Rice cultivation and water control

Importance of rice

Rice, wheat, and corn are the three leading food crops in the world and together they supply about 50 per cent of all calories consumed by the human race. In terms of area harvested each year, wheat is the leader, with 215 million hectares, followed by paddy rice with roughly 140 million hectares. The 200 million tons of milled rice produced each year provides the major source of calories in the diets of almost 40 per cent of the world’s population. Throughout vast areas of the less well-fed world, rice provides 75 per cent of the total calorie intake and almost 60 per cent of the protein intake. Rarely does either wheat or corn approach these figures (HUKE 1976).

Role of water

The role of water in rice cultivation is a dominant one. During the major part of its development, most rice is grown with a layer of impounded water on the surface of the fields. Long ago, Asian farmers found that they could till the soils with their simple implements only when the soils were saturated. They therefore erected bunds to keep water on the fields during tillage. The water level also provided them with a convenient guide to level the soil surface. The soil treated in this way was transformed into a liquid mud that could retain more water than a normal soil. Fortunately the rice plant is adapted to wet conditions and even derives benefits from them. The benefits of keeping a water layer of 5 to 10 cm on a rice field are (van de GOOR 1974):

- The continuous water supply means that the roots are surrounded by water so moisture stress will never occur
- The cover of water in the first 4 to 6 weeks after sowing or transplanting helps to control weed growth
- The protective water layer prevents splash erosion and the formation of a surface crust
- The water layer acts as a temperature regulator and creates a favourable microclimate.

The rice plant tolerates, but does not require, excessive quantities of water. It is more the attendant circumstances that make the use of water higher with rice than with most other crops. Nevertheless, rice is extremely sensitive to moisture stress and yield reductions can be expected as soon as the root zone is less than saturated. The impounded water is therefore of great value in avoiding this risk.
The effects of moisture stress are even more pronounced in the modern high-yielding varieties developed by the International Rice Research Institute (IRRI) in the Philippines. These varieties have a short growth duration (120 days from transplanting to harvest), a short sturdy column (110 cm long at maturity), and are insensitive to the photo period (their time of flowering is not dependent on specific length of daylight). When these varieties are grown, they can produce two reliable high-yielding crops of rice a year. But they react sharply to shortcomings in water management!

WICKHAM (1973) demonstrated the influence of moisture stress on yields of modern rice varieties, using the concept of stress days (days in excess of three for which the field was continuously without standing water). He also showed that extra nitrogen can compensate to a certain extent for stress effects during tillering (Table 1). Good water management for rice must not only ensure that a layer of water is kept on the field, it must also ensure that the layer is not too deep. Table 2 shows the reduction in yields when water depths are excessive (ILRI, in preparation).

It is obvious that rice does not require drainage in the same way as other agricultural crops. Nevertheless, good water management also includes the timely removal of water, not only to prevent too deep water layers but also to allow fertilizing to create good ripening and harvesting conditions, and to dry the soil between two successive rice crops.

The flooding, tillage, and puddling of the land has certain consequences for the chemical, biological, and physical conditions of the rice soil (van de GOOR 1974). One of these consequences is the nutrient supply, especially that of nitrogen. Because of waterlogging, the root zone is in a reduced state and nitrates, if applied, would be lost through volatilization. This problem can be overcome by placing ammonia fertilizer in the reduced zone.

<table>
<thead>
<tr>
<th>N-application 80 kg/ha</th>
<th>N-application 40 kg/ha</th>
<th>N-application 10 kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>S₁*</td>
<td>S₂*</td>
<td>S₁</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>4136</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>4216</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>3624</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>3272</td>
</tr>
</tbody>
</table>

* S₁ = stress days during the vegetative growth stage (tillering)
S₂ = stress days during the generative growth stage (panicle formation)
Table 2.
Relative yield (%) for period of 0–40 days and 40–70 days after transplanting (short-stem, ‘modern’ varieties).

<table>
<thead>
<tr>
<th>Period</th>
<th>0–40 days</th>
<th>40–70 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>duration of water level</td>
<td>1 day</td>
<td>5 days</td>
</tr>
<tr>
<td>water level above ground level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>125–150 mm</td>
<td>99</td>
<td>95</td>
</tr>
<tr>
<td>300–325 mm</td>
<td>95</td>
<td>68</td>
</tr>
<tr>
<td>575–600 mm</td>
<td>91</td>
<td>41</td>
</tr>
</tbody>
</table>

Irrigation for rice

In the traditional rice-growing countries, all of which lie within the tropical monsoon belt, the rice production season starts at the beginning of the rainy season and both seasons last for about five months. As the rainy season comes to an end and rainfall ceases, good conditions are created for ripening and harvesting of the rice crop.

Supplementary irrigation can be most useful in these areas to supply water during the period of land preparation (puddling). The demand for water is high at this time and the onset of the rainy season is erratic. Supplementary irrigation thus helps to maintain a strict cultivation calendar. Nor are the amounts of rainfall the same from year to year; in years of lower rainfall, supplementary irrigation can make up for deficits. In areas where supplementary irrigation has been successfully introduced, it has frequently promoted full irrigation schemes that allow double cropping of rice, i.e. a second (dry-season) crop can be grown as well.

Rice is also produced in areas that do not lie within the tropical monsoon belt. Examples are the Nile Delta, Pakistan’s Sind Province, northern Hokkaido, parts of the Sahel, and Manchuria. In these areas, temperatures are high, relative humidities are low, and the potential evaporation rates are among the highest in the world. Water demands for a rice crop in these areas are almost double the needs of the same crop in the humid tropics. Without irrigation, no rice production would be possible.

Of the world-wide total of 140 million hectares on which rice is grown, some 59 million hectares now have some form of irrigation (EARLY et al. 1979). This constitutes a large proportion of the rice-growing area and is a proportion that can only be expected to grow in the future.

Considering the vital role of rice in feeding so many of the world’s population, considering also the dependence of the rice crop on good water management, and considering further the vast numbers of small farmers who are – or will be – involved in rice irrigation schemes, let us take a critical look at these schemes and at the way the farmers function within them.

The tertiary unit

An irrigation scheme begins at the source of its water. This source may be a river, a reservoir, or a pumping station. The water is conveyed from its source through a main canal, from which it may be diverted into secondary canals, and proceeds further until it reaches a tertiary offtake. A tertiary offtake is a structure that diverts water from a main or secondary canal to supply a tertiary unit. A schematic of an irrigation scheme is shown in Figure 1. The terminology used here is that advocated by the International Commission for Irrigation and Drainage (BOS 1979).

In its journey from the source to the tertiary offtake, the water is the responsibility of the scheme authorities. When it passes through the tertiary offtake and enters the tertiary unit, it enters the domain of the farmers. Within the tertiary unit, which contains a number of farms, the group of farmers is responsible for distributing the water through the tertiary and quaternary canals to the farm inlets, after which each individual farmer assumes responsibility for the application of the
Fields of young paddy.

water to his fields.
As rice farms are usually very small, the tertiary unit of a rice irrigation project is likely to contain a large number of farms. Ensuring that each farm receives its equitable share of irrigation water demands a collective effort on the part of the farmers. A well-designed tertiary unit will alleviate many of the problems of water distribution.

Design
The task facing the designer of an irrigation scheme is a highly complex one, combining as it does a myriad of technical, economic, agronomic, and social factors. Basically, however, his task is to create a layout that achieves two things: it must use the available water as efficiently as possible, and it must enable an equitable distribution of the water among the farmers.

If an irrigation scheme is to be designed for hitherto virgin land that is being opened up for settlement, the designer's problems will be relatively few. The location of the source of irrigation water and the topography of the area will largely decide the layout of the main irrigation and drainage canals. Into this layout, the tertiary units must be fitted.

If irrigation is to be introduced into an already settled area or if an existing irrigation scheme is to be rehabilitated, the design may be greatly complicated by problems of land ownership, land

Figure 1.
Schematic of an irrigation scheme (BOS and NUGTEREN 1974).
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But whether the irrigation scheme is on 'old' or 'new' land, a wise designer will consult with the farmers before proceeding with the design of the tertiary units. The size of the tertiary unit, the method of water distribution that will be adopted, and how its delivery will be scheduled are all matters that deeply concern the farmer. The designer should provide the farmers with a tertiary unit that they can handle with ease and efficiency. At this stage it can also be decided in how far the farmers should participate in the construction of the tertiary facilities. Their involvement in these activities can be a major factor in creating the cooperative spirit so vital to the success of irrigation schemes. Not only does it promote the feeling among the farmers that the scheme belongs to them, it also helps to keep costs down. The farmers should not, of course, be burdened with tasks that are too onerous. Land clearing, land levelling, and road construction will usually be beyond their capacities.

As observed by NUGTEREN (1967): 'A tertiary unit is not only a key element in the design of an irrigation project, it also constitutes an organizational entity of great value for the social structure of the farming population'. But leaving social considerations aside, the technical aspects of tertiary unit design will involve decisions on the following three items:
- the water distribution method (continuous or rotational)
- the size of the irrigation module, i.e. the stream flow to be provided to each farmer
- the size of the tertiary unit.

**Water distribution**

In many rice growing areas, irrigation is provided by a system of continuous flow. Throughout the crop season, water flows continuously from the tertiary and quaternary canals into the rice fields. The distributary canals always contain water and each farm receives a share of the total flow in proportion to its area. This system is widely applied where rice is grown in the traditional way. Continuous irrigation, however, often means:
- tertiary offtakes lacking devices for measuring water
- poor facilities inside the tertiary unit for measuring, distributing, and regulating water flows
- a lack of clearly demarcated quaternary units and canals served by a group inlet
- a high degree of plot-to-plot irrigation with farmers close to the tertiary canal in a good position for both irrigation and drainage
- a relatively large irrigation stream flow entering the tertiary unit
- a low efficiency in water application
- problems in times of water scarcity, particularly in downstream fields.

Obviously, with so many shortcomings, equitable water distribution within the tertiary unit is no simple matter.

Under rotational irrigation, water is also drawn continuously from the tertiary offtake but it is supplied to the farms on a schedule of rotational flow. Rotational irrigation thus means a subdivision of the tertiary unit into quaternary units, with the quaternary canals carrying water only part of the time.

Rotational irrigation demands accurate measurements of the stream flow, proper facilities for distributing the flow, and a highly disciplined organization of the farmers. It thus offers better opportunities for water control and will do much to ensure equitable water distribution. It also enables farmers to time fertilizer applications and weed control (THAVARAJ 1975). Rotational irrigation may also mean savings in irrigation water. Some researchers in Taiwan claim that rotational irrigation uses 30 to 50 per cent less irrigation water (DE DATTA et al. 1973). It is often recommended in locations where it is desirable to irrigate as large an area as possible with a limited water supply.

The absolute advantages of rotational irrigation have been questioned by researchers in the Philippines (WICKHAM and VALERA 1978; MIRANDA and LEVINE 1978). Admittedly, rotational irrigation brings with it higher project costs for the provision of tertiary unit facilities, and also places heavy organizational demands on project management and farmers alike, especially in large
projects. Nevertheless, there seem to be more points in favour of rotational irrigation than against it.

Irrigation module
In the practice of gravity irrigation, the quantity of water that can be handled adequately by one farmer is known as the irrigation module (and also as main d'eau). The module may vary roughly between 15–60 l/s. The choice of the appropriate module depends on the field irrigation method (basin, border, furrow), the slope of the field, soil conditions, field dimensions, and the skill of the farmer.

Rice irrigation uses the 'basin' method and a module of around 30 l/s is considered acceptable. The size of the module may be higher or lower than this figure, depending on the facilities that are available to control the flow. A very low module of, say, 1 l/s would not be sufficient to flood the basin, while very high modules would mean excessive water use.

Size
The crucial factor in deciding the size of a tertiary unit is how the collective delivery of water can be successfully organized. When the farmers have a stable social structure because they belong to a strong village community, the distribution of water may present no problems and the tertiary unit can be larger. In such areas, a tertiary unit may contain up to 50 farms, but of course the farm size plays a role as well.

In new irrigation schemes, where the farmers may lack a strong community spirit, the design should be based on a more individual handling of the water distribution and the tertiary unit should be kept small. It should serve no more than 10 to 25 farms.

Generally speaking, the larger the tertiary unit, the greater will be the operational difficulties and also the greater will be the losses of water in the distributary canals. If units are too large, farms at the tail end of the tertiary canal are apt to suffer from poorly controlled water supplies further upstream.

A direct relationship exists between the size of the tertiary unit, the irrigation module, the water distribution method, the number of farms, and the size of the farms. This will be demonstrated by a simple example.

Let us assume an irrigation module of 35 l/s, which is an acceptable module for rice. If the daily irrigation water requirement is 10 mm (or 10/8.64 l/s/ha), the irrigation module can supply water to a tertiary unit of

\[
\frac{35}{10/8.64} = 30 \text{ hectares.}
\]

If the farm size is 1.50 hectares, the tertiary unit will contain 20 farms. If these farms are served by a system of rotational irrigation with an irrigation interval of, say, 10 days, the irrigation module can supply 2 farms each day with the 100 mm they need to meet their requirements. Each farm may receive either half the module for 24 hours or the whole module for 12 hours.

With a farm size of 0.50 hectares and the same irrigation module, the tertiary unit will still be 30 hectares but will now contain 60 farms. With the same rotational schedule of 10 days, distribution

Simple off-take from a main canal.
Figure 2.
Tertiary unit for rice cultivation in Sulawesi, Indonesia.

Figure 3.
Additional tertiary unit facilities for layout in Figure 2.
A complicated system of water conveyance and distribution. Division structure and tertiary off-takes Lamasi area, Sulawesi (Indonesia).

becomes more complicated as 6 farms must receive the module on one day. With an irrigation module of 70 l/s, the size of the tertiary unit will double. This may be required in certain projects for economic reasons or to give more flexibility to the design. In such cases the tertiary unit can be split into two and the tertiary canal provided with a division structure immediately downstream of the offtake.

Examples
The layout of a complex tertiary unit in a rice irrigation scheme in Sulawesi, Indonesia, is shown in Figure 2. Originally (about 1940), the size of the tertiary units was between 200 and 250 hectares. The scheme was rehabilitated in 1973 and was provided with extra secondary canals and a larger number of tertiary canals and off-takes. The tertiary units were reduced to 110 hectares. The average density of the conveyance canals was 6 m per hectare. Although reducing the size of the tertiary unit by approximately one half is quite an improvement, it remains doubtful whether good water management can be achieved within the unit. The quaternary canals have not been included in the design, and it is difficult to see how more than 100 farmers could cooperate effectively in distributing the water. Even with the addition of 1100 metres of tertiary canals and 4500 metres of quaternary canals as shown in Figure 3, the size of the tertiary unit, its configuration, and its facilities would seem to militate against good water management.

At the other end of the scale is a tertiary unit in the Kou Valley rice irrigation project in Upper Volta (WARDA 1975). There, the tertiary units comprise 12 hectares and have 12 farms within their perimeters. The project, which totals 1100 hectares, has a very high density of conveyance canals: 80 metres per hectare. A dense network of conveyance canals usually corresponds with small tertiary units. It also means higher costs and a greater loss of land. The average density of conveyance canals in nine rice irrigation projects (5 in Indonesia, 3 in the Philippines, and one in Malaysia) is 13 metres per hectare, with a minimum of 6 m/ha and a maximum of 22 m/ha (KEE SEUNG PARK 1975).

Need for a phased development?
A question that arises particularly in the rehabilitation of irrigation schemes is how intensive should be the measures that are taken. It is a question that certainly arises in areas where holdings are excessively fragmented because fragmentation unnecessarily complicates water management. A farmer who has fields in more than one tertiary unit, for instance, must observe more than one irrigation schedule, which is a burden both to him and to the project authorities. This is only one of the many problems that irrigated rice technology faces as a consequence of fragmentation (PAL 1978).

In Japan, rice irrigation development plans incorporate a detailed package of tertiary unit facilities, intensive on-farm development, and a programme of land consolidation, with land consoli-
Figure 4.
Tertiary unit in Northern Chao Phya, Thailand, prior to improvement (adapted from NEDECO/ILACO 1973).

Figure 5.
Low cost, less intensive tertiary unit improvement in section of area of Figure 4 (adapted from NEDECO/ILACO 1973).

Land consolidation also forms an essential part of irrigated rice development in the Northern Chao Phya area of Thailand (KARUNYAKAN 1978; NEDECO/ILACO 1973). The lack of tertiary units serves (see Figure 4) keeps rice production low in the wet season and double cropping can be practised only to a limited extent. Rehabilitated areas are provided with a completely new network of irrigation and drainage canals and farm roads. Each individual field has an irrigation inlet (if possible direct from the tertiary canal), a drain outlet, and access to a road. The re-allocated plots are rectangular. Land levelling is included as a vital part of the operation. Where the programme has been implemented, yields have increased dramatically and double cropping has become common practice.

Investment costs are not excessively high, but the time required for planning, designing, and implementing is very long. The annual output is less than 1000 hectares. This is creating an uneven distribution of benefits among the farming population. The question arises whether it would not be better to take less intensive measures that could be spread over a wider area and benefit a larger proportion of the people.

In the present situation (without improvement)
There is a complete lack of drainage canals, no internal road network, and the tertiary units are very large (between 200 and 250 hectares). A reasonable partial development could be achieved by the layout presented in Figure 5. This layout would reduce the size of the tertiary unit to around 70 hectares, improve drainage, reduce plot-to-plot irrigation, and enhance the irrigation efficiency. And it would cost only 25% of the costs of the intensive improvements. What is more, it would require no detailed cadastral survey beforehand. (To avoid sharp curves in the canals, small areas of land could simply be exchanged among the farmers). Partial improvement would mean a fast rate of development over a larger area and better distributed benefits. When various options are open, it would seem wise to start with a relatively simple programme covering large areas in a short time. One can always return later with a more complete programme.

Intensive development is also found in India, where a full-scale reconstruction of land surfaces and water distribution structures is being combined with an exchange of ownership units by a consolidation of holdings and a realignment of boundaries. This is known as the Kota Method, after the town in Rajasthan where it was first implemented. Here, too, the message would seem to be 'Study the alternatives'. As observed by WADE (1975): 'The choice of technique in irrigation command area development must be adapted to the rate at which land development is expected to proceed. The next few years will see less comprehensive, less elegant approaches in use with more attention to local variations; the Kota Method will be one end of a range of possible alternatives'.

Another school of thought which advocates a phased development but for a different reason is represented by BOTTRALL (1978). He argues that the technology introduced at the beginning of a project may be too sophisticated for the relatively modest requirements of the farmers, and that the operation and maintenance of the project may be beyond the capacities of local staff. Whether this represents a sound reason for making a simple start instead of a more sophisticated one (or the best) is difficult to say. A concerted effort in training could possibly do a lot to remedy the situation.

Nevertheless, the skills of the farmers and the competence of the project management must, of course, be taken into account. When the choice is being made between continuous and rotational irrigation, for instance, skills and competence will be highly relevant. To quote IRRI (1973): 'Choosing an appropriate level of sophistication for the design of a system, and maintaining a proper balance between physical design and human management capacities within it are difficult tasks that demand considerable attention'.

Conclusions

In rice irrigation schemes, the need for better water control at on-farm level is being increasingly recognized. Irrigation authorities have become
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aware that their task extends beyond the mere design and construction of the conveyance network. Whereas formerly they left the design of the tertiary unit and the construction of its facilities to the farmers, they are now recognizing that the tertiary unit is the 'heart' of an irrigation scheme and is far too important to be left to chance. In some places, on-farm development has become almost a slogan.

The authorities are also realizing that the smooth operation of the tertiary unit depends greatly on a spirit of cooperation among the farmers. As this is a somewhat fragile entity, they are now taking an element of human behaviour into account in their designs and are endeavouring to create 'foolproof' tertiary units. The watchword seems to be: Keep it small and keep it simple.

Nevertheless, there is an enormous area of land under rice; there are great variations in soil types and in geographical and hydrological situations; there are millions of smallholder rice farmers, all with varying social and educational backgrounds and all cultivating a small piece of land on which they may be utterly dependent. Hard and fast rules for the design of tertiary units are impossible to give. The design that may be right in one case need not necessarily be right in another. Each case requires individual study and all cases require that the farmers be consulted. A remark made at an irrigation seminar sums it up nicely: 'All designers should have to operate the systems they design'.

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