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Economic assessment of water saving irrigation methods in longan production in Northern Thailand

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Abstract
With a total acreage of more than 100,000 ha longan (Dimocarpus longan Lour.) is the most important fruit crops cultivated in northern Thailand. With flowering and main fruit development taking place during the dry season, irrigation is needed to ensure high yields and optimal produce quality. Water for irrigation is an increasingly scarce resource in the region as a whole. For the single farmers irrigation is related to high energy costs for pumping. Deficit irrigation strategies present an interesting alternative to increase water use efficiency (WUE), wherever water is a limiting factor to production. Therefore, at Mae Jo University, Thailand in cooperation with Hohenheim University, Germany, deficit irrigation strategies are tested in tropical fruit tree orchards and evaluated with respect to yield and plant responses to drought stress. Over two years of field experiments it was documented, that under “partial rootzone drying (PRD)” high yield can be obtained with 33% reduced irrigation water use.

Responding to farmers' request, a farmer controlled experiment was set up, where conventional irrigation was compared to deficit irrigation under field conditions. 200 trees have been split in to three groups: a. Farmer's irrigation (control), b. Optimised irrigation based on open pan evaporation and c. PRD with 60% of calculated optimal irrigation, alternately applied to different parts of the rootzone. Irrigation frequency and water consumption was recorded during the irrigation period. Total yield and yield per tree was measured, as well as fruit size and colour, as the most relevant quality parameters. Based on this data and under consideration of the current market prices for longan, an analysis of the economic suitability of deficit irrigation was carried out. The specific costs of irrigation were calculated under different scenarios regarding energy costs and possible water prices.

It was shown, that mainly the reduced costs for pumping make deficit irrigation attractive to farmers. Despite slightly lower yields, PRD was more cost effective due to energy savings. Different scenarios of water pricing offer institutional instruments to promote water saving irrigation practices.

Keywords: PRD, deficit irrigation, pumping costs, fruit tree irrigation

2. Introduction

With a total acreage of more than 100,000 ha longan (*Dimocarpus longan* Lour.) is the most important fruit crop cultivated in northern Thailand (Office of Agricultural Economics, 2006). With flowering and main fruit development taking place during the dry season, irrigation is needed to ensure high yields and optimal produce quality. Water for irrigation is an increasingly scarce resource in region as a whole. For the single farmers irrigation is related to high energy costs for pumping. The situation is more severe as many farmers produce off-season during the whole dry season (Poulpongpan, 2005).

Deficit irrigation strategies present an interesting alternative to increase water use efficiency (WUE), wherever water is a limiting factor to production. Successful attempts have included deficit irrigation methods like reduced deficit irrigation (RDI) or partial root zone drying (PRD) to improve WUE in various crops (Mitchell et al., 1991; Hutton, 2000; Kang et al., 2002; de Souza et al., 2004; Wahbi et al., 2005) with a concomitant increase in fruit quality (Bussakorn et al., 2000, 2001; Pickering et al., 2002; dos Santos et al., 2003; Spreer et al., 2005). PRD, as one of the irrigation techniques being used, is thought to reduce plants' water consumption by enhancing abscisic acid (ABA) in the drought stressed half of the roots, a hormonal signal controlling the stomatal aperture, hence reducing transpiration of the leaves (Davies et al. 2000, 2002, Stoll et al., 2000). Hereby, the well-watered half of the root system ensures the maintenance of fruit growth, while the vegetative growth is reduced (Dry et al. 1995, 2000).

At Mae Jo University, Thailand in cooperation with Hohenheim University, Germany, deficit irrigation strategies are tested in tropical fruit tree orchards and evaluated with respect to yield and plant responses to drought stress. In two years of field experiments with longans it was documented, that under PRD high yields can be obtained with 33% reduced irrigation water use (Ongprasert et al., 2006). However, an economic analysis on the benefits of water saving, so far, has not been carried out. Thus, the present study shall mainly focus on the economic viability for farmers in northern Thailand to apply deficit irrigation.

3. Materials and Methods

3.1 Experimental set-up and irrigation

The experiment was carried out in a 9 ha commercial longan orchard on a deep sandy loam soil close to Ban Hong, Lamphun province, Northern Thailand (18.30° N, 99.05° E, 300 m a.s.l.). A total of six hundred 15-year-old trees are planted in a 9 x 9 m pattern. Irrigation water is pumped to the orchard from two 80 m deep tube wells by use of two submerged multistage centrifugal pumps, powered with electro-motors and delivered to the trees by use of permanent hand-set sprinklers. During flowering (February 2006) twelve rows with a total of 200 trees with uniform in-season flower were selected for this study. Three irrigation treatments (Table 1) were randomly applied to four rows each. As the number of the trees in each row varied, the total number of trees in the four rows of each of the three treatments were 60, 78 and 62, respectively. Irrigation was applied from flowering (mid of February) until harvest (mid of July).

Farmer's irrigation (FI) was applied with owner's previously established sprinklers. Quantity and timing of irrigation depended on the farm keeper's decision. Optimal irrigation (OI) was applied with newly established micro-sprinklers. The number of micro-sprinklers per tree was adjusted to apply the required water within approximately two hours. Thus, five to ten of sprinklers were used for each tree, according to tree size. Irrigation was applied twice a week on approximately 90 % of canopy area. In the PRD treatment three to six sprinklers per tree were used. Irrigation was applied to one side of canopy area, while the other side remained without irrigation. After two weeks the wet and the dry side were changed. The optimal amount of irrigation was determined as gross water requirement (GWR) as crop evapotranspiration (ET_c) divided by the application efficiency (η_{irr}) of 85%. ET_c was calculated based on 10-year average open pan evaporation data, following the method of DOORENBOS et al., (1979). The calculated GWR was 883 mm. Effective rainfall was determined by total rainfall divided by a constant, 0.80.

Table 1: Overview on irrigation treatments applied to longan trees in the time from February to July 2006

	Farmer's Irrigation (FI)	Optimal Irrigation (OI)	Partial root-zone drying (PRD)
Number of trees	60	78	62
Sprinklers			
- type	mid-range sprinklers	Micro sprinklers	Micro sprinklers
- flow rate (L h^{-1})	800	125	125
- throwing width (m)	4	2	2
- sprinklers per tree	1	5-10	3-6
Scheduling	Farmer's decision	Twice per week	Twice per week
Wetted area (% of canopy)	80	90	50
GWR – effective rainfall (mm)	426	426	426
Irrigation events	18	14	14
Irrigation water applied (mm)	181	387	273

The number of irrigation applications in all treatments was recorded. In order to monitor the application rate in the FI treatment, three flow meters were installed close to the respective sprinkler nozzles. The average measured application quantity was multiplied with the number of sprinklers to obtain the total amount of irrigation water applied. Reading took place once per two weeks. The quantity of water used in OI and PRD was derived from number and duration of the applications multiplied by the number of sprinklers. The flow rate was obtained from the producer's data sheet and own tests. Daily rainfall data were obtained from Ban Hong Agricultural Office, about 4 km distant to the experimental side. Irrigation was skipped when there was enough rain. The rain in the later period of the experiment (April and July) amounted to 570 mm. This was 42 % above the 44 year-average of the area (Hydro.& Water Mgt. Centre, Upp. North, 2006). Thus, only 387 and 273 mm of irrigation water was applied in 14 times of two-hour duration for OI and PRD treatments, respectively. However, the actual application was 10 % over the intention, due to the calculation of the sprinkler heads used was rounded up to integer. In farmer's irrigation 181 mm of water were applied in 18 times with the duration of approximately one hour with irregular intervals.

3.2 Yield and fruit quality analysis

Fruit yield was recorded individually for each tree. One hundred fruits from each tree were sampled to determine hundred fruit weight (hfw). Fruits were sieved and sorted into fruit grades, according to Department of Agriculture of Thailand (2006).

In Thailand fruit colour – apart from fruit size – determines the price. The brighter colour is an important quality parameter in separating longan for table consumption from fruits, which are used for processing and, thus, obtain a lower price. The desired yellow colour is called "Lueang Tong" (golden yellow). However, no standard, expressed as chromaticity value, has been established. Separation is done visually, comparing different groups of fruits before harvest. In this experiment colour determination was done by use of a colorimeter (Colour Redder CR-10, MINOLTA, Japan). As higher L values indicate the brighter yellow tone of the fruit colour, which is more concordant with “Lueang Tong” colour, the L value has been chosen as an indicator for better colouring of the fruits.

The analysis of variance of the relevant data was done by use of SPSS 11.5 computer program (SPSS Inc.).

3.3 Energy requirement for pumping

The energy used for pumping of water (E_{pump}) was calculated according to equation (1),

$$E_{pump} = \left(\frac{H_{sys} * Q}{\eta_{pump}} \right) * t_{appl} \qquad (1)$$

The required total flow rate (Q) was the cumulative flow rate of all sprinkler in one treatment. The application time (t_{appl}) was approximately two hours for OI and PRD and one hour in FI. The pump efficiency (η_{pump}) was assumed to be 70%. The system head (H_{sys}) was calculated as the sum of different head components:

$$H_{sys} = \Delta h_s + h_v + h_b \qquad (2)$$

Data on ground water level and draw down were obtained from the owner of the orchard. An average static pumping height (Δh_s) of 45 m was taken as base for calculation. Friction losses and pressure requirement at the sprinkler nozzles at an average flow rate (Q) of 3 L s^{-1} were calculated as 20 m and 10 m, respectively.

4. Results

4.1 Yield and yield components

The fruit yield per tree in the PRD treatment was slightly lower than in the other treatments. However, this difference was statistically not significant, whereas the hundred fruit weight of OI and PRD were significantly higher than in FI. There was no difference between OI and PRD with respect to fruit weight. The L value of fruit colour was significantly higher in OI than in FI and PRD (Table 2).

Table 2: Yield of longan trees from different irrigation treatments, harvested in July 2006

Treatments	Yield (kg/tree)	100 fruit weight (g)	L value of fruit color
Farmer Irrigation, FI	152.20a	988.00a	41.73a
Optimum Irrigation, OI	155.47a	1,096.79b	42.87b
PRD	130.58a	1,102.74b	42.01a

The average values of the same column, which fallowed by the same letter were not statistical different by DMRD method at 0.05 probability.

The most important difference among the irrigation treatments was found in the fruit size. FI resulted in a distinctly lower percentage of ‘AA’ graded longans and a higher percentage of ‘B’ as compared to the other two treatments. PRD resulted in slightly lower percentage of fruits graded as ‘AA’ and slightly higher share of ‘B’ as compared to OI. But the differences were not statistically significant (table3). A good price can only be obtained for longans of grade ‘AA’.

In Thailand, longan are commonly sold “on the tree” to middlemen, who organize harvest, packing and transport. The fixation of the price is done before harvest by visual estimation. In this experiment the percentage of big fruits in the FI treatment was too low for being marketed, so that the middleman refused to harvest them. A price assessment is therefore not possible, even though sample trees have been harvested in order to obtain information on yield and fruit quality. The following economic assessment was therefore only carried out in comparison between OI and PRD.

Table 3: Fruit size composition in different irrigation treatments

Treatments	Grade AA (%)	Grade A (%)	Grade B (%)
Farmer Irrigation, FI	2.80a	51.41a	45.79a
Optimum Irrigation, OI	18.26b	57.96a	23.78b
PRD	12.72b	57.25a	30.03b

The average values of the same column, which fallowed by the same letter were not statistical different by DMRD method at 0.05 probability.

4.2 Cost of energy for irrigation pumping

In order to assess the economic benefit of the two irrigation strategies, two scenarios were calculated for in-season and off-season production, with respect to energy costs for water pumping. In two scenario calculations the actual present electricity price in Thailand and the double of that price, respectively, were used as data base.

Table 4: Cost for pumping irrigation water in different irrigation strategies with different prices for electricity

	In-season		Off-season	
	OI	PRD	OI	PRD
Period	Feb - Jul		Nov - May	
Pan Evaporation (E_{pan}), mm	1,039		1,116	
Crop water requirement (ET_c), mm	750		806	
Gross water requirement(GWR), mm	883		948	
Effective Rain mm	283		138	
Irrigation, mm	600	360	810	486
$m^3 ha^{-1}$	5,929	3,558	8,004	4,803
Kw-h ha^{-1}	1729	1038	2335	1401
Present electricity price, € Kw-h^{-1}	0.0833		0.0833	
Energy cost at present price, € ha^{-1}	144	86	195	117
Yield, kg/ha	17,592		14,074	
Average price, € kg^{-1}	0.117		0.521	
Income, € ha^{-1}	2,058		7,332	
Energy cost saving by at present electricity price, € ha^{-1}	58		78	
The pay off of PRD's energy cost saving by the percentage of yield reduction, %	2.82		1.06	
Pay off of PRD's energy cost saving by the percentage of yield reduction, in the case of double electricity price, %	5.64		2.12	

In addition, the scenarios were also calculated for the case of extreme shortage of water for off-season production, November – May, which periodically occurs at the coastal regions of South-East Thailand. This region is well known for its highly commercialised fruit production for both, domestic and export markets. Once in a while the extreme drought in April and May causes severe water shortage affecting the last 2 months of off-season longan production, as well as other in-season produced fruits, such as durian and rambutan. In such a case additional water for irrigation has to be carried by trucks from various sources of water, often more than 10 km away from the orchards. Cases are reported when the cost water arose to about €1 per cubic meter. Based on this, an extreme scenario was calculated, assuming that local water sources within the orchard were able to supply only a half of GWR of the two months. Thus, an additional 50% and 10% of GWR, for OI and PRD respectively, had to be taken from the outer sources.

Table 5: Cost for irrigation water under conditions of extreme scarcity

	OI		PRD
Water cost in the case of extreme shortage, € ha^{-1}	1,068		213
Income, € ha^{-1}		7,332	
The save of water cost by PRD, € ha^{-1}		855	
Pay off of PRD's water cost saving by the percentage of yield reduction, %		11.66	

Even though an extreme case of water scarcity and abnormally high prices, it illustrates the influence of a possible water price on the economic viability of water saving irrigation methods, to the extend that targeted withdrawal of water becomes economically interesting.

5. Conclusion

The rain in Ban Hong district during the experimental period was exceptional high. However, the deficit of water during the early fruit development in March and April and the last three weeks before harvest distinctly affected the fruit size and colour of longan in FI, while it did not affect longan in PRD, in comparison with OI. Rainfall must be considered to be one reason that yield and fruit size of PRD were not statistically less than those of OI. However, own results from previous years show, that under PRD yield and fruit size of longans do not suffer, even under conditions of more severe drought. Thus, after two successful years of applying PRD in longan under field conditions, it can be stated that the technique is a solid alternative to optimised irrigation under limited water availability. This was an important assumption when assessing the economics under extreme drought. Further research is needed on a physiological level, in order to assess plants reaction to different water availability and long term development. Biomass production, pruning requirements and plant fitness, which have not been examined in the context of this study, must be further investigated.

Where water is fully available in the orchards, PRD can save electricity costs. Considering the present price level, costs for water pumping can be reduced by €58 and €78 per hectare for in- and off-season cropping, respectively. These amounts of money equal to the cost of 2.82 and 1.06 % of income in the two cropping seasons, respectively. Therefore, PRD will pay off provides that it do not cause the income reduction by these percentages. In the case the electricity price was double, these percentages would rise to 5.64 and 2.12 %, respectively. Thailand is a net importer of fossil fuels and energy production is highly dependent on world market prices. Over the last years, energy prices in Thailand have increased dramatically. If the present trend prevails, a further doubling can be expected in less than 10 years. It is therefore, that commercial farmers are increasingly interested in production methods which can lower their energy requirement.

Where water is only in part available in the orchards themselves, as in the case of the extreme drought in South-east Coast of Thailand, PRD is able to save out source water costs by €855 per hectare. In this case PRD pays off if it does not cause an income reduction of more than 11.66%.
In conclusion, PRD has shown to be an economically interesting irrigation technique, which can save water and electricity costs under the prevailing economic conditions in Thailand and has a further potential to become more profitable with a shift of prices, making the relation between energy costs and revenues for agricultural produce less favourable. Though beyond of the scope of this study it has to mentioned, that the potential for water and electricity savings may have an

impact on a macro economic level and the promotion of deficit irrigation strategies might have a positive impact of the agricultural production in the whole region. Respective studies have to be carried out in order to assess socio economic impacts on a larger scale and provide appropriate information for decision makers.

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7. Literature

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