A review of 15 years of oil palm irrigation research in Southern Thailand.

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The climate in Southern Thailand has a regular dry season, with 3 to 4 months of soil water deficit, and Univanich started commercial irrigation of oil palms in the late 1980s. Research trials have compared irrigation methods, quantities of water applied, and interactions with fertilisers, and the responses of different breeding materials.

A comparison of four irrigation methods (sprinkler, microsprayer, furrow and drip) showed no significant differences in yield responses, though there was a suggestion that drip might be superior to the other methods, and drip was also preferred on grounds of operating costs and ease of management. Some practical aspects of drip installation are discussed in the paper. There were significant irrigation x fertiliser interactions, and with increased fertiliser inputs, the response to irrigation was more or less linear, reaching 10 t FFB/ha.yr at 6.4mm rainfall equivalent (450 litres/palm.day). The yield response to irrigation based on a calculated water deficit depended on the severity of the dry season. The response in any one year was related to the water deficit in the first quarter of the year, and also to that two years earlier; a multiple regression explained 91% of the year-to-year variation in yield response.

Results from progeny trials duplicated with and without irrigation show that some progenies appeared to be more sensitive to drought, and gave larger responses to irrigation, than others. This could give breeders the option of selecting drought tolerant material for planting in areas where irrigation is not possible, or irrigation-responsive material for sites where irrigation is intended.

Keywords: Elaeis guineensis, water deficit, economics, fertiliser, irrigation

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Univanich Palm Oil Public Company was the first company to grow oil palm (*Elaeis guineensis* Jacq.) in Thailand, with the first planting in 1969. The climate in Southern Thailand where the plantation is situated has a regular dry season, with 3 to 4 months of soil water deficit (*Figure 1*), and it was clear that this was a limitation for yield. Univanich started commercial irrigation of oil palms in the late 1980s, installing over 600 ha of furrow irrigation. This method was adopted because it had a low capital cost and was simple to operate, but it was recognised that it might not be the best method, and research on irrigation commenced at the same time as the commercial developments. The first trial, established in 1990 (Trial DIR90), examined different rates of drip irrigation. Early results were promising, but in a review of other irrigation trials Corley (1996) suggested that responses to drip or microsprayer irrigation might be smaller than to methods where the entire soil surface was wetted, such as sprinkler or flood irrigation. A possible reason for this was the observation that oil palm stomata may close when atmospheric humidity is low (large negative values of vapour pressure deficit – VPD) (Smith, 1989; Dufrene & Saugier, 1993). A trial to compare different methods of irrigation was therefore set up, commencing in 1993 (Trial MIR 93). Results of these two trials were presented by Palat et al. (2000). Following that review, the original DIR 90 drip trial was modified to investigate higher irrigation rates, and fertiliser application by fertigation was introduced. In recent trials the responses to irrigation of different breeding materials are also being investigated.

In this paper we discuss choice of irrigation methods, quantities of water to apply and interactions with fertilisers, and practical aspects of installation and operation, based on the yield responses and other results obtained from the trials mentioned above. Full trial descriptions were given by Palat et al. (2000). In all trials, irrigation was started when the potential water deficit (difference between pan evaporation and rainfall) exceeded 30 mm.

*Figure 1*  
Rainfall, evaporation and water deficit at Univanich, 1994-2005
METHOD OF IRRIGATION

Trial MIR93 commenced in 1993, and compared four methods of irrigation, each at three rates, 120, 240 and 360 litres/palm/day (1.7, 3.4 or 5.1 mm rainfall equivalent per day). The methods of irrigation were:

- Dripplers – 9 above-ground dippers per palm, operating every day,
- Sprinklers – one for every 2 palms (72 sprinklers per hectare); wetted area about 90% of total; operated every third day,
- Microsprayers – 2 per palm; wetted area about 28% of total, operated every second day, and
- Contour furrow irrigation – water pumped to the top of the slope, and allowed to spread over the soil surface by overflowing from one furrow to the next, applied every third day.

There were no significant differences in yield between the four methods of application (Table 1).

<table>
<thead>
<tr>
<th>Method</th>
<th>Yield (FFB/ha/yr)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate of irrigation (litres/palm/day)</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Unirrigated control</td>
<td>19.5</td>
</tr>
<tr>
<td>Drip</td>
<td>-</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>-</td>
</tr>
<tr>
<td>Microsprayer</td>
<td>-</td>
</tr>
<tr>
<td>Contour furrow</td>
<td>-</td>
</tr>
<tr>
<td>Standard error</td>
<td>-</td>
</tr>
<tr>
<td>Mean, all methods</td>
<td>19.5</td>
</tr>
</tbody>
</table>

* Mean (tonnes fresh fruit bunches/ha.yr) for 4 years, 1996-1999 (from Palat et al., 2000)

It has been shown in many oil palm irrigation studies that the main response is in bunch number, and the results in these trials have confirmed this (Palat et al., 2000). It is two years or more before effects of irrigation on inflorescence sex ratio are reflected in harvested bunch numbers (Corley & Tinker, 2003); so the first two years after installation were excluded from the analyses.

Averaged over all methods, the response to 360 litres/palm/day (equivalent to 5.1 mm) was no greater than to 240 l/palm (3.4 mm), and the method x rate interaction was not statistically significant. As there were no significant differences in yield between methods, we decided that the choice of method should be based on practical considerations, which included the following:
i. Microsprayers were expensive to install and to operate; they were fragile, and easily damaged in the course of routine field operations such as harvesting and pruning.

ii. Sprinklers required a larger and more expensive pump than drip or furrow irrigation. We know that oil palm stomata close in dry air, and the expectation was that sprinklers might overcome this by wetting all the soil surface, and humidifying the atmosphere. However, the yield response obtained was no greater than from other methods.

iii. Contour furrow irrigation was cheap to establish, but operation required constant supervision to ensure that water did not leak from the channels, which would result in parts of the field remaining unirrigated. The furrows also interfered with mechanised field operations.

iv. Drip irrigation had similar capital cost to sprinklers, and lower operating cost because a smaller pump was needed. It proved simple to operate, with no obvious practical disadvantages.

The conclusion, therefore, was that drip irrigation was the best method. This is valid for Univanich soils (Typic Paleudults), but might not apply to all soil types. In some crops, there is said to be rapid drainage loss from dippers on sandy soils.

**EFFECTS OF DRIP IRRIGATION ON YIELD**

The first trial on drip irrigation was trial DIR90, which commenced in 1990. This trial had only a single guard row around each plot, and it appeared that there was some poaching of water by the unirrigated control plots from adjacent irrigated plots. Yields were therefore compared with additional external control plots, established near to but outside the experimental area. If yield was increased by irrigation, it was anticipated that fertiliser requirements might also be increased. Trial DIR90 therefore included two levels of fertiliser input: the ‘normal’ commercial rate, as applied to unirrigated fields, consisting of 3 kg ammonium sulphate, 3 kg potassium chloride, 1.5 kg ground rock phosphate and 1 kg dolomite per palm per year, and double this normal rate.

Although the methods x rates interaction in trial MIR93 was not significant, the data suggested that the response to drip irrigation might be greater than to other methods at the highest level tested (*Table 1*). Based on this observation, the treatments in trial DIR90 were modified in 2000 to investigate higher rates of irrigation. The lower rate of 150 litres/palm/day was increased to 225 litres/palm/day. The higher rate of 300 litres was increased to 450 litres/palm/day. At that stage, fertigation was introduced instead of manual application of fertilisers. Results of both phases of the trial are summarised in *Table 2*. Note that the standard errors should not be used for comparisons with the external control plots, because the controls were not randomised with the other plots. The internal controls yielded 22 t/ha in both phases of the trial.
Although the fertiliser x irrigation interaction was not significant in the overall mean yields, the interaction was significant in some individual years, and as shown in Figure 2 a definite trend towards greater irrigation response at the high fertiliser level was evident. At the lower fertiliser level, the average response in Phase 2 for both irrigation treatments was 7 t FFB/ha/yr, but with high fertiliser combined with the high irrigation level it was about 10 t/ha/yr. Results in phase 1 were similar, with slightly lower yields (Table 2). The fertilisers applied were a standard mixture, as described earlier, so as yet we have no evidence as to which nutrient (or nutrients) gave the additional response. This is a subject for further investigation.

### TABLE 2

**YIELD WITH DIFFERENT LEVELS OF Drip Irrigation, Trial DIR90**

<table>
<thead>
<tr>
<th>Irrigation (l/palm/day)</th>
<th>Yield (t/ha/yr)*</th>
<th>Normal Fertiliser</th>
<th>Double Fertiliser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 1993-1999</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2 2002-2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 (external control)</td>
<td>17.7</td>
<td>17.6</td>
<td>19.8</td>
</tr>
<tr>
<td>150</td>
<td>22.3</td>
<td>24.3</td>
<td>22.9</td>
</tr>
<tr>
<td>300</td>
<td>23.0</td>
<td>25.0</td>
<td>26.0</td>
</tr>
<tr>
<td>standard error</td>
<td>0.75</td>
<td>0.84</td>
<td>0.75</td>
</tr>
</tbody>
</table>

* tonne FFB/ha/yr - data for phase 1 are from Palat et al., 2000

**Figure 2** Yield responses to irrigation, with and without extra fertiliser, in phase 2 of DIR90 (2002-2006) (external unirrigated controls)
In effect, three trials on drip irrigation have been done: MIR93, and phases 1 and 2 of DIR90. Results of these three trials are compared in Figure 3. The response to irrigation is approximately linear, up to the highest rate tested (450 litres/palm/day, equivalent to 6.4 mm/day rainfall).

The response to irrigation must clearly depend on the severity of the dry season; the average dry season potential water deficit (PWD) at Univanich from 1995 to 2005 was 235 mm (cumulative pan evaporation minus rainfall). To give an indication of the relationship between PWD and yield response, we looked at the yearly responses to the higher level of irrigation in DIR90 (combining data from both phases). The correlation with PWD 2 years earlier (allowing for the time-lag between sex differentiation and bunch harvest) was significant ($r = 0.758^*$, 7 d.f.). There was also a significant correlation with PWD in the same year ($r = 0.644^*$, 9 d.f.), which we assume to result from effects of irrigation on inflorescence abortion. A multiple regression of yield response against potential water deficit in the same year (PWD$_0$), one year earlier (PWD$_{-1}$) and 2 years earlier (PWD$_{-2}$) accounted for 91% of the variation in yield response ($Y_{inc}$) from year to year:

$$Y_{inc} = 0.0146 \cdot PWD_0 + 0.0191 \cdot PWD_{-1} + 0.0250 \cdot PWD_{-2} - 6.7 \quad (1)$$

**Figure 3** Comparison of responses in three drip irrigation trials

Note: The line is a regression through all data points shown. For DIR90, the unirrigated data are from the external control plots, and the irrigated data are from the plots receiving double the normal rate of fertiliser.
Actual yields are compared with predictions (from equation 1) in Figure 4. The model, based only on water deficits, predicted larger responses in phase 2 than phase 1. Thus some of the difference in response between the phases (Table 2) may be due to differences in dry season severity, rather than to the increased irrigation rates. This needs further investigation. It would probably be better to base irrigation on management of the water deficit, rather than simply applying predetermined amounts of water.

Comparisons with other work are difficult, because most oil palm workers have used the ‘IRHO’ method to describe water deficit. This was originally developed for estimating likely average yields at new sites where the only data available were rainfall figures, and is not really suitable for describing deficits in irrigation trials or in individual years. Several assumptions are made in the method: evapotranspiration is taken to be 150 mm/month if there are less than 10 rain-days, and 120 mm in wetter months. Soil available water capacity (AWC) is assumed to be 200 mm (but actual values can be substituted if available). The most dubious assumption is that the palms suffer no stress until soil moisture has been completely exhausted; in their discussion of irrigation Corley and Tinker (2003) noted that this is “plainly not true”.

*Figure 4* Actual yields in trial DIR90, for 1997-2005, and predicted from equation 1 (phase 1 includes transition period, 2000-2001)
Corley (1996) reviewed irrigation responses in relation to IRHO water deficits, and found that with deficits of up to 300 mm, responses approximated to the relationship described by Caliman (1992), but adjusted for fully irrigated yield of 30 t/ha rather than 22.1 t/ha. This relationship was:

\[ Y_{inc} = 0.0288 \times WD \]  

Assuming an AWC of 100 mm (typical of the top 1 m of similar Typic Paleudult soils in Malaysia – Foster et al., 1984), the average IRHO deficit for Univanich over the experimental period was about 227 mm (the assumed evapotranspiration figures are greater than the actual pan evaporation observed at Univanich, which partly compensates for the assumption that there is no stress until AWC is exhausted). From equation 2, a yield response to irrigation of 6.5 t/ha would be expected, which is close to the observed responses (see above). The response predicted from equation 1, with a mean PWD of 235 mm, was 7.1 t/ha. Our results appear to be in broad agreement with other oil palm irrigation studies, therefore.

The question of the optimal amount of water to apply will usually be better thought of in terms of the optimal way to use limited water resources. Assuming that the response to a unit amount of irrigation diminishes at higher rates, the total yield response should be greater from irrigating a large area with partial replacement of evapotranspiration (Eo) than from fully irrigating a smaller area. However, Palat et al. (2000) found that it was more profitable to fully irrigate a small area. This was because the capital cost of the system is the same per unit area, whether partial or full irrigation is done, and the return on capital was therefore greater with full irrigation. In practice, it appears that, with high fertiliser inputs, the response to irrigation may be more or less linear to more than 5 mm/day (Fig. 3), which approximates to complete replacement of Eo (mean pan evaporation during the dry season at Univanich was 4.2 mm/day).

**PRACTICAL ASPECTS OF IRRIGATION**

**Installation**
In trial DIR90 a pipe was buried along every row of palms within 1 m of the palm trunk, with 4 drippers per palm at 1 m spacing. Burying the pipes this close to the palm caused considerable root damage, and yields were depressed for the first 2 years after installation (data from that period were excluded from the analyses).

In trial MIR 93 a pipe was buried 2 m from each palm row, and no initial depression in yield was noted. Drippers were spaced at 1 m intervals along the line.

In DIR 90 there was some evidence that palms in unirrigated plots could take water from adjacent irrigated plots, despite a guard row surrounding each plot. It has also been shown that palms can take up radioactive phosphate from 36 m away (Zaharah et al., 1989). Thus for future projects, we consider that it should be quite adequate to install a single line of drippers between alternate rows of palms, so that every palm has a dripper line on one side.
Where young palms are to be irrigated from soon after planting, we have used a coiled dripper line around each palm; each line is 15 m in length, with drippers of 2 litres/hour capacity spaced 20 cm apart. Initially the pipe is laid on the soil surface close to the young palm; as the palm grows, the pipe can be moved to increase the diameter of the circle, and the pipe can be buried outside the weeded circle as the palms come into bearing.

A choice needs to be made between a small pump and small pipes, with a long irrigation time, or a larger pump with higher pressure, and a shorter irrigation time. This will depend on costs and practical aspects.

Irrigation scheduling
In all trials so far, we have started irrigation when the calculated potential water deficit (PWD; i.e. rainfall minus pan evaporation) exceeds 30 mm. As yet, we have not attempted to measure the ‘critical deficit’, beyond which the palms start to suffer stress, but on shallow lateritic soils in Malaysia it was less than 60 mm (Henson & Chang, 1990; Henson, 1991). In Ivory Coast, on a deep, sandy soil with available water content of 250 mm, the critical deficit appeared to be about 175 mm (Rey et al., 1998). From equation 1 we can estimate that a PWD of less than 101 mm should not reduce yield. Thus it appears possible that by using a PWD of 30 mm as the signal we may have started irrigation earlier than necessary, but this figure was adopted to try to ensure that at the higher irrigation rates the palms did not suffer any stress. Starting irrigation a few days too early will not make a great difference to overall costs, but it is important to use limited water supplies as efficiently as possible, and determining the critical deficit should be a subject for further research.

Other methods for scheduling irrigation include using a porometer to measure stomatal conductance, or tensiometers to measure soil moisture. We have tested both of these methods, but they are much more laborious than the simple PWD calculation, with extensive sampling required to give reliable data. Schmitz and Sourell (2000) found that soil moisture measurements were too variable to be used for irrigation scheduling. Henson (1991) confirmed Smith’s earlier observation that oil palm stomata close when VPD is large (Smith, 1989); Henson also found that irrigated palms in dry air might have lower stomatal conductance than unirrigated palms in humid air. Thus one cannot define an absolute value of conductance below which irrigation should commence. We consider that porometry and tensiometers are impractical for commercial irrigation scheduling of tree crops like the oil palm, therefore, but porometry might be used, with care, to estimate the critical water deficit.

Fertigation
The response to fertiliser at the higher irrigation level was very similar in both phases of DIR 90: 3 t/ha/yr in phase 1, and 3.2 t/ha.yr in phase 2 (Table 2). This suggests that the switch from separate application in phase 1 to fertigation in phase 2 made little difference. If that is so, then the choice of application method would depend on costs. Bhat et al (2007) found no significant difference in yield between fertigation and manual application in a trial with arecanut, but concluded that costs would be lower and profits greater with fertigation. It may be noted that trials on frequency of application in oil palm have generally shown no benefits from applying fertilisers more than once a year; Corley and Tinker (2003) considered that this might be
because the palm itself has sufficient nutrient storage capacity to control short-term variation in availability.

ECONOMICS OF IRRIGATION

Effects of irrigation on oil content of bunches were small, with no significant differences in DIR 90, and a small increase in oil/bunch under drip irrigation in MIR 93 (Palat et al., 2000). For economic analysis, we have estimated oil yields using a constant oil/bunch figure for all treatments. However, factory records show lower oil extraction rate during the dry season, when most of the incoming fruit is from unirrigated areas. Also in progeny trials the oil/bunch from irrigated blocks tends to be slightly higher than from unirrigated, so a positive effect of irrigation might be expected. Thus the benefits may be slightly underestimated.

At the costs then prevailing, Palat et al. (2000) considered that drip irrigation would be very profitable at a palm oil price of US$400/t, and even at $300/t would give an internal rate of return (IRR) of 9%. Since then, the cost of diesel fuel in Thailand has tripled, and capital costs have also increased considerably. As a result, a palm oil price of US$500/t would be needed to give an IRR of 9%. Today’s price is much higher than $500/t, and there is no doubt that irrigation would be very profitable at present, but investors should look carefully at payback periods in relation to future price expectations.

The question of whether full or partial irrigation is more profitable is discussed above. However, we have not taken into account the cost of water. Where borehole or reservoir construction costs are high, or there are competing uses for water or irrigation rights must be paid for, then response per unit water applied may be important. If so, then the possibility of partial irrigation of a large area rather than full irrigation of a small area should be considered.

BREEDING OBJECTIVES

As part of the Univanich breeding programme, several progeny trials have been duplicated with and without irrigation. In the first of these trials, some progenies appeared to be more sensitive to drought, and gave larger responses to irrigation, than others (Rao et al., 2008). Such results will give breeders the option of selecting drought tolerant material for planting in areas where irrigation is not possible. It would also be possible to select ‘irrigation-responsive’ material for sites where irrigation is intended. Where the dry season is relatively mild, there may actually be little to be gained by selecting specifically for irrigation responsiveness. If irrigation is intended, selection can simply be for high yield, disregarding drought tolerance. This is, of course, what most programmes have always done in countries such as Malaysia, where the dry season is usually negligible. However, oil palms are now being planted in areas with up to 8 months of drought, with temperatures reaching 45 °C, and under such conditions large VPD may to cause stomatal closure, even with irrigation. Material selected for irrigation responsiveness in a dry environment may be the best option in such a situation.
CONCLUSIONS

Fifteen years of research on irrigation of oil palms in Thailand have shown that drip irrigation is the best system. Yield responses of up to 10 t FFB/ha are at least as large as with other systems, costs are comparable, management is relatively easy, and irrigation can be highly profitable. For maximum response to irrigation, fertiliser inputs must be increased, but it has yet to be ascertained which nutrient is critical. Where lower rates of irrigation are used, additional fertiliser may not give a response. Further work is needed to determine critical water deficits in Univanich soils, and in future irrigation may be based more on managing the water deficit, rather than applying a predetermined quantity of water.

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