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Initial irrigation requirements of dry tilth paddy soil

(Keperluan pengairan permulaan untuk tanah padi putar kering)

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Key words: dry-seeded rice, irrigation, water advance rate, land soaking requirement

Abstrak

Kajian ini memberikan maklumat tentang keperluan pengairan kali pertama untuk pengairan sawah bagi penanaman padi tabur kering. Keperluan pengairan ialah jumlah air untuk memenuhi keperluan meresap tanah serta kehilangan melalui proses peresapan dan penelusan. Kajian ini termasuklah hubungan kemampatan tanah dengan masa air mara, kadar aliran air dengan masa berlaluan, kadar aliran air dengan keperluan meresap tanah, masa berlaluan dengan keperluan meresap tanah. Selain ini, masa air mara yang diperhatikan dan yang dikira juga dibanding. Kebanyakan parameter ini didapati berkait rapat satu sama lain seperti yang ditunjukkan oleh pekali regresi yang agak tinggi. Misalnya apabila kadar aliran air ialah 1.0 L/saat/m, masa purata air mara di permukaan tanah ialah 110 minit untuk sawah yang sepanjang 80 m dengan kedalaman purata pembajakan 120 mm. Dalam keadaan ini, keperluan meresap tanah ialah 80 mm kedalaman air.

Abstract

This study provides information related to the first irrigation requirement in irrigating a dry direct-seeded rice field. Irrigation requirement is the total amount of water applied to meet land soaking requirement, seepage and deep percolation losses. Soil compaction and time of water advance, water flow rate and elapsed time, water flow rate and land soaking requirement, elapsed time and land soaking requirement relationship were studied. The observed and calculated values of the water advance time were compared. Most of these parameters are closely related to each other as expressed by its relatively high coefficient of regression. For instance, when the water flow rate is 1.0 L/s/m, the average time of advance over soil surface is 110 min for an 80-m field run of an average tillage depth of 120 mm. The land soaking requirement is about 80 mm depth of water under such conditions.

Introduction

With the limitation in irrigation water availability for paddy production in the dry season (March-April), dry direct-seeded rice is adopted to save water. This would eliminate the practice of soil presaturation and wet soil puddling. As such, the seedlings will be raised initially under dry conditions while inundation would follow at a later stage. Thus, the irrigation practice, particularly the initial irrigation to soak a dry direct-seeded paddy field, is a totally different scenario compared with the conventional presaturation irrigation practice. The dry direct-seeding practice is only practical for the off-season planting. An

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accurate estimate of the net amount of water applied for the initial irrigation is a basic requirement for optimal irrigation management. Applying the correct amount of water is important both for efficient water use and to reduce groundwater contamination resulting from deep percolation (Zur et al. 1994).

Basically, the principles of surface irrigation are comparatively simple (Podmore and Eynon 1983). Water is applied to one end of the field at a rate that will provide coverage of the entire field in a short period. The water is then ponded until most of it infiltrates into the soil. In standard surface irrigation design manual (Anon. 1974), the formulae developed describe the field with intake family depending on soil type. For lowland direct-seeded rice field, the topsoil is pulverized by rotavation and the layer below the topsoil is compacted (hardpan). This soil characteristic does not fit well into any intake family.

Paddy soils, generally characterized by heavy texture, poor structure, low porosity and permeability as well as shallow hardpans, are different from other upland agricultural soils. Thus, the irrigation requirements for the dry tilth paddy soil will also be different from the conventional upland irrigation practices. The design and planning of an efficient surface irrigation system requires knowledge of the time it takes for the advancing water front to reach each point in the field. This will determine the total time available for infiltration (opportunity time) at any specific point. The first irrigation always takes the longest time of advance compared with subsequent irrigation, and hence the first irrigation parameters become the determining factors for irrigation system design. This study was conducted to determine the initial irrigation parameters for establishing irrigation design and management of dry direct-seeded rice. The study took into considerations the different amounts of water applied and levels of soil compaction on a dry tilled paddy field which is believed to improve seed germination according to local practices.

Materials and methods

The experiment was conducted in MARDI Research Station, Seberang Perai, during the December-to-February drought period from 1993 to 1996. The area was previously a rubber estate before it was converted into paddy cultivation. The paddy has been planted in the area for the last 14 years. Generally, the soil textures can be categorized as clay soil. The particle-size distribution for sand, silt and clay is 9, 25 and 66% respectively. The experimental field was graded to 0.1% and levelled with the aid of a laser levelling device attached to a tractor-mounted back-bucket. The three treatments were arranged in a randomized block design with three replicates as follows:

- T_0 – the field was prepared by three rounds of rotavation to 120 mm of tillage depth without compaction (control),
- T_1 – the field was prepared similar to T_0 but with one round of roller compaction, and
- T_2 – the field was prepared similar to T_0 but with two rounds of roller compaction.

The experimental blocks run parallel to each other with dimensions of 5.6 m by 80 m and separated by wood-reinforced ridges to minimize overflow, lateral seepage and leakage. The roller used for compaction measured 0.39 m in diameter, 2.52 m in length and weighed 101 kg. A constant and uniform stream of water was discharged into each block by using an elevated constant-head design fibreglass tank. The flow rate was calibrated for every water application and the total amount of water supplied was recorded. The water advance rate was recorded at 10-m intervals by visual observation of the water advance front on the soil surface. To compare time of advance over the soil surface under different levels of soil compaction, a constant flow rate was used.

The experiment assumed that prior conditions for studying various relationships of flow rate and time of advance of a dry seeded field are as follows:

- accurate land levelling and maintenance of a level surface,
- volume of water delivered to the field is adequate to cover the field to an average depth that is equal to the gross irrigation application (80–120 mm), and
- depth of flow is not greater than the field ridges.

Basic soil physical data were recorded before each water application. These included soil bulk density, soil moisture content and soil clod size distribution. Infiltration parameters for the Kostiakov-Lewis equation were taken using cylinder infiltrometer from test area and best fitted as a straight line after a logarithmic transformation (*Table 1*). The relation (Walker and Skogerboe 1987) is:

$$Z = K\tau^a + f_o\tau$$

where Z = cumulative infiltration (m^3/m)
K = empirical constant ($m^3/min^a/m$)
τ = intake opportunity time (min)
a = empirical exponent (dimensionless)
f_o = basic intake rate ($m^3/min/m$)

There is an implied width of 1 m for border and basin system.

The computer simulation program *SIRMOD* (Anon. 1989) was used to simulate the time of water advance over the soil surface at the field level for comparison with visual observation. *SIRMOD* is a software for simulating the hydraulics of surface irrigation systems at the field level. This involves the numerical solution at the Saint-Venant Equations. The software provides analytical capability with respect to all of the variables affecting surface irrigation design and management. It simulates the system response to input values of each variable.

Results and discussion

Soil compaction and time of advance

At a unit flow rate of 1.0 L/s/m, the results showed that time of advance between the three levels of soil compaction (at the soil moisture content of less than 10% on dry weight basis) was not significantly affected by compaction effects. This may be due to the high coefficient of variation (30%). Nevertheless, treatment 2 (T_2) resulted in the fastest average advance flow rate of water *(Figure 1)* by 20% over treatment 1 (T_1). At this soil moisture content (10%), the soil cannot be further compacted as measurements of soil bulk density indicated *(Table 1)*. For the advancing front to proceed forward, the tilled soil above the hardpan has to be saturated first which subsequently will develop an inflow depth and push the water further. Since there is no significant difference in compaction effects, the rate of soaking is also not influenced by

Table 1. Some soil physical characteristics of experimental plot

Treatment	Bulk density (g/cm^3)	Soil moisture (% dry weight)	Distribution (%) of 4 clod sizes (mm)				Empirical constant ($m^3/min^a/m$)	Empirical exponent (a)	Basic intake rate ($m^3/min/m$)
			>30	20–30	10–20	<10			
T_0	1.19	7.8	3.3	6.9	19.3	71.6	0.0040	0.60	0.00002
T_1	1.17	4.7	4.4	8.2	24.7	62.7	0.0045	0.56	0.00002
T_2	1.23	4.7	3.6	7.5	24.4	64.6	0.0041	0.66	0.00002
C.V. (%)	5.56	12.65	65.4	46.3	12.4	12.2			

T_0 – the field was prepared by three rounds of rotavation to 120 mm of tillage depth without compaction (control)
T_1 – the field was prepared similar to T_0 but with one round of roller compaction
T_2 – the field was prepared similar to T_0 but with two rounds of roller compaction

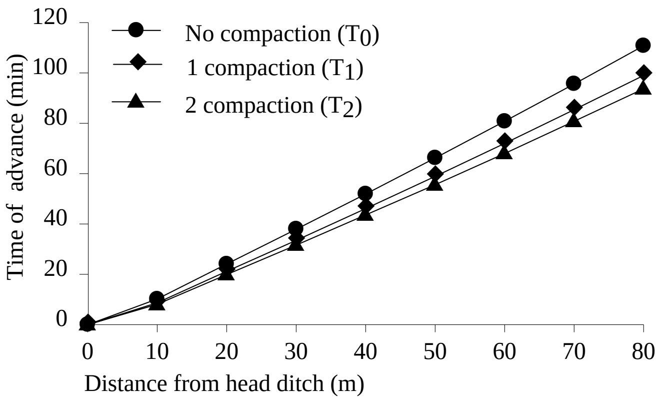

Figure 1. Advance of water (at 1.0 L/s/m) over soil surface at two levels of soil compaction

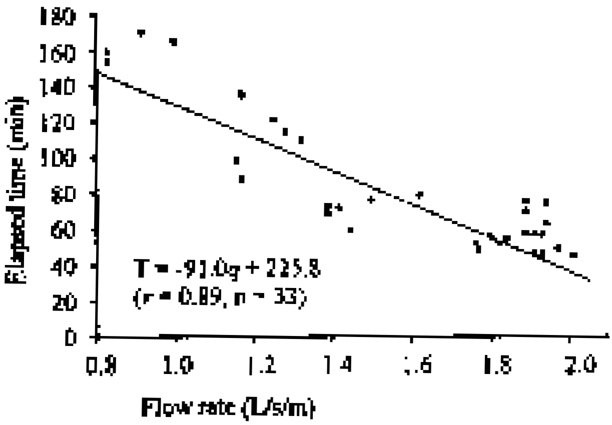

Figure 2. Relationship between flow rate and elapsed time to cover an 80-m field

the compaction treatments as expected. Therefore, a pooled equation can be used to estimate the time of water advance under the similar field condition given the unit flow rate. The relation is T = $0.016x^2 + 0.6x + 5.9$ where T is elapsed time (min) and x is the distance from head ditch (m). Value of the Manning Roughness Coefficient, 0.1 for the freshly tilled soil condition, was used as soil clod on the field surface obstruct the water movement (Walker and Skogerboe 1987). The average time of advance to cover an 80-m field run ranged from 90 min to 110 min, when the flow rate was 1.0 L/s/m.

Flow rate and elapsed time

Results of the regression analysis between flow rate and elapsed time for an 80-m field run showed that the elapsed time decreased linearly with an increase in flow rate *(Figure 2)*. The relationship can be expressed as T = $-91.0q + 225.8$ where T is elapsed time (min) and q is flow rate (L/s/m). The flow rate should not exceed the maximum erosive velocity, that is 31.4 L/s/m for basin irrigation (Walker and Skogerboe 1987) which generally depends on the soil type. On the other hand, the flow velocity must be large enough to attain high water application efficiency which is dependent on soil infiltration characteristics and the field slope. In normal practice, the flow rate should range from 1.4 to 2.4 L/s/m and the elapsed time should not be more than 3 h for a 100-m field run.

Flow rate and land soaking requirement

Land soaking requirement is the total amount of water applied to a depth equivalent to the depletion of soil moisture below field saturation at the time of application over the entire field. The term *land soaking requirement* is used here instead of presaturation requirement or

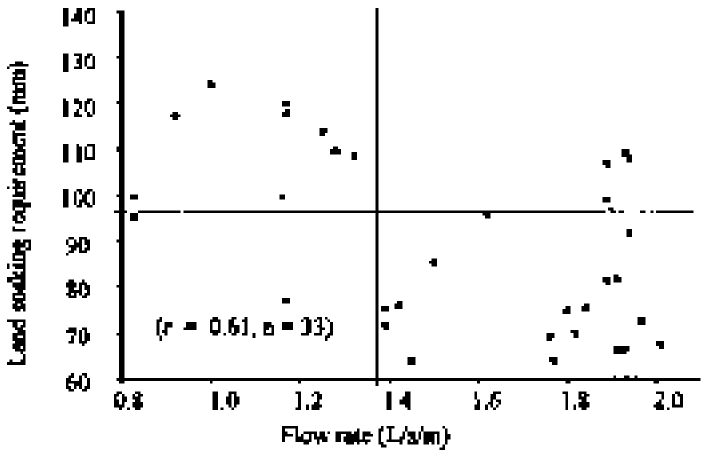

Figure 3. Relationship between flow rate and land soaking requirement under dry tillage environment

application depth because of two reasons. Firstly only the tilled soil is saturated soon after contact with the water front and secondly low vertical percolation occurs due to low permeability of the hardpan. Presaturation requirement is the total amount of water required to saturate a dry paddy field and maintain 50–100 mm depth of standing water before land preparation. Normally, the presaturation period lasts more than a week. Under the present irrigation practice, the designed presaturation requirement is 150 mm depth of water. The studies showed that the land soaking requirement declined linearly with an increase in flow rate *(Figure 3)*. However, the relationship is not well correlated where *r* value is only 0.61. If the flow rate values were separated into two sections ranging from 0.7 to 1.4 L/s/m, and 1.4 to 2.1 L/s/m, the land soaking requirement values for the first section was always higher than 100 mm compared with the second section. As the flow rate increases, an inflow depth will be developed at the advancing front in a shorter time, which gives the driving force or a hydraulic gradient. This causes the advancing front to travel faster on the soil surface, which subsequently will reduce the vertical percolation and lateral seepage losses for a given length of field due to the faster completion of advance. When the flow rate is 0.8 L/s/m, the average depth of water required to cover an 80-m field is 120 mm compared with the flow rate of 2.0 L/s/m where it requires only 80 mm depth of water. Thus, a 30% reduction of water requirement can be achieved with a greater flow rate. For field practice, flow rates higher than 1.4 L/s/m should be recommended. The current irrigation system was designed for transplanting. The designed water duty for presaturation period was 41.5 mm/day (4.8 L/s/ha), and supplementary irrigation of 7.6 mm/day (0.9 L/s/ha) (Kitamura 1987). This supply rate is far too low to meet the irrigation requirement compared with the flow rate used (125 L/s/ha) in the experiment.

Elapsed time and land soaking requirement

The relationship of elapsed time and land soaking requirement can be established *(Figure 4)* from data shown in *Figure 2* and *Figure 3,* and can be expressed as $D = 0.38T + 57.1$ by regression analysis where D is the land soaking requirement (mm) and T is elapsed time (min). The land soaking requirement increases linearly with the increase of elapsed time, indicating that the longer it takes to soak the field, the higher the land soaking requirement. Thus, to save water, the duration for the water to cover the field should be reduced as much as possible, but the flow rate should be within the maximum allowable flow to prevent erosion. For instance in this case, when the elapsed time to cover an 80-m field run is less than 100 min, the corresponding land soaking requirement is always within 100 mm depth of water.

Observed versus simulated time of advance
The simulated time of advance values for different flow rates were predicted based on the Saint-Venant Equation which is the combination of mass conservation and momentum conservation principles (Anon. 1989). Since the computation involved a numerical solution, the computer program *SIRMOD* was used. The input data required to run the program include method of water application, flow rate, Manning Roughness Coefficient, infiltration parameters and field length. When compared with the visual observation values, values of simulated time of advance were close to the calculated values when the time of advance is small. When the time of advance becomes longer, the calculated values were lower than the observed values which appear as data point above 1:1 line *(Figure 5)*. This could be due to the large opportunity time, which subsequently caused more seepage losses, that was not taken into account in the Saint-Venant Equation. Thus, this could indicate that the lateral seepage component is the most important factor that must be

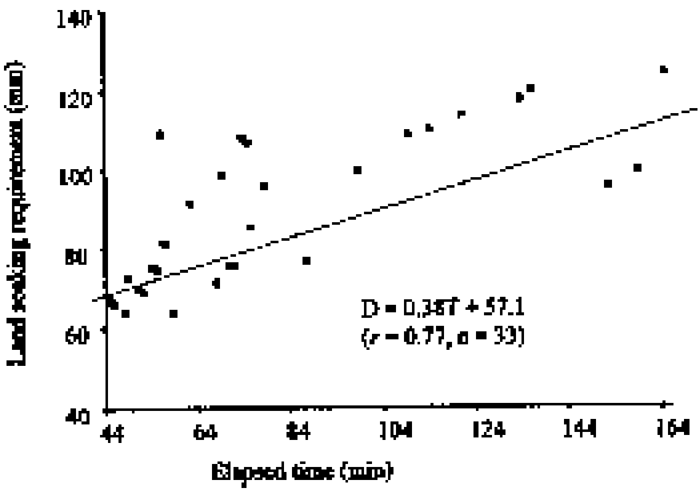

Figure 4. Relationship between elapsed time and land soaking requirement to cover an 80-m field

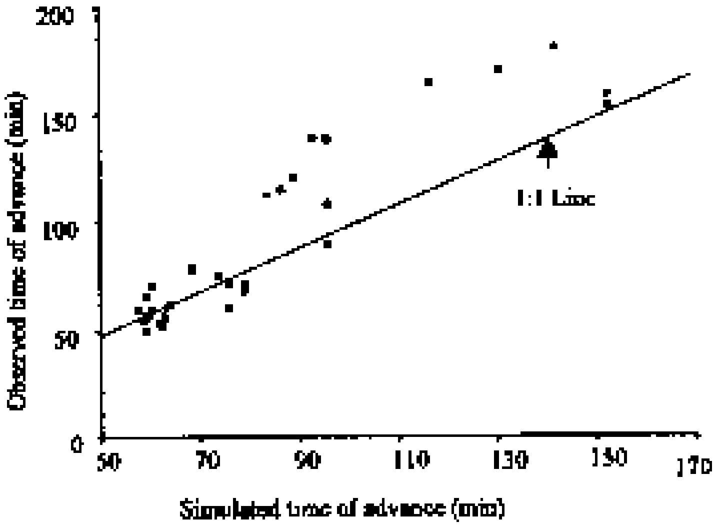

Figure 5. Observed versus simulated time of advance

considered when this equation is used, particularly if the field is relatively narrow.

Conclusion

The initial irrigation requirement can be calculated based on the stream size available, plot configuration and the average tillage depth. For a dry tilled paddy field, initial irrigation requirement decreases with an increase in flow rate, a decrease in advance time and consequently a better application efficiency. At an average tillage depth of 120 mm and a flow rate of 1.0 L/s/m, the average time of advance over the soil surface is 110 min. While the average application depth is 80 mm depth of water to cover an 80-m field. The recommended flow rate for initial irrigation on dry tilth paddy soil should range from 1.4 to 2.4 L/s/m for a 100-m field.

Experiments also showed that compacting dry soil at less than 10% of soil moisture content on dry weight basis using roller compactor has no significant effect on advance rate. The *SIRMOD* model can be employed to calculate the advance rate or initial irrigation requirement as long as the effect of lateral seepage is given due consideration for a narrow basin field layout.

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