NORTHERN TERRITORY MANGO IRRIGATION SURVEY: HOW MUCH FRUIT FROM HOW MUCH WATER?

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April 2012

Bibliography:

Bithell, S. L. (2012). Northern Territory Mango Irrigation Survey: How much fruit from how much water? Northern Territory Government, Australia. Technical Bulletin No. 341

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Technical Bulletin No. 341
ISBN: 978-0-7245-4749-4

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SUMMARY

This report presents the main findings of a survey of mango growers in the Northern Territory (NT) to benchmark current irrigation practices.

The survey included responses from 17 orchard managers who managed 25 separate properties. Irrigation volume records were sourced from meter readings, hours of irrigation and estimates based on descriptions of irrigation schedules and sprinkler application rates. There was uncertainty about the accuracy of estimated irrigation volumes.

A comparison of NT water use efficiency (WUE) values with those from Queensland indicated that irrigation of mango trees in the NT was relatively efficient, with 2.37 and 3.18 tonnes packed fruit per ha/ML of irrigation per ha for two of the most common cultivars. The use of WUE based on the level of production of class 1 fruit, was identified as a useful method for growers to establish a link between water use and economic productivity.

A number of growers reported above average yields from using low to moderate irrigation volumes. For other growers, there is scope to improve the efficiency of irrigation by such practices as calibrating sprinklers to understand actual applications per tree, improving soil water monitoring methods, determining an appropriate maximum irrigation depth and basing irrigation frequency and volumes on soil water-holding capacity. Such practice changes should be kept in mind when designing new systems. Using mango cultivars with high yield capabilities in new orchards will improve WUE.

Growers identified a number of areas where they required information to improve irrigation practices, including the effects of irrigation on fruit quality, partial root-zone drying and regulated deficit irrigation, the effects of cincturing on tree water requirements, soil type effects on water availability, the validity of a crop factor of 0.7 and the water requirements of cultivars other than Kensington Pride (KP). Addressing these issues will enable current growers to improve irrigation practices.

INTRODUCTION

The sustainable management and proper use of water resources for food production are important issues for Australia (Pigram 2006; Khan et al. 2009). To achieve these goals, the National Water Initiative has called for the implementation of water management plans (Anon. 2004). The NT has introduced water allocations for irrigators in some areas and has more plans under consideration (Anon. 2009a). Much of the irrigation water in the NT is from ground water (Anon. 2009b). Hence, the improved management of groundwater resources has been identified as a high priority (Anon. 2004). Concern for groundwater resources has led to the need for labelling the source of irrigation water used in mango production (Ridoutt et al. 2010).

In view of ongoing change and emphasis on more efficient water use in food production, a number of Australian agricultural industries, including tree fruit producers, have been involved in irrigation benchmarking initiatives to quantify current use levels and to identify where more efficient use of water can be made (Anon. 2002; Boland et al. 2006; Toll et al. 2008).

There is little current information on irrigation practices and water use by NT mango growers. Surveys (Kulkarni and Landon-Lane 1991) and on-farm monitoring (Diczbalis and Bowman 1991; Diczbalis et al. 1995) were conducted. Since then the mango industry has grown, particularly due to large plantings in the Katherine area (Moore 2009).

This Technical Bulletin presents the main findings of a mango growers' survey in the NT that was conducted to benchmark existing practices and recommend changes in practice.

IRRIGATION AND PRODUCTIVITY

A number of studies have demonstrated the importance of post-flowering irrigation to achieve adequate mango fruit yields in the NT (Anon. 1988; Kuppelwiesser 1990). Studies on preflowering irrigation practices showed that controlled droughting could improve flowering and fruit yields (Lu and Chacko 2000). Recent overseas work has also shown that the volume of irrigation post-flowering affects yield and that excessive volume can reduce yields (da Silva et al. 2009). Each of these studies has shown that mango productivity is strongly affected by irrigation practices.

BENCHMARKING

Benchmarking allows growers to measure and compare their performance with that of other growers. A study in Queensland highlighted a large range in irrigation volumes used in mango production (Anon. 2002). Another study showed a best practice group of mango irrigators produced above average yields by using lower than average irrigation volumes (Anon. 1999).

By linking water use to production levels, an increase in WUE can be viewed in terms of obtaining larger yields from the use of the same amount of water, similar yields from less water, or even larger yields from less water. A quantification of current use and productivity (WUE, as yield/irrigation volume (Doorenbos and Kassam 1979)) is required to provide a record from which future improvements in WUE can be gauged. This survey attempts to provide information that should allow a comparison to be made between actual mango tree irrigation and WUE in the NT.

METHOD

SURVEY METHODS

Orchard selection

A list of ten orchards in each of the Darwin and Katherine regions for the survey was sourced from the NT Mango Industry Association and DoR records of mango growers. Where possible, larger orchards were selected for the survey to maximise the area studied.

Survey method

Growers were asked by phone to participate; they were then interviewed face to face in the months prior to the 2010 mango-picking season. However, one grower was interviewed in January 2011. In late December, 2010 and early January, 2011 growers were requested by phone and email for the 2010 mango-season yields and irrigation volumes used. About 75% of growers were revisited, when a number provided additional information, up to February-March, 2011.

Survey procedure

An initial version of survey questions was trialled with one Darwin and one Katherine grower. Some questions were then modified to improve the information from responses. At the first meeting, the objectives of the survey and confidentiality management were explained. The growers were asked to sign a declaration for consent. A copy of the material along with the survey form is shown in Appendix 1. Growers were later provided with a copy of their consent form. Confidentiality protocols identified by the Human Research Ethics Committee of the NT Department of Health and Families and the Menzies' School of Health Research were followed. A list of participant names and an identification code for each name was secured. The code was the only identification used to identify respondents on survey sheets. The list of participant names with identification codes was then destroyed once the survey and requests for additional information had been completed.

The interviewer read the survey questions to the respondents and then noted the answers on the survey form. The responses were then recorded on a spread sheet and summarised. Some responses were later checked with respondents by phone or email.

As a number of respondents managed multiple properties, a separate survey form was filled for each property.

Some orchards had more than one cultivar and a range of tree ages and planting densities for each cultivar. In such cases, growers often provided an average mango yield across all cultivars for each property. For those properties, yield information for the predominant cultivar was requested. If yield information from the predominant cultivar included both mature and immature trees, yield information from mature blocks was requested; otherwise, the estimated yields from immature trees was excluded.

DETERMINATION OF IRRIGATION VOLUMES

A range of methods was used to determine irrigation volumes. Access to meter readings was requested for properties with metered bores. In some cases, properties with one cultivar of uniform age and all trees in production provided a straightforward indication of water use by mango trees. . Other cases were more complex where a single property had different cultivars, of different ages and some trees not in production, and which had various planting densities. In some cases, where the planting history was complex, growers were able to provide records of irrigation hours for specific blocks with common age trees, known planting density and yields. In other cases, farms had no water meters or had meters but also produced other horticultural crops or had substantial domestic use by pickers during the picking season, making it difficult to isolate mango tree water use from non-mango tree water use. Meter readings provided a monthly value for water use across a whole year.

Some growers did not wish to provide meter readings. Where meter readings or records of irrigation hours were not available, estimates were made using the irrigation schedule descriptions (see Appendix 2) where irrigation periods were identified by flowering or panicle emergence, depending on orchard practice and end of picking dates for the 2009 and 2010 season for each property. For example, for schedule number 9 as described below, flowering commenced on 2 June, 2009 and picking ceased on 20 October; the following year, flowering commenced on 5 June, 2010 and picking ceased on 22 September. For both years, this gave an approximate length of the main irrigation period (non-preflower irrigation and non-post-harvest irrigation) of 20 weeks. Schedule 9 below provides an example for estimating the irrigation method.

Schedule 9. An example of an irrigation schedule and estimated irrigation volumes

Schedule 9
Preflowering: total drought

At bud push leading up to flowering: top 40 cm bring to field capacity; this can take up to 8 h of irrigation.

Post-flowering: start 3 h/week, then increase through 2 x 3 h/week, to 3 h/at 3 day intervals (average 2.3 applications per week) to a final of 4 h/at 3 day intervals (average 2.3 applications per week) at maximum fruit fill prior to harvest. Timing of increases depends on wind and temperature. Early rainfall at the end of the season can lead to a reduced end-of-season irrigation.

Estimated irrigation volumes
The length of the main irrigation period for 2009 and 2010 was 20 weeks each.

The number of weeks for different periods of the main irrigation season was calculated on the basis of the lengths of different phenological intervals (Oosthuyse 1991) and the number of hours of irrigation occurring during these intervals (on a weekly basis) multiplied by the delivery rate of the sprinklers at that property, or a block within the property:

= (8 h+ (3 h x (1 pw x 5 w)) + (3 h x (2 pw x 5 w)) + (3 h x ((7/3 pw) x 5 w)) + (4 h x ((7/3 pw) x 5 w))) x 70 L/h for a 20-week irrigation season; h = hour, pw = times per week, w = week.

For this example, the estimated total irrigation volume was 11 060 L/tree.

This value was then multiplied by the number of trees per hectare to give total volume per hectare. In this case, the density was 244.8 trees/ha, which gave a value of 2.71 ML/ha for both seasons. The time from flowering to cessation of picking varied between years for most orchards. This example used the same interval for both seasons for simplicity.

For properties practising preflower irrigation, the number of weeks from 30 March to the flowering date in 2009 and 2010 was calculated. This date was based on preflowering irrigation start dates from a four-year trial in Darwin (Wicks et al. 1999). This value was used to estimate the number of weeks that preflowering irrigation occurred in each season. This value was added to the main production season irrigation volume value to provide a total L/tree and ML/ha for preflowering and main flowering to harvest irrigation volumes.

A number of properties, which did not provide meter readings or irrigation hours, used post-harvest irrigation. However, information on the timing of these applications in relation to early rains indicated that such practice was quite variable from year to year. No attempt was made to estimate post-harvest irrigation volumes for these properties.

DATA SUMMARIES

For questions regarding orchard and irrigation management, information from multiple properties supervised by a single manger was not duplicated, as it represented a single management strategy. Where orchards had a range of planting densities or yields from two or more differently sized blocks, weighted means were used to summarise this data.

The canopy surface area was calculated from a survey response regarding canopy diameter (in-row and across row) and height of trees. The surface area of a five-sided hexahedron based on these values was first calculated. A correction was then made for the area from the ground to the lower canopy (1 m).

In order to protect the confidentiality of growers, each cultivar, except KP, was given a number instead of its name. Also, data from Darwin and Katherine farms was pooled in order to reduce the chance of a grower being identified within a region.

For fruit quality, information from fruit quality assessments carried out at Berrimah Farm for another project (Moore et al. 2010) for the properties in the survey was used. The lenticel spotting values for these properties were also compared with irrigation volumes.

Due to the relatively small number of survey participants and the variable quality of irrigation volume and yield information, no statistical comparisons were attempted.

RESULTS

PARTICIPATION

Out of the list of 20 managers, 17 managers of 25 properties fully completed the survey interview; 13 properties were from the Darwin region and 12 from the Katherine region. In Darwin, one manager managed three properties and another managed four. Three managers from Katherine managed two separate properties each. In total, the survey included 2124 ha and 315 482 mango trees. In some cases, yields were provided for whole orchards with a single cultivar of similar age; in others, yield information was provided for specific blocks within an orchard due to different plant ages and/or the presence of multiple cultivars. The average area for yield information was 71 ha.

VIEW ON IMPORTANCE OF IRRIGATION

Managers were asked to categorise the importance of irrigation or irrigation scheduling on four aspects of fruit yield. Responses were received from 16, 16, 14, and 13 of the 17 managers to each of the four yield aspects, respectively (Table 1). Some managers provided responses different to the four options asked; the largest percentage for 'Other' was for the number of fruit (12.5%) (see Table 1). Fifty percent of managers considered irrigation or scheduling as very important to fruit number, similar percentages of growers considered irrigation as either not important (12.5%) or moderately important (18.8%). The majority of respondents viewed irrigation as either moderately or very important to the timing of fruit maturity. Of the four questions, the size of fruit had the least spread of responses with 86% considering irrigation as very important. In contrast, similar percentages of managers viewed irrigation as either moderately or very important to fruit quality.

Table 1. The response of managers when asked: How important is irrigation or irrigation scheduling to number of fruit, timing of fruit maturity, size of fruit and fruit quality

Growth stage or Yield component	Don't know (%)	Not important (%)	Moderately important (%)	Very important (%)	Other (%)
Number of fruit	6.3	12.5	18.8	50.0	12.5
Timing of fruit maturity	6.3	12.5	31.3	43.8	6.3
Size of fruit	0	0	7.1	85.7	7.1
Fruit quality	7.7	7.7	46.2	53.8	0

SOIL WATER MONITORING METHODS

The single most common method of monitoring soil water content was by using a shovel (24% of managers). In contrast, 36% of mangers used one of three electronic methods (Enviroscan, Diviner, G-bug) of monitoring soil water content (Table 2). Two managers also used both physical and electronic methods to monitor soil water content.

Eighteen per cent of managers did not use any soil water monitoring methods; one manager had used tensiometers in the past but was currently not monitoring soil water content; together 24% of managers were not using any soil water monitoring methods. Some of these growers who did not monitor commented that they may break the soil surface with their heel to check that sprinklers had operated, but did not know the depth of irrigation or soil moisture content at given depths before or after irrigation.

Table 2. Percentage responses for methods used to monitor soil water content for the 25 properties and by 17 managers

	Properties (%)	Managers (%)
Shovel	32	24
Enviroscan	16	18
Digstick or auger	12	18
Enviroscan and auger	4	6
Diviner and digstick	4	6
Tensiometers (not currently)	12	6
G bugs	8	6
None or heel of boot	12	18

A small study of soil water tension values was undertaken at two sites where no soil water monitoring was being carried out (Appendix 3). Results from this study were limited in scope but indicated that there could be large differences in the depth of irrigation between orchards.

Managers were asked if soil water results were used to check if irrigation was operating as expected or actively managed the irrigation. Thirty one per cent responded that results were used to actively manage irrigation volumes and 8% used soil water monitoring to check that the irrigation schedule was operating as expected. The largest percentage of managers (62%) responded that the soil water results were used for both active management and for checking performance.

Managers were asked a number of questions about soils (Appendix 1, Section 5a of the survey sheet). There was a general lack of knowledge on soil types; three managers were able to refer to soil maps or reports on soil types prepared by consultants. In general, there was an absence of knowledge of water infiltration rates or water-holding capacities of the soils at these mango orchards. There had, however, been work by consultants for two managers on three properties where estimates of the plant available water in the root zone had been identified for soil types.

IRRIGATION METHODS AND PRACTICES

The use of mini-sprinklers in orchards was universal; however, irrigation practices both within the main irrigation period (post-flowering to fruit harvest) and outside of this period differed between regions and/or orchards within a region.

Irrigation methods

Delivery

Sprinkler types and rate of water delivery differed between multiple properties under a single manager in three of four cases. Therefore, this information is based on a property as the basic unit. All surveyed properties with fruiting trees applied irrigation using micro-sprinklers; one property had young non-fruiting trees under drip irrigation. Two other properties (one in Darwin and one in Katherine) had drip irrigation trials that had been operating on the property for five to10 years. The most common delivery rate of sprinklers was

70 L/h (Table 3). There was a preference for growers to use sprinklers with high delivery rates as 80% had delivery rates 70 L/h or above and 20% had a delivery rate of less than 70 L/h.

Table 3. Summary of sprinkler irrigation delivery rates for 25 properties

Sprinklers(L/h)	No. properties	% of properties
20	1	4
40	3	12
50	1	4
70	10	40
85	2	8
90	3	12
94	2	8
100	1	4
105	1	4
120	1	4

Forty four per cent of properties reported using pressure compensating sprinklers, 8% did not have compensating sprinklers and the rest were unsure if their sprinklers were compensating or not.

Fifty three per cent of managers reported making calibrations of the delivery rate of their sprinklers. Two managers who had not carried out sprinkler calibration noted that they could monitor volumes applied by sprinklers by dividing the monthly volume of water used by the number of trees or by monitoring delivery pressures.

Irrigation scheduling

Schedule descriptions

A wide range of irrigation schedules was used by growers. For example, some growers had fixed irrigation programs throughout the post-flowering to fruit harvest season and others had changing schedules, depending on the stage of fruit growth, tree fruit load and seasonal conditions. It needs to be acknowledged that a number of growers, when asked for descriptions of schedules for ‘typical’ seasons, pointed out that there was no true ‘typical’ season due to changing conditions each year. Appendix 2 provides a brief description of these ‘typical’ schedules.

After describing their schedule, growers were asked if their irrigation schedules could be categorised as either: (a) set - same weekly amount applied across the irrigation season; (b) set with some variation; (c) changing, in relation to fruit growth, phenology etc.; or (d) changing in relation to changing soil moisture and environmental conditions across the season (Table 4). They were also given the option of choosing more than one category. One grower was unsure of differences between the categories and did not choose any description. Similar numbers of growers chose either schedule descriptions a, b, c or d as their schedule. Among growers who chose schedule (b), one said that variation was due to weather in one case or reductions in application volumes at the end of the season in another case. Forty four per cent of growers chose to combine schedule descriptions c and d; this combination represented the most common schedule.

Table 4. Percentage of managers who chose one of four options of schedules a, b, c and d descriptions from a) Set, gives the same amount to trees across the irrigation season; b) Set with some variation; c) Changing, in relation to fruit growth, phenology; d) Changing in relation to changing soil moisture and environmental conditions across the season, or chose multiple categories

Schedule descriptions	a	b	c	d	c and d
Percentage	12.5	12.5	12.5	18.8	43.8

Managers were asked to what depth of soil or root zone they wished to irrigate. Two growers indicted that they periodically (typically after the wet season) use deep irrigation (to ~ 90 cm) to flush soil nitrate below the root zone but that this was not their usual irrigation depth. The most commonly identified depth was 40 cm; but there was a wide spread of identified depths (Table 5). Almost a quarter of growers indicated that they had no information on the depth irrigation may reach.

Table 5. The depth of irrigation that 25 managers aimed to achieve

Depth of irrigation (cm)	Managers (%)
unknown	23.5
30	11.8
40	23.5
60	11.8
70	5.9
90	17.6
100	5.9

Growers were asked how they developed or designed their schedule. For example, was it based on long-term experience, use of consultants, government information or other sources (Table 6). The most common response was that they had developed the schedule from their own experience or experience and education. This may also have involved advice from other growers. The second most common response was that the schedules had been developed from their experience in combination with consultants.

Table 6. Information sources for developing irrigation schedules

	(%)
Own experience, own education or experience of other growers	50.0
Consultants	8.3
Government	8.3
Experience and consultants	25.0
Experience, consultants and government	8.3

Preflower and post-flower practices

The prevalence of preflowering irrigation differed between Darwin and Katherine; it was common in Katherine at 89 % (Table 7a). In contrast, in Darwin almost two thirds (63%) of growers did not irrigate during the preflowering period. The percentages of managers who also used post-harvest irrigation was the same as for preflowering irrigation; in Katherine, the same managers who used preflowering irrigation used post-flowering irrigation (Table 7b). This was not the case with Darwin managers, some of whom did not irrigate preflowering, but did so post-harvest and vice versa.

Table 7. The percentage use of preflowering irrigation (a) and post-harvest irrigation (b) in Darwin and Katherine

a) Preflowering irrigation

Region		Managers (%)
Darwin	Yes	37.5
Darwin	No	62.5
Katherine	Yes	88.9
Katherine	No	11.1

b) Post-harvest irrigation

Region		Managers (%)
Darwin	Yes	37.5
Darwin	No	62.5
Katherine	Yes	88.9
Katherine	No	11.1

Irrigation schedules and volumes over time

Information from descriptions of a 'typical' season's irrigation was plotted using flowering and cessation of harvest dates for the 2009 season for 12 properties in Darwin (Figure 1). A 'typical' season may not occur due to season-to-season variation in rainfall and other important environmental variables; however, the figure provides a general indication of the volumes per tree per week provided at different stages of the season for different types of schedules. The large range in volumes between individual properties following the initiation of post-flowering main season irrigation and differences in volume at different stages of the season highlights the operation of different irrigation schedules. Schedules differed in particular for the estimated volume applied during the final fruit-fill period. The flowering dates for cultivars at properties and differences between cultivars in the duration of the main season irrigation also had a large effect on the timing and duration of irrigation.

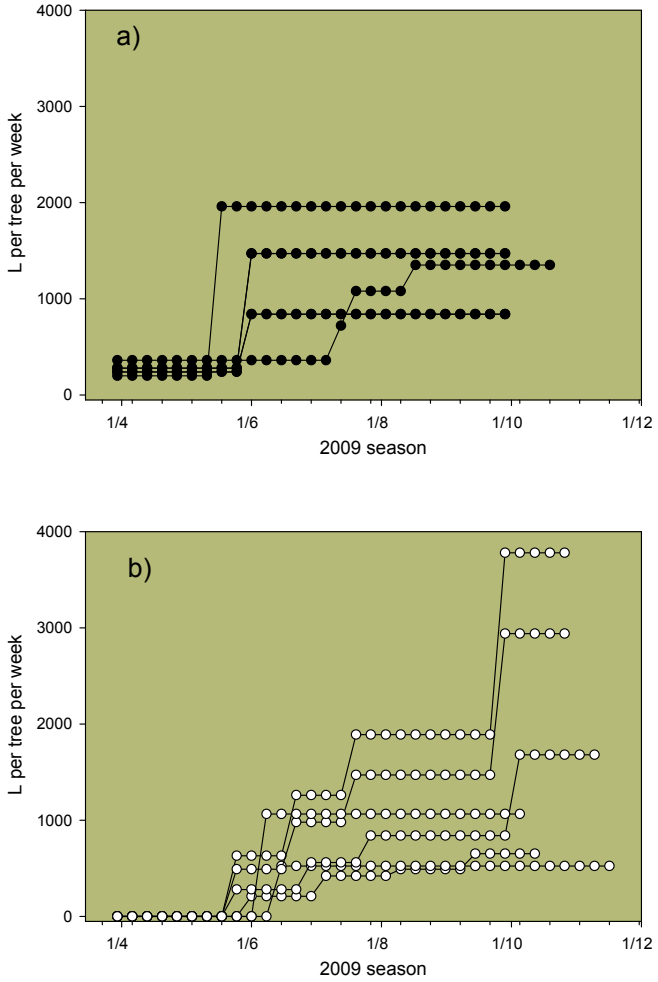

Figure 1. Estimated irrigation (L/tree/week) on 12 Darwin properties during the 2009 season for three mango cultivars from March (1/4) to December (1/12); (a) properties that provided some irrigation during the preflowering period; (b) properties that did not irrigate during the preflowering period – Note: short term events such as wetting up following droughting are not indicated.

IRRIGATION VOLUMES AND WATER USE EFFICIENCY

Estimated volumes

There were three information sources available for calculating irrigation volumes for separate properties: meter readings, records of hours of irrigation and estimates. No single property had all three sources available; the majority of properties had a single source of information available for estimating irrigation volumes.

Some growers were able to provide meter readings, which gave clear indications of irrigation volumes where single cultivar orchards had trees of uniform age and planting densities and no other fruit or horticultural operations were using metered water on the property. In some cases, meter readings were available for properties with trees of different ages (in production or not) or had different cultivars receiving different volumes of irrigation. In these cases, growers were required to provide information on how the proportion of water or watering hours differed between ages of trees or cultivars in order for irrigation volumes to be calculated for particular cultivars producing fruit. In some cases, meter readings reflected other operations using metered water. For example, in one case meter readings gave misleading information on mango irrigation for some months because large volumes of metered water were used for other uses during the

main irrigation season, such as resident seasonal mango pickers. In such cases, estimates were used. In two cases, meter readings were available but breakdowns or running problems with pumps or bore head works led to lower than the required application, considered insufficient for optimal irrigation. Values from such orchards were not included in WUE calculations.

Irrigation volumes for eight properties were based on meter readings in each season; for another two properties, records of irrigation hours were used for particular blocks within a property. For the remainder of properties (15) irrigation volumes were based on estimates.

Estimated vs. actual volumes

Estimates for four orchards were compared to determine how accurate meter values were (Figure 2). The results were mixed; estimates were close to actual figures at property 1 for the available 2009 data; the actual figure was higher than the estimated at property 2 for 2009. Problems were experienced in the 2010 season with the bore and pump at property 2. The readings for 2010 from this bore were considered reliable; however, the problems resulted in a lower than required volume during the peak irrigation season. Therefore, this value should be disregarded. For properties 3 and 4, actual values were lower than estimates in both years. The manager noted that 2010 in particular was an unusual year with 71, 151 and 132 mm of rain recorded at this property that season in September, October and November, respectively. As fruit harvest ends around the end of November at property 4, the rains from September to November had a large influence on actual irrigation volumes for the 2010 season. The 2009 season also had 99 mm of rain in September at property 4. Although data is limited, these results indicate that large rainfall events mean actual irrigation volumes for the 2010 season may have been substantially lower than estimates.

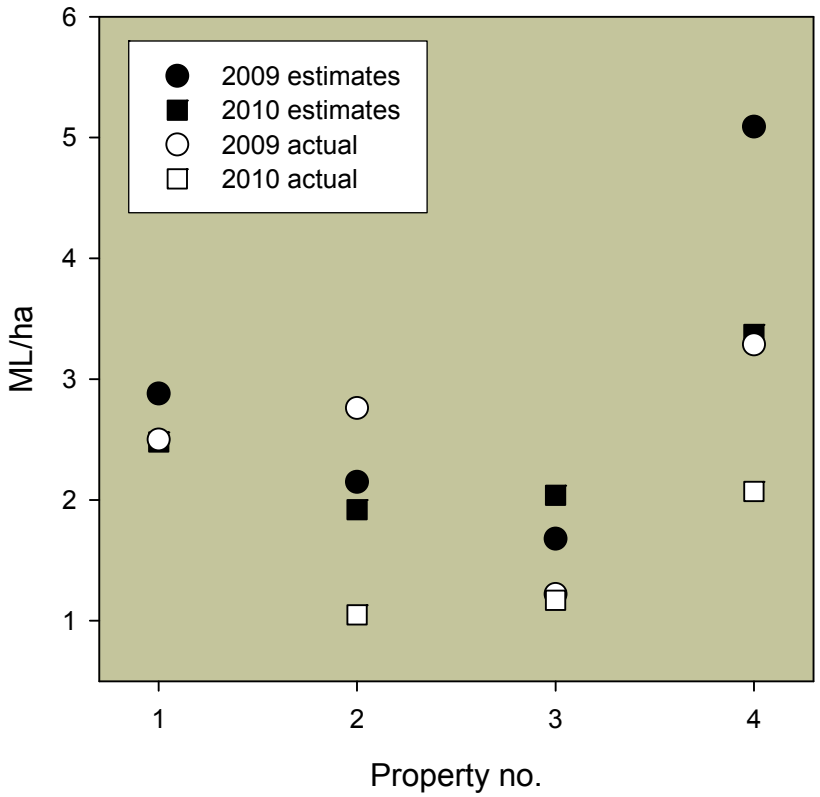

Figure 2. Estimated and actual irrigation (ML/ha) for four properties; actual values for properties 1 to 3 were from meter readings; actual values for property 4 were from recorded hours of irrigation; the meter failed at property 1 during the 2010 season

Water use and yields: water use efficiency

Water use and yields

A comparison of estimated or actual irrigation volumes to yields of packed mango fruit indicated no clear relationship between the volume of irrigation water and yield (Figure 3a), although a number of other factors, such as cultivar, tree density, tree age, exclusion of unpicked or reject fruit and seasonal variation in yields, may have affected these values. The presentation of the same orchard yields and irrigation volumes on a per tree level provided a comparison of WUE independent of differing tree density per ha (Figure 3b). The L/tree data also indicated no clear relationship between irrigation volume and yield. In both cases, there were orchards achieving high yields (greater than 10 t/ha or greater than 50 kg per tree) from relatively low irrigation volumes or relatively high irrigation volumes expressed as ML/ha or as L/tree. Figure 3 also included three properties, which had insufficient water supply in one season due to pump or bore operational problems.

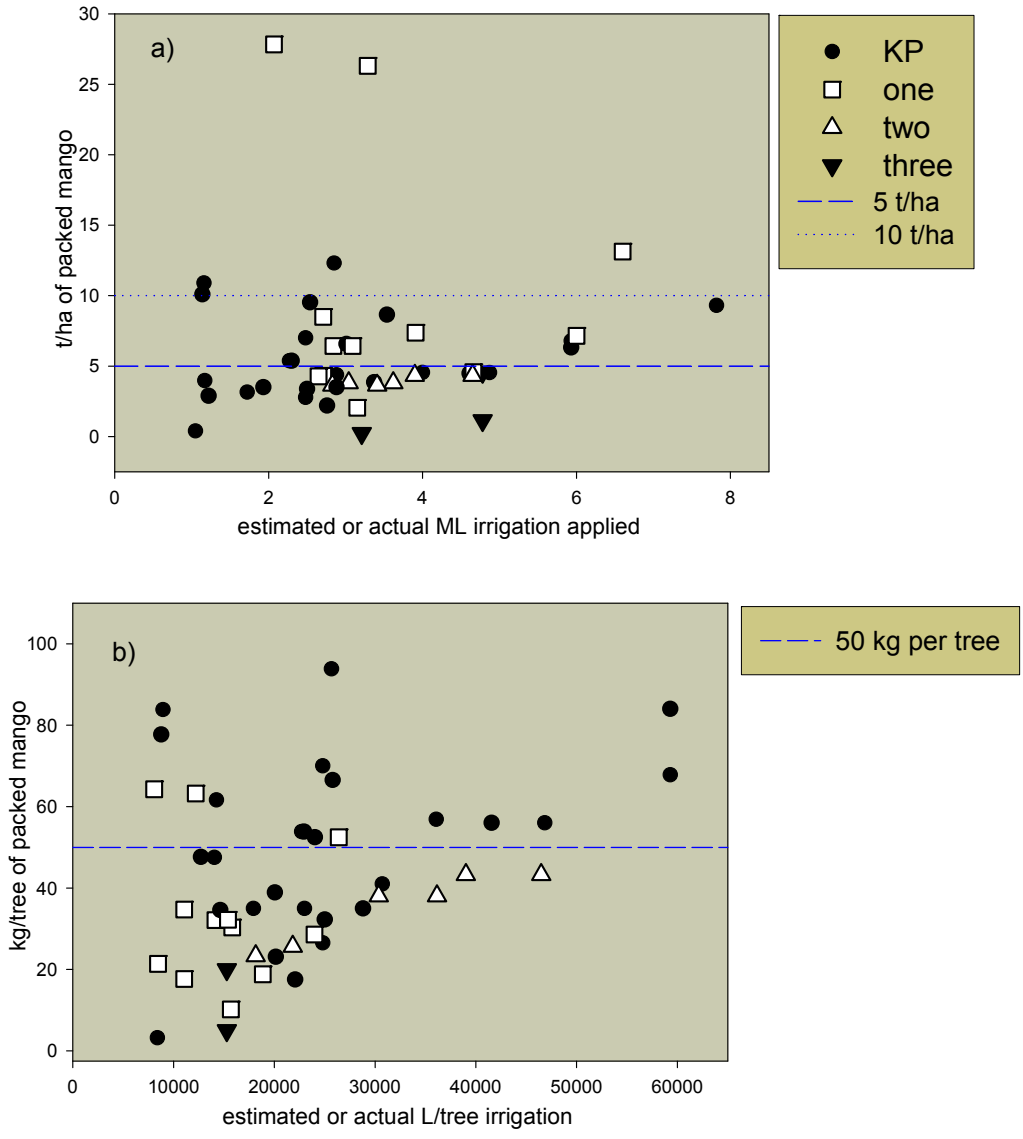

Figure 3. a) Estimated and actual irrigation (ML/ha) for packed fruit (t/ha) yields for four cultivars (KP, one, two and three) and two production thresholds (5 and 10 t/ha); b) Estimated and actual irrigation (L/tree) for packed fruit (kg/tree) and one production threshold (50 kg/tree), for all properties in the survey for both the 2009 and 2010 seasons

WUE values were calculated for three age groups of trees for the two most common cultivars from properties where yield and irrigation volume values were available for both seasons and which had no pump or bore problems (Table 8). WUE values for KP overall were 2.37 t of fruit/ML of irrigation water; in comparison, values for cultivar one were higher at 3.18 t of fruit/ML of irrigation water. A comparison between age classes of these two cultivars was restricted due to the different number of properties in each cultivar class.

Table 8. Water use efficiency (t packed fruit ha/ML ha of irrigation) for KP and cultivar one by tree age class averaged over both (2009 and 2010) seasons for 19 properties.

Cultivar	Age (years)	n	WUE, t fruit ha/ML
KP	< 8	1	0.79
KP	8-14	5	2.38
KP	> 15	8	2.56
		average	2.37
One	< 8	4	1.45
One	8-14	1	10.10
		average	3.18

Two alternative methods of presenting WUE in terms of the production of class 1 fruit (Figure 4a) and canopy surface area (CSA)/yield are presented (Figure 4b). There was less information from orchards on particular properties for class 1 fruit values than for all packed fruit, but for this method and the CSA/yield method there was again no clear indication of a causative relationship between irrigation volume and yield.

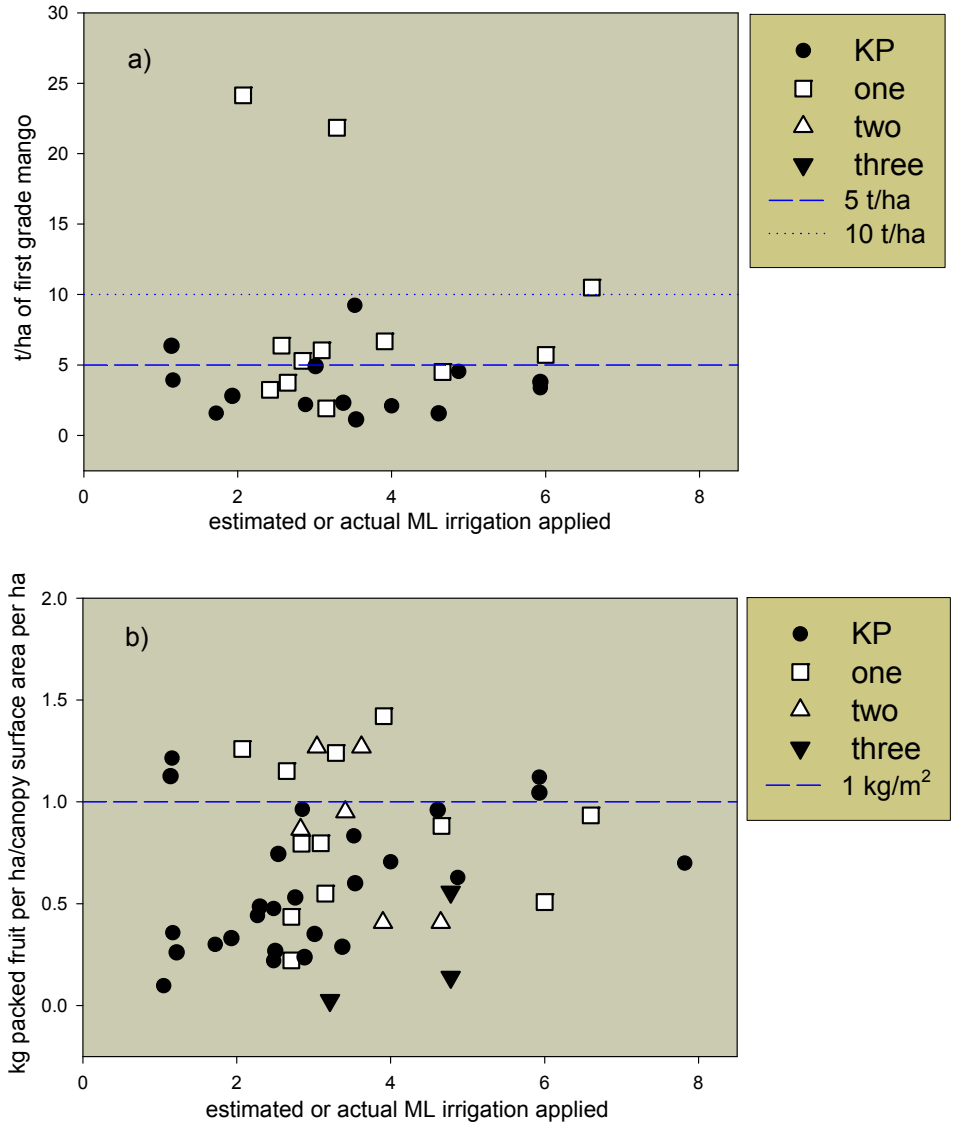

Figure 4. a) Yields of class 1 fruit (t fruit/ha) for four cultivars and two production thresholds (5 and 10 t/ha) and b) CSA/yield and a production threshold (1 kg/m^2 canopy) in relation to estimated and actual irrigation (ML/ha) for all properties in the survey for both the 2009 and 2010 seasons

Practices associated with above or below average yields

To evaluate the effects of irrigation practices associated with differing productivity, the results for the cultivar KP were used for trees over eight years old, for which there were 14 properties, seven in each region. Five of these properties had trees between eight and 14 years of age; the rest were over 15 years old (Table 9a); the older group of trees had slightly higher production levels. Overall, average fruit production was 6.4 t/ha and 53 kg/tree with a WUE value of 2.55 t fruit/ML irrigation water. Properties in Katherine had higher production and WUE values than those in Darwin (Table 9a). For other cultivars, there were too few properties with mature trees to allow a meaningful comparison.

Table 9. KP fruit production (packed fruit) for tonnes per ha, kg/tree, kg of fruit/m^2 of canopy area surface (CSA) and irrigation as ML/ha, litres/tree and water use efficiency (WUE) as tonnes of packed fruit ha/ML ha of irrigation for 14 producing properties grouped by (a) age of tree and (b) region

a)	Age (years)	n	t/ha	kg/tree	CSA	ML/ha	L/tree	WUE (t/ha)
	8-14	6	5.92	43.94	0.47	2.71	20212	2.38
	≥ 15	8	6.65	58.97	0.71	3.49	30100	2.66
		Overall mean	6.37	53.19	0.62	3.19	26297	2.55
b)	**Region**							
	Katherine	7	7.94	59.11	0.77	3.66	27250	3.11
	Darwin	7	4.39	45.23	0.42	2.53	24323	1.90

Of the 14 properties, two in Darwin did not practise preflowering irrigation. These two and another from Darwin as well did not practise post-harvest irrigation. The remaining 11 properties, four in Darwin and seven in Katherine, all practised both preflowering and post-harvest irrigation. As such, productivity and WUE comparisons were limited to properties from the Darwin region. Production/tree was very similar between the three groupings (Table 10). The low sample numbers prevented meaningful comparisons as the practice of preflowering irrigation but none during post-harvest, occurred only at one property.

Table 10. Fruit production (packed fruit) for tonnes per ha, kg/tree, kg of fruit/m^2 of canopy area surface (CSA) and irrigation as ML/ha, litres/tree and water use efficiency (WUE) as tonnes of packed fruit ha/ML ha of irrigation for seven KP producing properties grouped by preflowering and post-harvest non irrigation or irrigation

Irrigation	n	t/ha	kg/tree	CSA	ML/ha	L/tree	WUE t/ha
No pre and no post	2	4.49	46.74	0.39	2.05	20919	2.15
Pre but no post	1	5.47	43.75	0.29	2.94	23529	1.86
Pre and post	4	4.07	44.84	0.47	2.66	26224	1.78

Practices associated with higher than average water use

Growers were asked to what depth of soil or root zone they irrigated. The practice of irrigating to a depth of 90 cm was associated with a higher average per tree irrigation than to depths of 30, 40 and 60 cm (Figure 5). Twenty four per cent of growers did not know to what depth they irrigated.

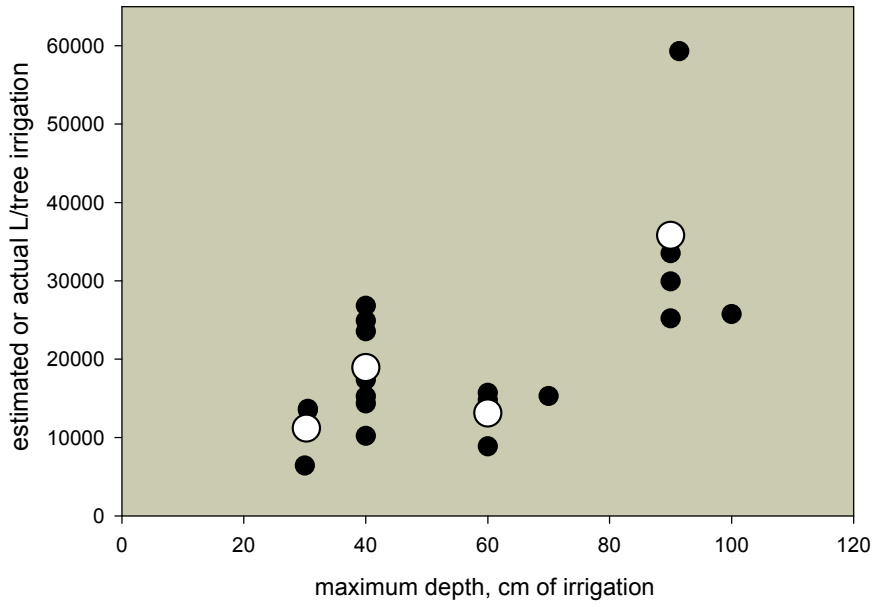

Figure 5. Depth of irrigation (cm) plotted against the average estimated or actual irrigation for the 2009 and 2010 seasons for individual properties (●) and average irrigation (○) volumes across properties with multiple cases for given depths

Practices associated with fruit quality

Eight of the 16 managers provided information on their typical defect problems. These problems included cleavage, under-skin bronzing, lenticel spotting, sap-burn, blemishes, small fruit, sooty mould, flatheads, wind damage and rub, bruising, stem end rot, shape, ripeness, mechanical damage and sunburn. Commonly identified causes for rejects in the 2009 season were wind damage, sap-burn, lenticel spotting, blemishes (cause unidentified) and maturity. The most common of these problems were blemishes (identified by four managers) and lenticel spotting (identified by three managers).

Lenticel spotting

Due to interest in a possible association between lenticel spotting and irrigation practices, where there was fruit quality data for properties in the survey, the incidence of lenticel spotting was plotted against irrigation volumes (Figure 6). There was an inconsistent association between lenticel spotting and irrigation volume. For the two assessments in Darwin in 2009, the percentage of lenticel spotting had increased at the second assessment at the property receiving an intermediate irrigation volume, but decreased at the property receiving the highest rate (Figure 6a). In the following season, lenticel spotting was positively associated with irrigation volume in Katherine properties but negatively related with irrigation volume in Darwin properties (Figure 6b).

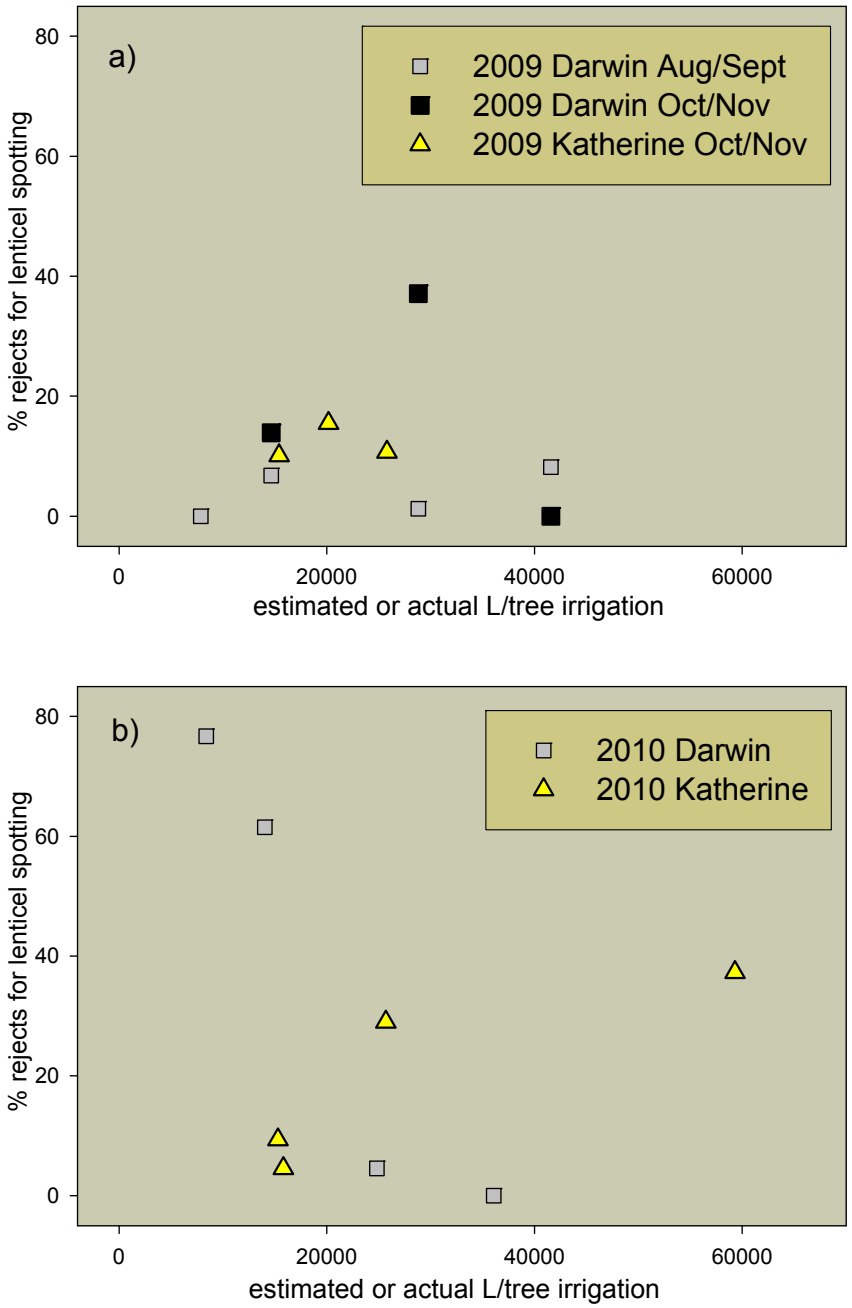

Figure 6. Estimated or actual irrigation per tree plotted against the percentage of lenticel spotting for (a) the 2009 season and (b) the 2010 season (lenticel spotting data was supplied by Moore et al. (2010))

Grower requirements for information

Growers were asked what information they needed on irrigation, such as mango water needs, irrigation systems or scheduling. A range of responses were received (Appendix 4) including requests for information on the effects of irrigation on fruit quality; irrigation strategies, including partial root-zone drying and regulated deficit irrigation; the effects of cincturing on tree water requirements; soil type effects on water availability; the validity of a crop factor of 0.7; and the water requirements of non-KP cultivars.

DISCUSSION

This Section addresses the two central and inter-related survey questions, which were: can irrigation practices be identified to improve productivity and improve WUE?

A relevant comment to both of the questions is that the data was limited in terms of the number of properties and especially the number of properties with similar aged trees of the same cultivar. There was also uncertainty about the accuracy of estimates of irrigation volumes. Therefore, further work will be required using larger samples to confirm the findings from this study. As such, the results from this study should be viewed as preliminary in nature.

IRRIGATION PRACTICES TO IMPROVE PRODUCTIVITY

When plotted against irrigation volumes, the yields from all properties did not indicate a clear relationship with irrigation volume (Figure 3). High levels (> 10 t/ha or 50 kg/tree) of fruit were attained by low, medium and high volume irrigations, although a number of other factors affected yield, such as season, the age of trees and cultivar differences. In a study of irrigated stone fruit in Australia, a similar relationship was observed where it was concluded that there was a poor relationship between the estimated amount of irrigation applied and yields, which implied that more than sufficient water was applied and that yields were not limited by water application (Boland et al. 2006). That conclusion also appears relevant to our study.

Data from a group of properties growing KP was used to further investigate the effect of irrigation on yield, averaged across seasons to minimise seasonal effects. The results showed that Katherine orchards had higher productivity than Darwin orchards (Table 9). Although the results were averaged across two seasons, Darwin orchards in 2010 on average had lower production historically (C Moore, pers. comm.), which contributed to the result. Interestingly, both preflowering and post-harvest irrigation was used at all the Katherine properties growing KP. However, only a small number of orchards that did or did not use either preflowering or post-harvest irrigation could be compared in Darwin. No clear differences in productivity were observed due to different irrigation practices (Table 10). An observation of soil water tension values from two properties in Darwin that did not use post-harvest irrigation showed that this period lasted between one and two months, depending on when the harvest ceased and that high soil water tensions (60-80 kPa) can quickly develop (Appendix 3). These post-harvest soil water conditions would have been equivalent in effect to a post-harvest drought.

Post-harvest irrigation is important to support early vegetative flush in some mango producing regions, especially if trees are pruned during this period (Davenport 2007). Early flush is important as the age of flush in the tropics determines the earliness of flowering in mango trees (Ramirez et al. 2010). A range of irrigation practices has been evaluated in the NT (Bithell et al. 2010) but the use of post-harvest irrigation for either early flushing or to improve productivity by reducing stress during the post-harvest period has not been evaluated. Given the variability of the onset of the wet season in the NT (Mollah and Cook 1996; Garnett and Williamson 2010), some years will experience dry breaks following the cessation of mango picking prior to the start of the wet season. It would be useful to evaluate the possible contribution of post-harvest irrigation during these periods to improve productivity.

WATER USE EFFICIENCY

How does the NT compare?

A study in Queensland of irrigation volumes identified that some mango growers can achieve high WUE values by irrigating at 1.5-3 ML/ha for yields of 9-11 t/ha, but average values were 5.5 ML/ha for yields of 7.3 t/ha (Anon. 2002). This average value is equivalent to a WUE value of 1.33 t fruit/ML of water. An earlier survey in Queensland in 1999 reported an average use of 5.5 ML of water/ha for mango yields of 4.9 t/ha (Anon. 1999), or 0.89 t of fruit/ML of water. Average WUE figures across all properties, cultivars and age of

trees were not calculated in this present study because of the wide range in values, especially between cultivars (Figure 3 and Table 8). Cultivar-specific values for KP and cultivar one were 2.37 and 3.18 t of fruit/ML of water, respectively. When calculating these values, properties with bore or irrigation problems were excluded. The Queensland studies calculated averages across all properties; these differences in methods would have contributed to the higher WUE values in the NT.

One of the Queensland studies identified best practice levels. The best practice group achieved an average of 11.1 t fruit/ha using 2.4 ML water/ha (a WUE value of 4.63 t fruit/ML water) (Anon. 1999). A comparison of this value with the WUE values in the NT indicates that WUE in the NT is closer to Queensland's best practice values, rather than to Queensland's overall average WUE values. The NT study highlighted that some cultivars, such as cultivar one, can achieve a very high WUE value (10.10 t fruit/ML). However, the values were based on one property with mature trees of cultivar one. As there are other younger plantings of this cultivar in the NT, it will be interesting to see in the future if they can achieve a similar WUE value when mature.

Measuring WUE linked to productivity

One common method of expressing WUE is simply yield/irrigation volume. However, there are many ways of expressing yield in either biological or economic terms. A study of irrigators in Australia identified those whose enterprise profitability is directly linked to improved crop water management are more likely to use objective irrigation scheduling tools (Montagu and Stirzaker 2008). Therefore, expressions of WUE efficiency that relate well to the economic returns of mango growers may be more useful than other measures. Two alternative measures for linking WUE to productivity were presented, one for CSA/yield and the other on Class 1 fruit production. In discussion with a grower regarding differing WUE measures, they considered that the Class 1 method was useful and relevant as the majority of the growers income came from Class 1 fruit (pers. comm. M. Linton). Due to interest in this measure future NT WUE studies should consider including this WUE measure.

Improved practices

Studies on other irrigated crops in Australia show that the greatest improvements in WUE mostly came from two factors, improvements in yield due to changes in varieties and changes in agronomic practices; a change in agronomic practice was the more important factor (Meyer 2008). The results for cultivar one in our study showed that the choice of cultivar will have a major effect on WUE values. This large effect of cultivar is probably due to the low productivity of the most common cultivar, KP. However, the large range of irrigation volumes for common cultivars, such as KP, also showed that irrigation practices and WUE values differ between growers, with a number of KP growers attaining higher than average yields from relatively low irrigation volumes. These results indicated that there is currently scope for changes in agronomic practice.

There are two broad areas for future improvements in practice. The first is in practices used in current plantings and irrigation systems. The second is in future plantings. For current plantings, responses from growers indicated that in some cases there was uncertainty over the actual volumes of applications due to the use of sprinklers that were not calibrated and/or the use of non-pressure compensating sprinklers. A number of growers reported irrigating to depths of more than 70 cm. This practice was associated with higher than average water usage. The current DoR recommendation is for a maximum irrigation depth of 70 cm for mangoes (Diczbalis et al. 2006). A recent study on a Blain soil in Katherine found that mango feeder roots were predominantly present in the top 20 cm of soil (S. Bithell, unpublished data). More studies are required to identify if such feeder root distribution is common in other NT mango orchards. A number of growers were not sure to what depth they irrigated. Greater adoption is required of soil water monitoring methods that indicate the maximum irrigation depth.

Currently, the most common monitoring method is by using a spade. However, some growers are using sophisticated soil water monitoring equipment. An Australian study found that tools to guide irrigation

scheduling, such as soil water monitoring equipment, are more likely to be used by large growers than by small growers (Montagu and Stirzaker 2008). This observation was true in some respects in our study where most of the large mango properties used sophisticated monitoring techniques; there were also some notable exceptions. However, smaller growers may require the most assistance to adopt soil water monitoring methods. Central to improved management of soil water is to provide information to growers on water infiltration rates and water-holding capacities of soils so they can have more confidence to determine the correct frequency and volume of irrigation.

New orchards may be able to use irrigation systems that have greater application efficiencies than micro-sprinklers, such as drip or trickle systems (Solomon 1993). Bores and pumps can be designed to give small but regular irrigations, which minimise the potential for deep drainage. One NT mango property currently has such a system and uses a strategy called pulsing, which provides short but frequent applications to keep roots moist during hot days and allows some cooling of the canopy. In addition, as already mentioned, it is now possible to choose cultivars with a high yield capability which will contribute to improve WUE values.

CONCLUSIONS

A comparison between WUE values in the NT with those in Queensland indicated that irrigation of mango trees in the NT was relatively efficient; however, on average, it was not as efficient as that of a Queensland best practice group. The use of WUE measures that are based on the level of production of class 1 fruit will provide growers with a more immediate link between water use and productivity. A number of growers have above-average yields in spite of low to moderate irrigation. For some existing mango orchards, there is clearly scope for practice change to improve WUE. This could include calibrating sprinklers to determine actual applications per tree, improving soil water monitoring methods, determining an appropriate maximum irrigation depth, and basing irrigation frequency and volumes on soil water-holding information. It will be important for those planning future orchards to have access to relevant information rather than to repeat past orchard designs. Growers identified a number of areas where they require information to improve irrigation practices, addressing them will assist growers to improve irrigation practices.

ACKNOWLEDGEMENTS

All participating growers are thanked for their generosity in participating in the survey and often providing detailed and useful information that took their valuable time to locate. Nick Hartley and Chelsea Moore from DoR kindly assisted with particular components of the survey.

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APPENDICES

APPENDIX 1. SURVEY INFORMATION AND CONFIDENTIALITY

Information given to participants:

2010 NT Mango Irrigation Survey, Department of Resources, Berrimah Farm, GPO Box 3000, Darwin NT 0801

Coding system to ensure confidentiality:

1. Growers names given a code
2. Code use as an identification for survey response sheet ID only
3. Code list with names only to be accessible to the project officer: Sean Bithell
4. List of names with codes will be destroyed following the completion survey

Survey information to be managed by:

Sean Bithell
Sustainable Production Research Officer.
Department of Resources.
Berrimah Farm.
office: 08 8999 2352
mobile: 0429 5529 55
sean.bithell@nt.gov.au

2010 NT Mango Irrigation Survey, Department of Resources, Berrimah Farm, GPO Box 3000, Darwin NT 0801

The purpose of the survey is to identify irrigation practices for improving mango production and water use efficiency.

Consent for use of survey responses for the purpose of the survey.

I …… give consent for the use of survey information for the purposes of the survey, providing that confidentiality is ensured.

Signed:

Date:

Survey information will be managed by:

Sean Bithell
Sustainable Production Research Officer.
Department of Resources.
Berrimah Farm.
office: 08 8999 2352
mobile: 0429 5529 55
sean.bithell@nt.gov.au

Survey form:

Identification of irrigation practices and capabilities for improved water use efficiency in NT mango orchards

	Code no:
1	**Locality** Do you collect weather information (rain or temperature data etc) in any blocks or garden? Response: If so, what your average annual rainfall or average/seasonal other data? Response:
2	**Orchard details**: Area in ha under mango plantings? No. of trees All producing? Or does the above include new plantings? Specify block no.s
3	**Tree details** Table 1 - Site 1

block no.	variety	age	density	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

Table 2 – for additional orchard sites

Site no.	block no.	variety	age	density

4 **Management details** (Separate responses in Tables 3 and 4 if blocks differ)
What is your estimated canopy ground cover (% canopy/total area of land)?

Or an estimate of canopy diameter in m?

Height?

Information on pruning regime.
Ideally, what size of tree of tree do you want to maintain?

Want a hedge style canopy? Or want separate trees?

Does this require severe (defined as removal of 25% of canopy/tree) pruning to achieve this?

What growth regulator products do you use?

If used, how regularly are they used? Twice a year? Annually? Each second year?

What are your ground cover preferences? Eg. do you want bare ground under trees and or between rows?

Table 3 - Site 1

block no.	Canopy cover (%)	Diameter (m)	Growth reg. history	Ground cover	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

Table 4 – for additional orchard sites

Site no.	block no.	Canopy cover (%)	Diameter (m)	Growth reg. history	Ground cover	

5 **5a Soil types** (Separate responses in Tables 5 and 6 if blocks differ)

Can you tell me about the soils under your mango plantings?

What soil types do you have? (circle or describe)

Blain Tippera Cockatoo sand or others, please describe

Is this type consistent or different across orchard (details for blocks Tables 5 and 6, if needed)

Could you describe each of your soil in terms of being (circle or describe) :

Type 1 sandy-loam sand clay-loam clay or?

Type 2 sandy-loam sand clay-loam clay or?

Is there changes in soil type with depth eg. 0-0.5 m and 0.5 m-1 m with any of your soil types, please describe?

Do you have an estimate or values for the water infiltration rates or water holding capacity of any soils on your property? If so please describe.

Table 5 - Site 1

block no.	soils		
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			

Table 6 – for additional orchard sites

Site no.	block no.	soils	

5b Soil water monitoring (Separate responses in Tables 7 and 8 if block info. is available)

Do you use any soil water monitoring tools or methods?

If so, what are they?

What depths do you monitor?

How long have you used this method? No. yr.s? Have you used different methods in the past? Y / N If yes, what were these methods and why did you change?

How often are monitoring results assessed to inform irrigation practices? Daily weekly or ?

Whose job is it to assess the results? yourself? the manager? operations staff? Consultants?

Are the results used to turn on/turn off irrigation?

Are the results used to change the delivery volumes (number of hours/day or week etc)?

In summary, are results used to check that the irrigation is doing what you expect, or rather used to actively manage the irrigation?

Table 7 - Site 1

block no.	Monitoring method	No. of sensors	Depth of sensors		

Table 8 – for additional orchard sites

Site no.	block no.	Monitoring method	No. of sensors	Depth of sensors	

6 **Irrigation system** (separate responses in Tables 8 and 9 if block info. is available)

Do you have one system at each orchard, or multiple systems within an orchard?

The age of delivery system (including tree lines and sprinklers)?

Type used: sprinklers or ??

Brand: Colour:

Delivery rate per tree or mm/unit area: L/h? Delivery area:

Pressure?

Do you make any calibrations to check delivery? Y / N If so how often? When was the last check?

Cleaning or back-flushing of system? Used (acid, sodium hypochlorite?) If so how often? When was last check?

Table 9 - Site 1

block no.	Irri. system	Age	Brand colour	Sprinkler rate l/hr	Sprinkler area m^2	Calibrations

Table 10 – for additional orchard sites

Site no.	block no.	Irri. system	Age	Brand colour	Sprinkler rate l/hr	Sprinkler area m^2	Calibrations

7 **Bores**

Number of bores per orchard? Register no:

Your pump capacity? Typical operating capacity (l/hr , m^3/hr or ML/hr)

Water quality? Have you information on pH? Levels of calcium?

Do you have a meter?

	Can we access meter readings during this coming mango season?
8	**Irrigation scheduling for trees in production** How important is irrigation or irrigation scheduling to affecting the: a) Number of fruit? Choose: Don't know, Not important, Moderately important, Very important b) Timing of fruit maturity? Choose: Don't know Not important, Moderately important, Very important c) Size of fruit? Choose: Don't know, Not important, Moderately important, Very important. d) Fruit quality? Choose: Don't know, Not important, Moderately important, Very important e) Overall yield? Additional comments? Do you have an irrigation schedule? Please describe Do you use the same schedule each year? If not, how has the current schedule changed from what was used in the past? To what depth of soil or root zone are you wishing to irrigate? What period do you generally irrigate from until? For example, 1. prior to flowering to x weeks before harvest, to harvest, to x weeks after harvest? 2. after flowering (defined as X% panicle emergence or X% flowering etc.?) to x weeks before harvest, to harvest, to x weeks after harvest 3. or?

Would your schedule be best described as:

a) Set: gives same amount to trees across the irrigation season?
b) Set with some variation: mostly the same across season, but some variation, which is: describe:
c) Changing: change in relation to fruit growth, phenology etc. : describe:
d) Changing: change in relation to changing soil moisture and environmental conditions across the season? describe:

What scheduling or practices do you use after harvest?

How did you develop/design your schedule? For example, was it based on long term experience, use of consultants, government information, or ?

9 **Irrigation scheduling for trees new plantings not in production**

Does the irrigation management of these blocks differ to areas under production?

What schedule and system is used?

10 **Yield** (separate responses in Tables 10 and 11 if block info. is available)

Is it possible to provide yield estimates for the last three years in:

Gross t/ha (before grading) or
Pack out t/ha (after grading) or
and or no. trays of firsts, seconds etc. (note tray sizes needed)

Is yield info. available for different age of variety blocks?

Table 10 - Site 1

block no.	**Gross t/ha**	**Pack out t/ha**	**Trays 1sts** *Tray size?*	**Trays 2nds** *Tray size?*		

Table 11 – for additional orchard sites

Site no.	block no.	Gross t/ha	Pack out t/ha	Trays 1sts *Tray size?*	Trays 2nds *Tray size?*		

What are your typical fruit defects/quality issues? Please list

Anthracnose bruising lenticel spotting ripeness sap burn skin blemishes (marks, rubbing…) shape size stem end rot

Other?

Can you rank the issues for volume of rejects in last season?

1. 2. 3. 4. 5. ?

And for prior season?

1. 2. 3. 4. 5. ?

Other notable quality problems?

Lenticel spotting:
Any problems with lenticel spotting? Y / N

If so is it a problem in early and late fruit? or?

Or particular blocks Or other associations?

Or some years?

Can we contact you for yield info. at the end of this season? Y / N If so what date would be good to contact you on?

11 **Water allocations**

What is your water allocation licence? How long is it current for? Which Aquifer?

If you have excess water in the future, are you interested in water trading?

Do you understand water trading?

If you are interested in trading what information would be useful?

12	**Are there areas that you want more information on in terms of** Mango tree water needs? Irrigation systems, in terms of delivery? Scheduling? Or?

Thanks very much!

APPENDIX 2. IRRIGATION SCHEDULE DESCRIPTIONS

Irrigation schedule descriptions are listed below in no particular order; values for number of litres or hours of irrigation are estimates only and refer to general practices rather than specific actual day to day values.

Schedule 1
Preflowering: start 1 hour a day just before flowering (April) for this cultivar.
Post-flowering: Once fruit have set from there up to a fruit diameter of ~3 cm trees receive 2*1 h a day (morning and early evening). This then increases (from 1-1.5 h per application, twice a day) to during fruit growth up to a maximum of 2-3 h per application (twice a day) for approximately the last six weeks of the season.
Post-harvest: nil.

Schedule 2
Preflowering: almost nil, some fertigation applied (4 h, single application).
At flowering: depends on stage of tree, and then based on soil moisture values.
Post-flowering: irrigation started at 30% of panicle emergence try to maintain a profile through the season, at fruit-fill consumption increases (big increase in September), cease after picking (Mid November).
For example, post flower one block receives 2 h*2.5 times per week, while a second block on a different soil type requires 4 h*2.5 times per week. An average of 3 h*2.5 times per week was used to estimate application for this orchard.
Note: every year different due to environmental factors also different blocks with differing soil types.
Post-harvest: some irrigation depending on timing of rains.

Schedule 3
Preflowering: 600 L every 15 d.
At flower: 600 L per two weeks
Post-flowering: during fruit set 800 L tree/week for approx. four weeks, then increasing to 2*6 (12 h) per week or 2*8 h (16 h) per week for approx. four weeks, depending on crop and conditions, for the final four weeks irrigation will continue at 2*8 h (16 h) bit if more than 12 trays/tree irrigate at 2*10 h per week and if more than 20 trays/tree irrigate at 2*12 h per week.
Post-harvest: will irrigate 8 h per week for flush (usually November) till wet starts and if dry breaks occur in the wet season for two weeks, then irrigate for 6 h to keep wet.

Schedule 4
Using soil monitoring results, weather information from BOM and a spread sheet to calculate pan evaporation demands to make decisions on timing and volume of irrigation.
Preflowering: out of wet monitor moisture and let the soil dry down to provide a bit of stress, then irrigate between stress and refill once a week, when buds start to push, increase irrigation but not trying to fill the profile.
At flowering: irrigating but not trying to fill the profile.
Post-flowering: after full flowering then try to maintain soil moisture at about 80% of a full profile.
Post-harvest: maintenance schedule, 1/3 of pan evaporation applied.

Schedule 5
Preflowering: do irrigate but limited volumes, want to hold moisture in top 60 cm and keep trees above soil moisture levels where stress occurs
At flowering: as buds start to push out, more water is applied progressively as flower development progresses. Generally moving from 1 to up 3.5 h of irrigation per week over this period.
Post-flowering: irrigating up to three times per day every second day during the hot part of the season September-October. For example, the first day 100 minutes early morning, then two separate pulses for 30 minutes each during the heat of the day to reduce stress, then another 100 minutes at end of day. For day

two only the two separate pulses for 30 minutes each during the heat of the day to reduce stress. Day three then repeats the day one applications. Note: varies a lot, as duration of irrigation is based on soil moisture readings.
Post-harvest: generally stop irrigation after picking as storms come in third or fourth week of November.

Schedule 6
Preflowering: small amounts, estimate at 4 h per week.
Bud push: wet up 30-40 cm profile at bud push (up to an 8 h single application).
During flowering: up to 2 h a day 6 d a week (~180 L/tree/day) through flowering.
Post-flowering: irrigate six of seven days a week providing up to 1000 L/week, but 800 L/week is usually enough.
Post-harvest: no irrigation unless fertigating.

Schedule 7
Preflowering: no irrigation.
At flowering: when flowers open, turn on irrigation, for 1 h only.
Post-flowering: 2-3 h/day; when fruit bigger, reduce a little; if dry and hot, irrigate more often. If an area has poor flowering, then irrigate less.
Post-harvest: nil.

Schedule 8
Preflowering: a) two weeks after rains have stopped give ~200 L/tree (~3 h/week b) one week before flowering (defined as when buds start to push) increase to few hours 2-3 h/tree.
Post-flowering: 12 h every third day. Regulate size by cutting back or adding more. Once fruit size is correct, cut back.
Post-harvest: nil.

Schedule 9
Preflowering: total drought.
At bud push leading up to flowering: top 40 cm bring to field capacity, can be up to 8 h of irrigation to achieve this.
Post-flowering: start 3 h week, then increase through 2*3 h a week, to 3*3 h a week to final of 3*4 h/week at maximum fruit fill period before harvest. Timing of increases depends on winds and temperatures. Early rainfall at the end of the season can lead to reduced end of season irrigation as well.
Post-harvest: irrigate until the first rains.

Schedule 10
Preflowering: some sites treated differently, one site kept moist with 1 h week preflowering, others more stress.
Post-flowering: wet up after flowering approx. 1500 L in one application.
Then water every day to give 700-800 L/tree/week, increase if windy 1000-1200 L/tree/week. Also increase irrigation if trees have more fruit (1000-1200 L/tree). Then reduce water close to harvest to bring maturity forward ~800 L/tree/week.
Post-harvest: irrigate until 2 inches of rain received

Schedule 11
Preflowering: not wanting irrigation below 30 cm.
Post-flowering: wet up profile, then targeting the 60-90 mm profile, broadly calculated pan evaporation*CF and use of monitoring results.
Post-harvest: only if fertigating.

Schedule 12
Preflowering: very little, seasonally dictated, once a fortnight small irrigations.
At flowering: slowly increased irrigation at flowering.
Post-flowering: at fruit set increase further, from early fruit set to mid-season (4 h, twice a week = 8 h/week), end of season (depending on size) may increase (6 h, twice a week = 12 h/week).
Post-harvest: 4-5 h two days a week until rains, also fertigating.

Schedule 13
Preflowering: 16 h/week.
Post-flowering: wanting to provide 24 h (comprised of four 4 h and a single 8 h applications) of irrigation over an eight day period at 70 L/h.
Post-harvest: keep watering until rains come, may reduce to 20 h/week.

Schedule 14
Preflowering: from April when drying out want to keep moist, use pulsing applications, three times a week.
Post flowering: 250-300 L/week to fruit set then up to 800 L/week. Final maximum application rate is based on fruit load, a smaller crop may be allocated ~ 700 L/week.
Post-harvest: keep moist 300-350 L/week, depends on how close the picking is to start of the wet.

Schedule 15
Preflowering: dry down for three to four months; wait for 75% of large flower buds present until irrigation is turned on.
At flowering: some fertigation and irrigation during flowering (about 1 h every second day).
Post-flowering: at fruit set increase irrigation up to 3 h/day, fruit fill is treated as a different period and apply about 1 h/day, once fruit is ripe reduce to ½ or ¾ h per day.
Post-harvest: ½ h per day until the rains start.

Schedule 16
Preflowering: irrigate through March and April to keep root zone (20-40 cm) moist, reduce applications in May to provide a managed drought (i.e. small applications made instead of a total drought).
At flowering: increase irrigation, trigger of -35 kPa in top 30 cm.
Post-flowering: slow increase in volumes to peak applications during September and October (large heat and wind effects).
Post-harvest: if wet after picking no irrigation, but otherwise irrigate.

Schedule 17
Preflowering: nil irrigation.
Post-flowering: young trees receive 2 h/day; old trees receive 4 h/day. If rain occurs on two consecutive days, the irrigation is stopped; the irrigation is started again once there have been two consecutive days without rain.
Post-harvest: nil.

APPENDIX 3. SOIL MOISTURE STATUS AND IRRIGATION DEPTH CASE STUDY

Sites and methods

At two Darwin orchards where soil water monitoring methods were not being used, a small study was carried out to investigate the soil moisture status from the period of peak fruit growth to the end of fruit picking and during the post-harvest period. The two orchards were approximately 6 km apart. At both orchards tensiometers were placed between the trunk and drip line of two trees (all Kensington Pride) in approximately the mid-range of the mini-sprinklers throw range. Orchard 1 had a set irrigation schedule of three ~ 650 L applications a week for all of the main irrigation season, orchard 2 had a changing irrigation schedule of about six applications of 250 L per week for the main irrigation season.

At orchard 1 tensiometers were placed at 30, 60 and 85 cm, at orchard 2 they were placed at 30, 60 and 80 cm; rock shelves beneath the mangoes prevented deeper placement of tensiometers at orchard 2 and limited the ability to place them at the same maximum depths at both sites. Periodic tension readings were taken with a Soilspec Tensiometer System (H&TS Electronics Pty Ltd) until early rains in late November.

Findings

Soil tension values varied greatly between the two orchards. For orchard 1, when the main season irrigation was operating, results indicated that water from sprinklers was getting to a depth of 85 cm (Figure 1). At that site the 30 cm tensiometer values were also similar to those at 85 cm. In contrast, at orchard 2 soil tensions were much higher at the three measured depths. Results for orchard 2 indicated that irrigation was not reaching the 30 cm depth.

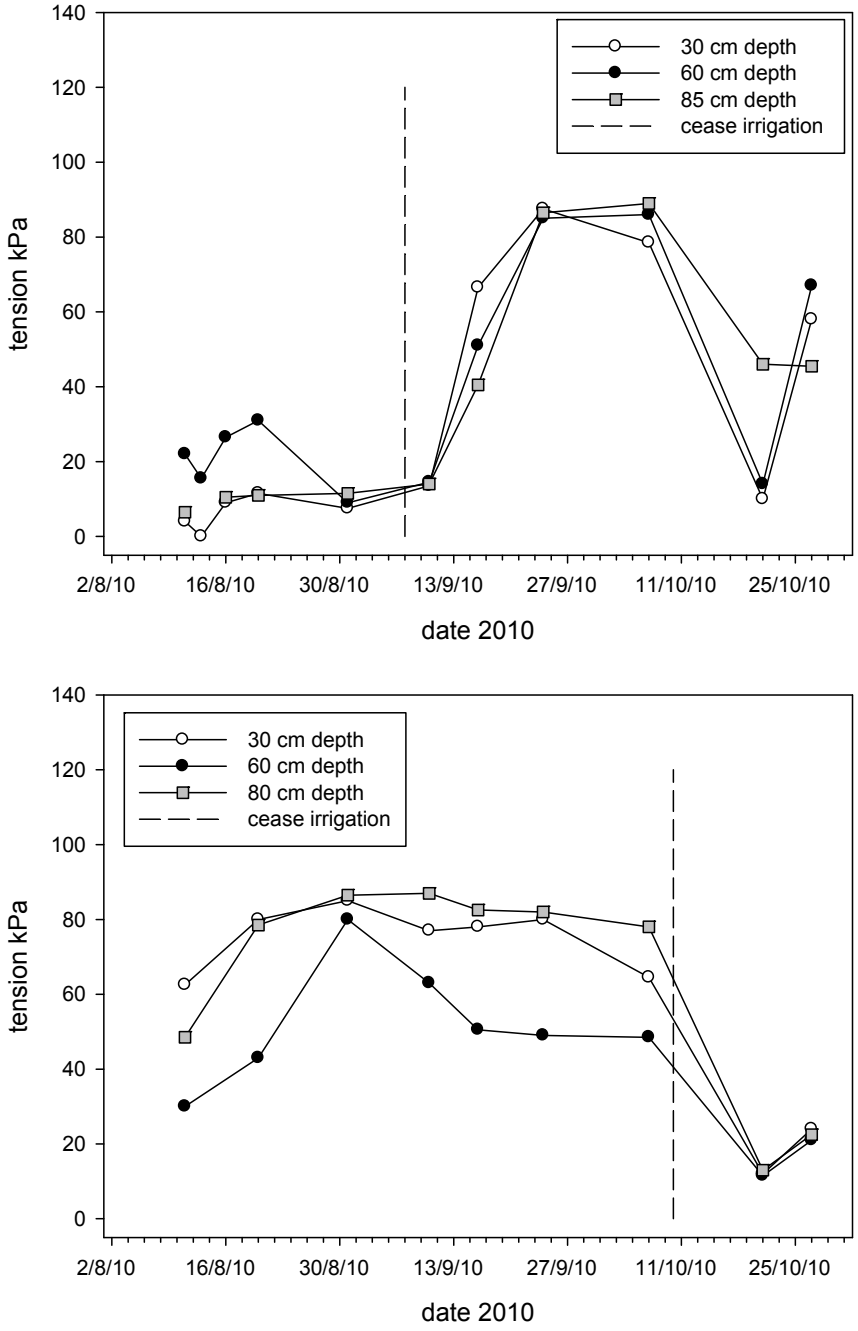

Figure 1. Average reading from two tensiometers at each depth for orchard 1 (top) and orchard 2 (bottom)

APPENDIX 4. LIST OF INFORMATION AND QUESTIONS IDENTIFIED BY PARTICIPANTS

Information or research identified by growers during the survey; each row represents information requests from a single manager

Information wanted	Information wanted	Information wanted	Information wanted
1. Want average from survey for information on what most people are doing.	2. Information on irrigation management for fruit quality.		
1. Want benchmarking to compare against rest of industry.	2. Want studies similar to Queensland Water for Profit a) benchmarking b) soil water monitoring.		
1. Want to know if survey respondents are all commercial growers = primary income from mangoes.	2. Want information on the water rights of leasehold properties.		
1. Work on regulated deficit irrigation and partial root zone drying methods.	2. Effects of cincturing on water use, especially half cincturing, trees need less water?	3. Use of buried drip lines? Effective? Problems?	4. Effects of soil type effects especially sand and organic matter on water availability and holding
1. Cleaning of irrigation systems to void calcium build up, unsure of use of phosphoric acid for voiding.	2. Can acid be fertigated to decrease the pH of soil?	3. Validity of crop factor (0.7)	4. Can surface roots be kept alive? If so, is this useful to production?
1. Want info. on volume of water used.	2. Interested in differences between Katherine and rural Darwin in water use.		
1. Want to know if we irrigating correctly.			
1. Why are we getting better production from one side of the tree?	2. From what size of fruit can that fruit be determined a keeper? i.e. will not drop.		
1. Want to know water requirements of our cv. (not KP), this cv. behaves (crops & produces) differently e.g. produces more but may use more water. Information for KP is not so useful.			
1. Want more work on consumption levels, currently using barely half the allocation. Want accurate figures on consumption and comparisons of these to climatic demand made.			
1. Keen to know how much water mature Calypso trees will need, few mature trees available to evaluate.			