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Water management in raised bed systems: a case study from the Chao Phraya delta, Thailand

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Abstract

Agricultural diversification is a major trend in Asian rice-based systems. In lowlands, however, soil and water conditions are mostly suitable for rice cultivation and the development of raised beds is often required to accommodate vegetables or fruit trees. Raised bed systems go together with specific techniques of water management, both at the polder level (between the plots and the canals) and at the plot level (bed irrigation). Details of this management in the Chao Phraya Delta are given for three different crops: mango, grapes and asparagus and differences are explained. The water balance over 1 year is specified, showing the impact of seepage and estimating water requirements. Water quality is shown to be a major issue. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

In many regions of tropical Asia, agriculture is undergoing a very rapid transformation characterised by the diversification of traditional rice based systems. Agricultural

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diversification is fuelled by the low profitability of rice and by the development of urban and export markets and reliable transport infrastructures.

Ecological conditions in flood prone lowlands are hardly suitable for any other crop than rice. In deltaic environments of tropical Asia in particular, deep water and floating rice varieties are found in the lower parts, ceding their place to high yield varieties when water can be controlled, and often to sugarcane in upper locations. To be able to diversify in such hydromorphic conditions, farmers generally resort to techniques including diking, polderisation and use of raised beds. Such techniques of land development bear different features according to the conditions of soil (acidity, salinity, etc), water (water regime, influence of the tide, saline intrusion, etc) and crops (field crops, trees, vegetables).

The development of raised bed systems, with partial or full protection from the flood regime, is under full swing in southeast Asian deltas: in the Chao Phraya delta (central plain of Thailand), they have been present since the 19th century and they now total more than 100 000 ha. The characterisation and understanding of the constraints faced by these systems must be thoroughly investigated in order to assess the conditions of their development and to provide regions which have still limited experience with technical references. This paper analyses water management in three poldered plots of the Chao Phraya delta.

2. Material and methods

2.1. Plot and water flows description

The case study was carried out in the Damnoen Saduak area, in the western side of the lower Chao Phraya delta (Fig. 1). A farm composed of three adjacent polders, planted with crops highly representative of the area: mango, grapes and asparagus, was chosen and monitored for almost one year (November 1995–October 1996). Fig. 2 gives the layout of the farm: the three plots are surrounded with protection dikes and are located along a perennial canal.

The beds have an average width (measured at the top of them) of 2.2, 3.2 and 3.1 m for mango, grapes and asparagus, respectively (Table 1), while their (absolute) elevation ranges from 1.1 (grapes) to 1.33 m MSL (asparagus). For an average water level in the ditches, the water body corresponds to around 40% of the total plot area. The three plots total 3.5 ha.

Table 1
Characteristics of plots and beds

Crop	Plot area (ha)	% water (for an average water level)	Number of beds	Average bed width at the top (m)	Average bed height (m MSL)	Average slope of bed sides	Average ditch width for an average water level (m)
Grapes	1.10	37	24	3.23	1.11	1 : 1	2.1
Asparagus	1.22	41	23	3.13	1.33	1 : 1	2.4
Mango	1.19	39	23	2.2	1.25	1 : 1.5	2.1

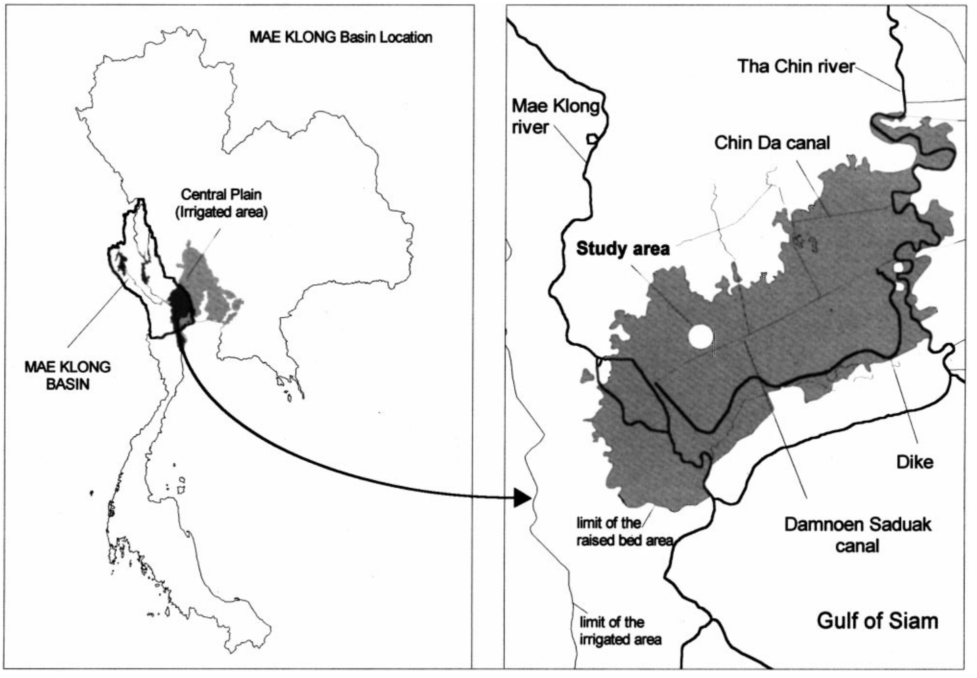

Fig. 1. A map of the Damnoen Saduak area.

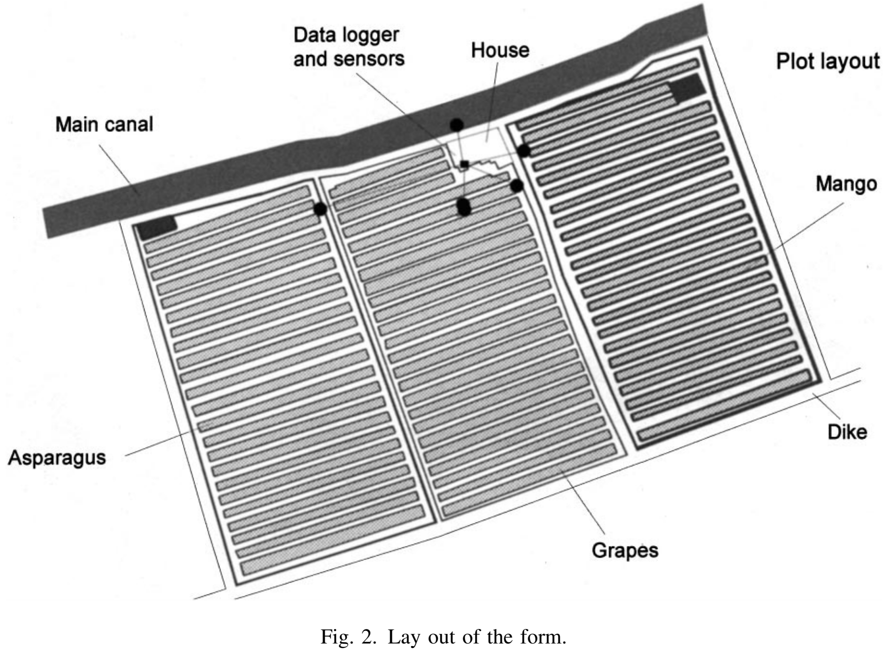

Fig. 2. Lay out of the form.

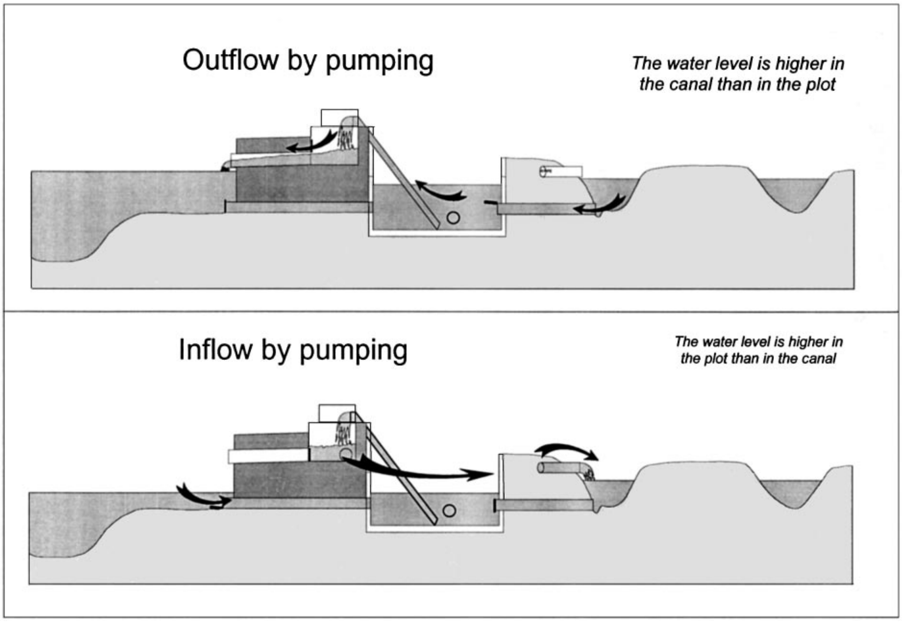

Fig. 3. Double-purpose pumping device.

Agricultural management is very intensive. All the three crops are treated with hormones and produce three times a year, although with varied yields. Heavy fertilisation and pesticide application are observed. Water flows between the canal and the plots can be either by gravity (through pipes buried in the dike) or by pumping, depending on the need (irrigation or drainage) and relative water levels inside and outside the plots. Pumping into and out of the plot can be performed by a single and fixed double-purpose pump.

In cases of excess water in the plot (and of a higher external water level), water is simply pumped from the forebay into the division box and, then, conducted out into the canal (Fig. 3). In cases of water demand in the plot (and lower level in the canal), water is first admitted into the forebay through a pipe located in a very low position (so that inflow may always be possible). It is then lifted by the pump but the lateral outlet of the division box is now opened, in order to direct the flow towards the plot (through a pipe), instead of rejecting it to the canal (Fig. 3).

Inside each polder, raised beds alternate with ditches in which water stagnates permanently. Crops planted on the beds can be irrigated by lifting water from the ditches onto the beds: this can be done manually but in the Damnoen Saduak area almost all the farms use small boats which are led along the ditches successively: these boats, either pushed or auto-propelled, are equipped with a pump which sprays the beds laterally, on both sides.

2.2. Measurements

Water levels in the canal, plots and within one of the beds planted with grapes were monitored and recorded on an hourly basis for 10 months (18 November 1995–2 October

1996), before being interrupted by exceptional floods. This data collection was made possible by using a data logger and six sensors located in the canal, the plot ditches, and inside one of the grapes beds (in PVC tubes), as indicated in Fig. 2. An error of manipulation of the block data and sensor failures due to siltation of the membranes are responsible for missing data in some limited periods.

In order to establish a water balance of each of the three plots, a rainfall gauge and an evaporation (Class A) pan were installed, together with twin tanks meant to measure percolation (located far from the canal to reduce perturbation from seepage). These tanks have been sunk in the surrounding ditch of the mango plot and differ in that one tank is deprived of bottom while the other tank is not. The difference in the decrease of the water levels in both tanks is taken as an estimate of the percolation rate. Humidity and temperature have also been recorded to allow an estimation of ET.

Seepage through the main dike, between the canal and the plots, has been assessed by soil sampling and hydraulic conductivity measurements, using the Auger hole test.

All operations related to water management (inflow, outflow, by pumping or gravity; irrigation of the beds inside the plots) have been recorded with the corresponding duration. Plot irrigation timing has been for short periods monitored alongside soil wetness in the grapes and asparagus plots. The applications of agrochemicals have been noted and in situ measurements have been carried out to assess the variability of some basic elements and variables (pH and DO).

3. Results

3.1. Water management at the regional level

A regional understanding of water management in the Damnoen Saduak area will help in analysing the water regime observed in the canal. As shown in Fig. 1, the raised bed area of the lower Mae Klong basin is sandwiched between the Mae Klong and Tha Chin rivers, crossed by the Damnoen Saduak (main) canal. Its southern border is limited by a dike which impedes the intrusion of saline water. South of the Damnoen Saduak canal itself all the streams flowing into the two rivers are gated, with the exception of some canals in the western part. These channels are, therefore, directly connected with the rivers and allow the propagation of some tidal effect, which attenuates further inland. This is seen in Fig. 4 where the water levels in the Mae Klong river, at the extremity of the Damnoen Saduak canal, and near the plot have been plotted. There is one main tide everyday but some small indentation can be perceived in some of the 'hunches', indicating secondary tides.

In the rainy season, excess water is evacuated through the main regulators located along the southern dike and at the outlets to the rivers on both sides. In the dry season, all the gates are closed in order to retain the fresh water.

3.2. Water regime in the main canal along the plot

Fig. 5 displays the evolution of the water level in the canal along the year, together with rainfall. The average water level decreases in November–December (dry season),

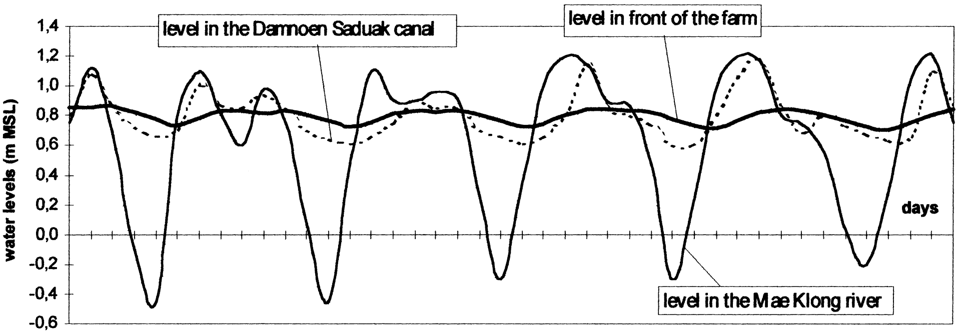

Fig. 4. Water levels in the river, the canal and near the plot.

increases again during the second half of May, shows a short term peak around the 1st of July (flash floods) before starting to rise regularly. Around 15 October, the water level reached 1.80 m, which is unusual for this area; after reaching more than 2 m, the data logger had to be removed to escape one of the highest floods ever seen.

If we ignore the unusual flood at the end of the year, we can state that the water level is rather regular in the canal: it commonly varies between 0.7 and 1.2 m (MSL), with an average level of 1.00 m. This variability, however, will have a decisive impact on the possibility to generate flows between the canal and the plots by gravity.

3.3. Water management at the farm level

3.3.1. Water flows between the canal and the polder

The water inside the plots is regulated according to the kind of crops. Fig. 6 displays, as an example, the evolution of water levels in the canal and inside the three polders

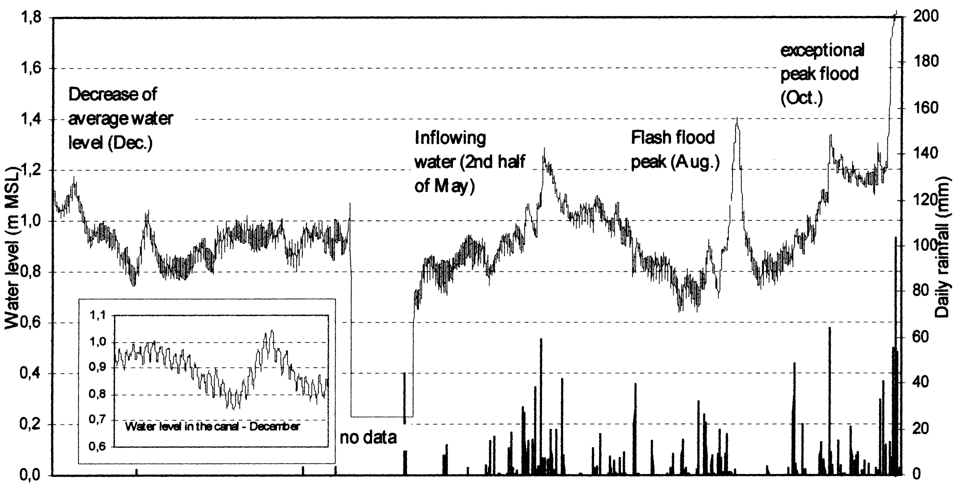

Fig. 5. Evolution of water level in the canal (November 1995–October 1996).

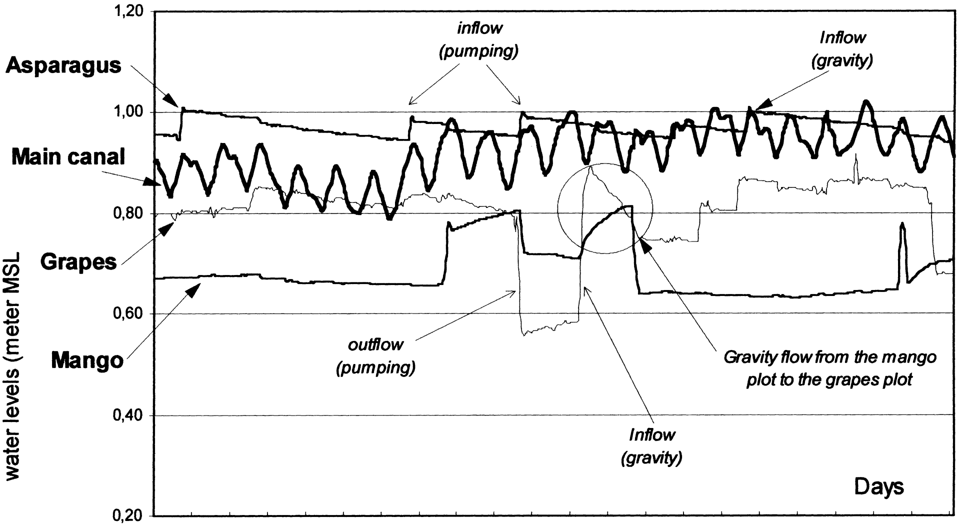

Fig. 6. Water levels in the three plots and in the canal (10–30 January).

during 20 days in January. We can observe that the average water level in the asparagus plot is higher than the grapes which, in turn, is higher than the mango plot. This, of course, reflects the fact that water management is attuned to the depth of the root system of each plant, as specified in a later section.

In the asparagus plot, some inflow is periodically added in order to restore the water level up to the desired value. This has to be done by pumping because the water level in the plot is higher than in the canal. As the latter increases, however, their relative levels are inverted and the last two inflows can be obtained by gravity (Fig. 6).

- The water level inside the grapes plot is (at this period of the year) most of the time lower than the level in the canal. Inflow can, thus be simply created by opening the pipe. In the middle of the graph a 2-days' slump can be observed, with a draw-down of 25 cm obtained by pumping the water out. This corresponds to a renewal of water made necessary by the degradation of its quality. Inflow is further provided by gravity and stops when the water levels equalise.
- In the mango plot, water is kept particularly low due to a deeper root system, except for a few periods when it is raised to ease watering of the trees.
- More generally, decisions to provoke a flow between the canal and the plot are triggered by the following main reasons (this will be either by gravity or by pumping, according to relative water levels):

  outflow 1: to drain excess water. This happens in case of heavy rainfall, of uncontrolled inflow, such as occurs when the pipe has not been properly closed, or high seepage from the canal into the polder;
  outflow 2: to flush out water when its quality gets too poor inside the plot;
  outflow 3: to lower the water level in order to dredge the ditch more conveniently;

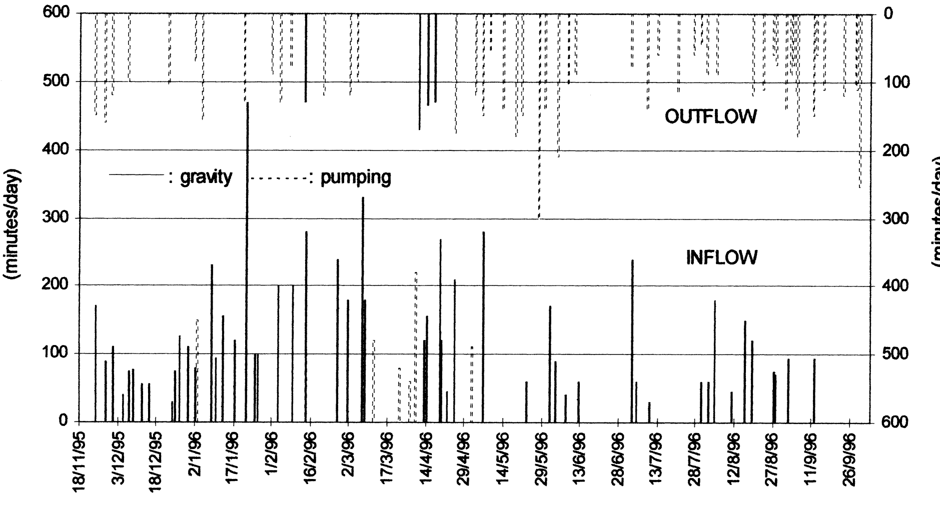

Fig. 7. Inflow and outflow in the grapes plot.

outflow 4: to lower the water level to induce flowering (fruit trees) or at harvest time;
inflow 1: to restore the required water level when water is depleted by crop consumption or for any of the above mentioned reasons;
inflow 2: to raise the water level before irrigating the beds so that the movement of the boat will be eased.

In order to assess the frequency of water flows required for each plot and whether these can be obtained by gravity or need pumping, all their occurrences have been plotted in Fig. 7. Table 2 provides the accounting of all operations, together with the breakdown by season.

The frequency of operation (inflow or outflow) is the highest for grapes (three times/week), followed by asparagus (2.6), while remaining significantly lower for mango (1.6). Inflow and outflows have similar frequencies, except for mango for which outflows make up two thirds of the operations. Operations carried out through pumping make up 53% of the total for grapes (mostly outflow), 87% for asparagus (predominantly inflow) and 66% for mango (only outflow). The average pumping duration is around 2.2 h.

3.3.2. Irrigation inside the polder

The frequency of watering is not only governed by the climatic and crop demand and by net seepage loss in the plots, but also by the type of crops: trees with well established root systems (coconut, mango, citrus, etc) are often not watered and take advantage of the underground irrigation created by pounding water in the ditches. Smaller trees (guava, rose-apple, etc), or the former ones when they are still small, are periodically watered. Vegetables, of course, require frequent watering.

Fig. 8 displays the distribution of all the irrigation operations in the grapes plot along the 10 months, together with the rainfall pattern and the cropping calendar (in the

Table 2
Frequency of inflows and outflows by plot

Plot	Frequency of flows (time/week)	Frequency and % of inflows and outflows	Frequency and % of gravity and pumping
Grapes	3	Inflow: 1.6 (53%)	Gravity: 1.3 (44%) Pumping: 0.3 (9%)
		Outflow: 1.4 (47%)	Gravity: 0.1 (3%) Pumping: 1.3 (44%)
Asparagus	2.6	Inflow: 1.5 (59%)	Gravity: 0.2 (7%) Pumping: 1.4 (52%)
		Outflow: 1.1 (41%)	Gravity: 0.2 (6%) Pumping: 0.9 (35%)
Mango	1.5	Inflow: 0.5 (34%)	Gravity: 0.5 (34%) Pumping: 0 (0%)
		Outflow: 1.0 (66%)	Gravity: 0 (0%) Pumping: 1.0 (66%)

background). The frequency and duration of bed irrigation are shown in Table 3. High discrepancies are evident, with asparagus receiving water 2.6 times a week, grapes 1.3 and mango as little as 0.4. Requirements, of course, vary greatly between seasons: in the dry season, asparagus is irrigated every 2 days and grapes almost every 3 days, whereas weekly frequencies are as low as 1.4 and 0.5 during the rainy season. The duration of water application is quite regular, around 1 h 30′ for grapes and asparagus (i.e. 20 m length/mn), longer for the mango plot, which beds are watered with an older and less powerful pump and for which a higher amount of water must be brought, demanding a slower pace of the boat.

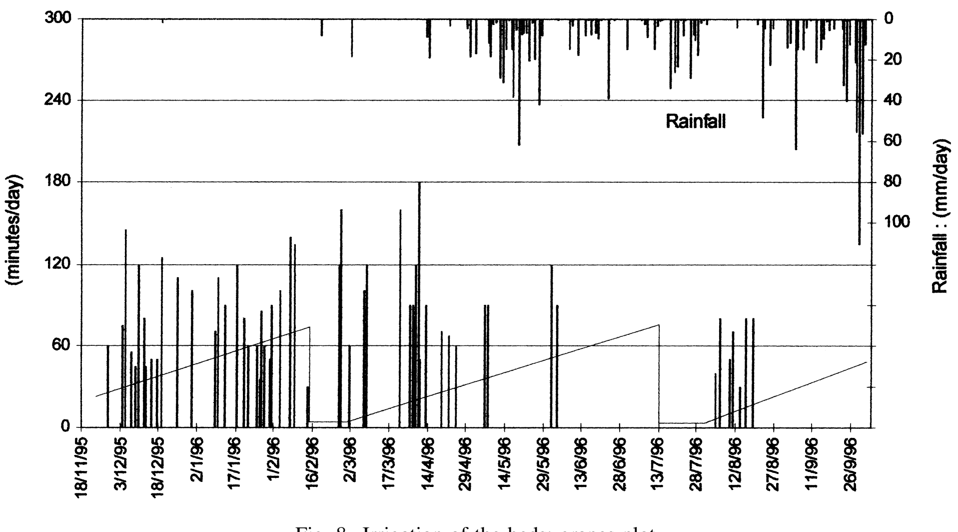

Fig. 8. Irrigation of the beds: grapes plot.

Table 3
Frequency of plot irrigation

	Season	Grapes	Asparagus	Mango
Frequency of plot irrigation (times/week)	Rainy season	0.5	1.4	0.1
	Dry season	2.1	3.8	0.7
	Whole year	1.3	2.6	0.4
Average volume by irrigation	m^3	38	37	63
	mm/soil area	5.5	5.2	9
	Water depletion in ditch (mm)	9.3	7.5	13

However, the last line of Table 3 shows that the irrigation doses are quite small (between 5.2 and 9 mm, on the average), let alone the percentage of water which does not infiltrate into the soil and flows back directly to the ditch. This contributes to the explanation of why irrigation frequency is rather high. We will see later, however, that there is no evidence that such a high frequency is really necessary.

Fig. 9 shows that the water level inside the bed (as given by two sensors, A and B) dovetails very neatly the fluctuation in the ditch. The level in pitch B corresponds almost perfectly to the one in the ditch. When a sudden drop of the water level occurs in the ditch, sensor A shows a lag-time of approximately 24 h in the response of the water level in pitch A. This is probably due to heterogeneity in the soil hydraulic conductivity.

It is also worth noting the effect of bed irrigation. The two sensors respond on the spot to watering and record water levels a few centimetres higher than in the ditch. This is most probably attributable to the infiltration of surface water along the PVC tube which raises the water level near the sensors.

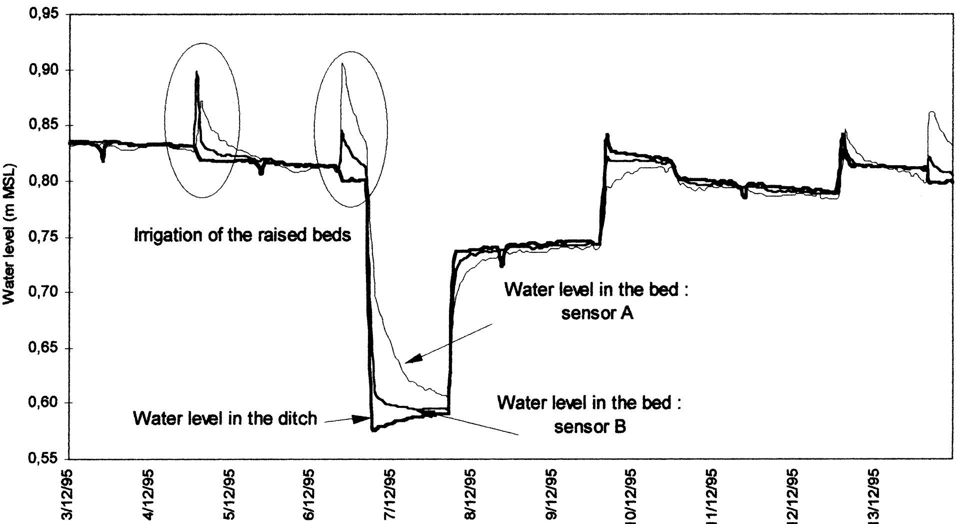

Fig. 9. Ground water fluctuations in the grapes bed.

The soil characteristics are, therefore, very favourable to a controlled water regulation because farmers can visualise the inner water level by only looking at the outer one. This is not the case in raised beds located in heavy clay soils, in which the water table may show high dynamic discrepancies with water in the ditch (Chareansiri and Yingjajaval, 1989; Chareansiri, 1991).

In order to assess farmers' practices, the soil moisture in the beds was monitored. It was noted that irrigation seems too frequent and unnecessary, as it was carried out even when soil moisture was around 5 centibars, while it is considered that no stress occurs under 30 centibars.

3.4. Water balance and consumption

3.4.1. Equation of the water balance

The water balance equation of the polder over a given period (in volume) is:

$$\Delta V = \textit{inflow} - \textit{outflow} + \textit{net seepage} - \textit{Percolation} - (\textit{water evaporation} + \textit{crop ET})$$

Controlled inflows and outflows are expressed in terms of duration (pumping) and variation of the plot water levels (recorded by the sensors). These values can be transformed into volumes using the pump discharge or geometric relations between the water area, the stored volume and the water depth in the ditch. These have been calculated as:

$$S\,(\text{water}) = 0.057 + .455^{*}h\,(\text{asparagus})\ \ (h > 0.70m)$$
$$\Delta v = 0.057\Delta h + .455^{*}(h\Delta h + \Delta h^2/2)$$
$$S\,(\text{water}) = 0.079 + .591^{*}h\,(\text{mango})\ \ (h > 0.40m)$$
$$\Delta v = 0.079\Delta h + .591^{*}(h\Delta h + \Delta h^2/2)$$
$$S\,(\text{water}) = 0.081 + .397^{*}h\,(\text{grapes})\ \ (h > 0.45m)$$
$$\Delta v = 0.081\Delta h + .397^{*}(h\Delta h + \Delta h^2/2)$$

where h is the (absolute) water level in the ditch (m MSL), Δh a given increase of h, Δv the corresponding increase of the water volume; S is expressed in ha, Δv in m^3.

3.4.2. Climatic data and evaporation

The average air temperature was rather stable, around 27°C (with a daily amplitude of 8–10°C), except for the December–March period, when it lowers a few degrees. Air humidity was more variable, especially during a 24 h period, with a maximum (at night) always close to saturation (100%), while the minimum usually varies between 40% and 60%.

Potential evapotranspiration has been estimated based on the Ivanov formula which gives ET in mm/month through $\text{ET} = 0.0018 \times (25 + T)^2 \times (100 - \text{RH})$, where T and RH are average values of temperature and air humidity. The choice of the formula was governed by the available data, although this formula has been developed for drier areas[1].

[1] The Thornthwaite and Blaney–Criddle formulas, based on temperature, gave unacceptable values (higher than Class A tank values).

Ditch evaporation appeared to be always lower than the plot Class A Pan. Evaporation in the ditches was 10% lower than in the Class A pan (mostly because the temperature in the pan is higher than in the ditch), while ET is 74% of the Class A pan only.

Percolation, as estimated from the comparison of the twin tanks, has been computed at 3% of the evaporation rate. Seepage is, on the contrary, a term of very significant magnitude. In accordance with the Darcy law, we expect it to increase with the difference of water levels between the canal and the plots. This relates to seepage coming from (or going to) the main canal. However, as the average difference of water levels between the plots is also significant, seepage between plots must also be taken into consideration. It appears that the average seepage flow to the mango plot, which comes both from the canals and the adjacent grapes plot, totals an equivalent of 2.27 mm/day, or 5.5 mm/day, if expressed in terms of area of the sole water body. This explains why, in some instances, the water level in the mango plot keeps on rising, seepage being higher than the evapotranspiration in the plot.

3.4.3. Consumption

Water consumption in the plot comprises the evaporation (EV) from the water body (ditches) and the evapotranspiration (ET) from the beds. While (EV) can be assessed from pan data, (ET) could eventually be estimated as the remaining term of the water balance, the plots functioning like large scale lysimeters. Lateral seepage, however, appears to be a very significant term of the water balance which cannot be assessed with precision (only a few soil analysis have been done and there is no knowledge about the incidence of possible cracks in the dry season). However, ET – or the crop coefficient to the Class A pan – have been computed for short periods in which the plot water level was close to the outside ones (making seepage negligible), except for mango. For asparagus, the crop consumption (ET + EV) coefficient was 0.81 to the Class A Pan and 1.15 to ET [Ivanov], while the overall plot consumption appears similar to Class A pan evaporation. This value is exactly the one observed by Sutassanamarlee (1993), who found a 1.01 coefficient between asparagus and the Class A pan.

Evapotranspiration in the grapes plot was computed at 6.2 mm/day on the average, which is slightly higher than the Class A pan. This rather high consumption is coherent with the particular structure of the grapes crop, which offers a flat canopy to the sun and can be swept by the wind both over and underneath. As the ditches are permanently shaded, it was also computed that, for an hypothesis of the real ditch evaporation being 50% lower, crop consumption rises from 6.2 to 7.3 mm/day, while the crop coefficient with the Class A pan would be 1.22 mm/day.

3.4.4. Overall water balance

An overall water balance over 9 months is made difficult by the imprecision stemming from uncontrolled flows, mostly pipe leakage and seepage. However, a series of inflows and outflows, considering both gravity and pumping, has been constructed by filling in a few missing data based on the geometric relations given earlier and on average discharge laws for pipes and pumps. Coefficients for crop consumptive use (related to the Class A pan values) have been taken as 0.94, 1.2 and 1.0 for mango, grapes and asparagus,

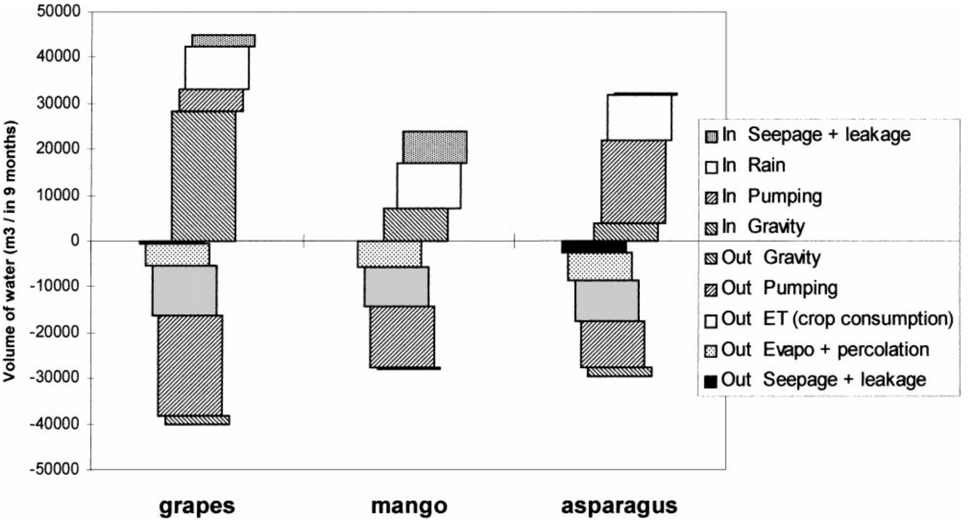

Fig. 10. Overall water balance (9 months).

respectively. Seepage between the canal and the different plots has been estimated by the Darcy law, using the daily head between the different units.

The breakdown of the overall water balance is shown in Fig. 10: a first striking lesson is that plot consumption (ET + EV) only amounts to around 50% of the inflow, and even less for grapes (40%). The magnitude of the seepage flows also sticks out, especially for the mango plot. It will observed that the totals of in and outflows do not exactly match. The inflow is 10% higher than the outflow for grapes and asparagus, whereas this is reversed for mango. This imbalance is probably due to an underestimation of seepage and of the flows occurring because of bad pipe closure.

Table 4 provides extrapolated values for a complete year: the plots are found to consume an amount of water close to 20 000 m^3/year. In comparison, rice double cropping, with an estimate of 8000 m^3/crop in the dry season, including land preparation, and about 60–70% of this value in the rainy season, corresponds to a net plot consumption around 14 000 m^3/year. If we consider that the raised beds produce and are watered almost the year round, such consumptions appear of the same order of magnitude.

Table 4
Magnitude of inflows and outflows over a complete year

Crop	Plot consumption (m^3)	Plot consumption per ha (m^3)	Volume of water transferred in 1 year (m^3) (inflow + outflow)	Volume of water transferred in 1 year/ha (m^3) (inflow + outflow)
Grapes	20 968	19 061	104 979	95 436
Mango	19 395	16 298	64 235	53 979
Asparagus	20 510	16 812	76 572	62 764

Table 5
Frequency and quantity of agro-chemicals applications

	Grapes	Asparagus	Mango
Number of pesticide treatments	84 (in 135 times)	44	20
Number of applications of fertiliser	20	25	5
Total N/P/K (chemicals), kg (October 1995/August 1997)	586/784/440	561/512/74 + cow dejection	Incomplete data

The total plot water intake is much higher than plot consumption, pointing out to a low efficiency of water use. This efficiency concept, however, appears to be highly scale-dependent as losses imputed to upstream areas are reused by downstream areas (Molle et al., 1997): this makes efficiency at the regional level of the raised bed area appear, in contrast, very high as there is almost no loss from the system (negligible percolation, reuse, efficient water control by the surrounding dikes and regulators).

Another salient aspect is the magnitude of flows between the plots and the canal, and the proportion of pumping. The grapes plot, for example, registers a yearly exchange-flow (12 months) with its environment amounting to almost 100 000 m^3! A very significant part of this flow is moved by pumping, especially in the asparagus plot where pumping accounts for half of a total flow of 76 000 m^3.

3.5. Water quality and pest management

3.5.1. Agro-chemicals application

Pesticide application is widespread and frequent in this area with intensive agriculture. Grape is probably the crop which is sprayed with the highest frequency, upto every second day in the wet season. As shown in Table 5, it received 84 treatments during the 10 months of the survey, and these have occurred over 135 applications (as the farmer will often spray only half of the plot in 1 day)! Asparagus receives, on an average, one pesticide application per week, this frequency being halved for mango. This rather strenuous task is made easier by the use of a network of pipes laid on the trellis. Agrochemicals are diluted and mixed with water in a 25 m^3 tank, from which the liquid is distributed under pressure in the pipes.

As for fertiliser, quantities applied appear to be extremely high, even considering the three periods of production per year (Table 5): grapes, in particular, receive 586/784/440 kg of N/P/K[2]. A frequent renewal of water, with subsequent loss of elements, partly accounts for this apparent overuse. Various other products are also used, including metals and hormones to induce flowering.

3.5.2. Aspects of water quality variability

Water quality in the plots is obviously altered by all the inflows and outflows, together with the use of agrochemicals. Degraded water quality is visually sensed by the farmer (it

[2] These totals are approximate: some fertiliser (such as 'FirmGrow' in the grapes plot), is powder to be diluted and sprayed: the composition, but not the concentration, is indicated on the box. An important amount of other elements (Ca, Ferous elements, Boron, Zinc, etc.) is also used.

turns greenish) who will periodically renew it. In the grapes plot, where this is very intensive, yields are reported by some farmers to be significantly higher on the rows located near the canal than on the remote ones. One explanation reckoned by the farmer is that water in the most remote areas is less renewed than in the ones located near the outlet, which makes its average quality worse with time. Some parameters were checked to substantiate these assumptions.

Values and variations of pH and dissolved oxygen (DO) were first observed every hour during 24 h. The daily amplitude of DO in the grapes was around 100%, while plot values were two to four times higher than in the canal, and significantly higher (15%) in ditches located far from the canal than in the ditches close to it. pH also showed higher values in the plot than in the canal.

BOD_5 is a significant parameter to express the quantity of degradable organic matter in the water. Values in the canal are also lower than in the plots, and plots' values are slightly higher for remote parts, suggesting that cultural practices deteriorate the water quality, probably through the contamination by a xenobiotic compound, either a pesticide or a plant stimulation compound.

Electric conductivity (EC), does not vary much around an average of 1 mS/cm. Only the grapes plot shows some locational differences, with distant-from-canal areas having EC values 15% higher than near-canal ones. Absolute values, however, are quite high and may create some accumulation of salts in the beds. It is not clear whether this salinity is induced by the sea through the (rather attenuated) tidal effect or has its origin in the alluvial sediments or upstream areas.

Phosphorus and COD in the canal and the plot do not show significant differences. Nitrates seem to be higher near the canal than away from it, and in-depth than near the surface. For an average water volume stored in the ditches of the grapes plot of 2000 m^3, a concentration of 0.2 mg/l, as found for P and N (for both ammonium and nitrate) gives quite high average storage of elements in water: 400 kg.

4. Conclusions

Flows between the canal and the plots are achieved either by gravity or by pumping: this is governed by the relative water levels in the canal and in the plots. The proportions of flows by pumping or gravity are very crop-specific, as farmers tend to regulate the average water level in the plot according to the crop root system. Inflow by gravity is possible most of the time in the grapes plot, while in the asparagus plot pumping-in largely predominates. All controlled inflows in the mango plot are by gravity.

These inflows and outflows are provoked for several reasons which appear to be much more diverse than only providing canal water to the plot: renewal of bad water, removal of excess water created by seepage or a bad closure of the pipe, raising the water level to allow a convenient use of the small boats used to irrigate the beds, or decreasing it to help inducing flowering in fruit trees, etc. The frequency of such flows is also very crop specific, ranging from 1.5 times/week for mango, to 2.6 and 3.0 times/week for asparagus and grapes.

Overall consumption has been found close to what could be expected from a combination of open water and beds with full supply to the crop. ET is not excessive (almost always lower than 4 mm/day), which is partly due to a high level of humidity in the air, especially at night when it is close to saturation, and to average temperatures generally under 30°C. For the whole year, the three crops are found to consume around 18 000 m^3/ha, almost 50% more than rice double-cropping, but for a whole year round production. In addition, re-use of water, permanent water in the canal and a high water table create conditions for an extremely high regional water use efficiency, only partly offset by direct evaporation in the numerous water ways.

The share of plot consumption within the plot balance, appeared much less than one could expect. For the three plots on the average, crop consumption amounts to only 15% of the total flow (inflows and outflows), stretching to 23% if the evaporation in the ditch is considered too. It corresponds to approximately one-third of the outflow from the plot.

A striking feature is the absolute amount of water which makes up the yearly In/outflow in the polder. In the grapes plot (1.1 ha), around 100 000 m^3 are exchanged between the plot and its environment.

The controlled inflows in the mango plot are by gravity but of lesser magnitude than in the other plots: this is because renewal of water for poor quality reasons is not so frequent and because the magnitude of in-seepage is as high as the total controlled inflow: while percolation has been found to be almost negligible, seepage through the dikes (along the canal but also between plots) appears to be a very significant contributing factor, but also a disturbing one as regards to establishing a water balance.

Plot irrigation appears to be very wittily conducted: questions remains, however, on the real necessity of the rather high frequency of watering, given that even with limited doses, soil wetness is always kept very high above limits supposed to trigger irrigation.

Water quality sticks out as a major issue in the water management of the raised beds (Sutthi, 1998). Water quality in the canal does not appear to be degraded, while water quality in the plots is directly correlated to the amount of agrochemicals used, which is the highest in the grapes plot. Intensive flushing out to renew water is responsible for a dramatic loss of nutrients. This helps explaining the abnormal quantity of fertiliser used.

Poor water quality also impacts negatively on yield. This is particularly sensitive in the grapes plot, where differences of productivity between the beds close to or far from the canal are sizeable at view. Higher water renewal near the outlet than in remote areas, where movements of water are reduced, is probably responsible for variations observed in several variables: DO, pH and BOD5 did not prove significant and it still remains to understand which factors are responsible for yield decrease in the grapes, with a closer look at the impact of pesticides on micro-fauna and micro-flora.

The skill demonstrated by farmers, however, is noteworthy: this includes sound knowledge of adapted land development, the design of ingenious devices such as the double-purpose fixed pump, the small boat equipped with sprinklers used to water the beds or the pipe network to distribute pesticide or liquid fertiliser under pressure.

It appears that daily care and attention is required for a good management, which demands numerous minor adjustments or operations. The total pumping time, for 10 months, is 94, 239 and 233 h for mango, grapes and asparagus, but is distributed in more than 210 separated operations. The 463 h of bed irrigation also represent 183 operations (in 10 months). This generates a cost for farmers although it appears to be largely offset by the economic return of the cash crops planted.

Farm economics showed some surprises, with a yearly net income above one million baht (i.e. US $50 000 over 3.5 ha, or half of it with post-crisis rates), and a significant share (73%) taken by grapes. This, of course, makes diversification in raised bed systems very attractive (Cheyroux, 1996). Other research is being currently conducted to determine the driving forces and constraints, both physical and socio-economic, governing the expansion of such systems which already encompass around 100 000 ha in the Central Plain of Thailand and represent an impressive agricultural wealth.

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