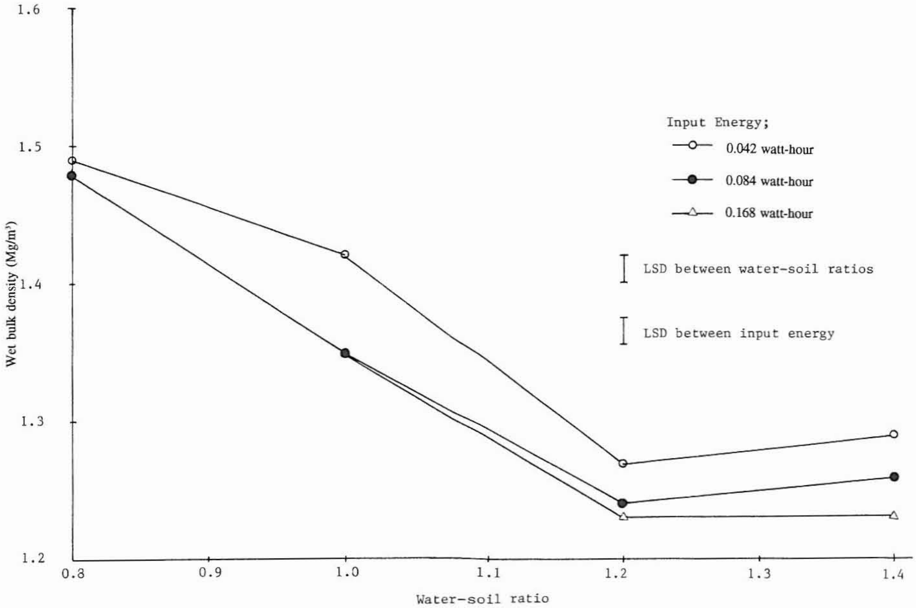


*Fig. 3. Wet bulk density against water-soil ratio for different input energy*

breakdown and reduce the wet bulk density values. The reduction in soil wet bulk density with input energy was due to the slower settling rate of the fine particles remaining in suspension. This increased the height of puddled soil and hence its volume at the time of measurement. These aggregates would have settled with time, increasing the wet bulk density values.

In the field situation, the amount of water required would depend on the initial state of the soil and the type of soil. Furthermore, considerable amounts of water would be needed to overcome percolation and evaporation losses. The input energy would depend on the degree of puddling required to create the environment conducive for rice root growth and support. Where energy is limited but water readily available, increasing the supply of water would be beneficial, but there would be little gain from using an excess. On the other hand, where energy is in abundance, the use of water could be reduced. Hence in soil puddling, there ought to be a balance between energy requirement and minimum water use.

## CONCLUSIONS

Based on the results of the laboratory study, the following conclusions could be drawn:

1. Aggregate breakdown could be achieved by increasing the input energy at all water-soil ratios.

2. For a given input energy, aggregate breakdown increased with water-soil ratio up to a certain limit beyond which there was very little change.
3. Soil wet bulk density decreased with increasing input energy at all water-soil ratios.
4. For a given input energy, soil wet bulk density decreased with increasing water-soil ratio. The effect was only significant up to a point beyond which there would be very little gain.

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