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Soil Moisture Stress and Irrigation Management Promote Mangosteen (*Garcinia mangostana* L.) Flowering

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ABSTRACT

Soil moisture stress experiments were conducted on 23 year-old mangosteen (Garcinia mangostana L.) trees at the Chanthaburi Horticultural Research Center, Thailand to develop a practical method to promote flowering of mangosteen. It was demonstrated that irrigation strategies after attaining a threshold water stress condition could be used as an agro-management practice to stimulate mangosteen flowering. Trees were subjected to the stress conditions that induced a leaf water potential of –0.93 to –1.08 MPa. Irrigation with either 1.85 times the total daily evaporation every 3rd day or an initial application of 35 to 40 mm of water per tree plus half that initial rate applied at 7-day-intervals induced production of the largest amount of flowers and fruits.

Soil moisture stress affects flowering intensity in several tropical fruit trees. Research on carambola and rambutan (Salakpetch et al,. 1990, 1992) as well as mangosteen (Poonnachit et al., 1996) has shown that these crops require a period of water stress before flowering. Soil moisture stress has also been shown to be a prerequisite for flowering in cashew (Nambiar, 1977) and mango (Singh, 1977). Alvim (1977) reported that flower initiation in cacao is enhanced by a dry period while flower growth and development are inhibited under soil moisture deficits. A period of water stress is also necessary for flower bud development in coffee (Alvim, 1960; Maestri and Barros, 1977; Schuch et al., 1992). Chandraparnik et al. (1992) reported that a continuous dry period to achieve a mild stress condition is crucial for flower initiation in durian, but irrigation is required to promote growth and development of the flower buds to anthesis. However, rainfall greater than 10 mm/day for about 3 to 5 continuous days suppresses development of flower buds during the first stage of emergence.

Mangosteen is a high value crop due to high orchard establishment costs resulting from its long juvenile period. Once the juvenile period is complete, obtaining consistent flowering is imperative to recover investments associated with orchard establishment. Development of a practical method that can be used in an agro-management system to manipulate flowering of mangosteen trees is needed. The objective of this study was to develop a method to promote flowering in mangosteen by regulating water stress.

KEYWORDS: flower, leaf water potential, mangosteen, soil moisture stress, water management.

MATERIAL AND METHODS

Plant material

The study was conducted on 23 year-old mangosteen trees, at the Chanthaburi Horticultural Research Center, Chanthaburi, Thailand (≅ 12˚N and 101˚E), in the 1997/1998-production year. All trees were fertilized immediately after harvest with a 16-16-16 (N P_2O_5, K_2O) granular fertilizer plus minor elements + cow manure, with 8-24-24 (N, P_2O_5, K_2O) fertilizer at 2 months later, and 13-13-21 (N, P_2O_5,

K_2O) during fruit growth and development. Trees were pruned immediately after the first fertilizer application. Irrigation was applied by a sprinkler system, and the schedule was based on water requirements at different stages of development. The requirements during vegetative growth, and during fruit growth were 60%, and 80% of the daily evaporation from a Class A evaporation pan, respectively. The surface area under the canopy of each tree averaged 44 m^2, and approximately 75% of that area was irrigated by the sprinkler system. Before the experiment commenced, trees were irrigated with 60% of the daily evaporation only when the rainfall ceased for longer than 7 consecutive days. At least 9 weeks after emergence of the terminal shoots, all experimental trees were foliarly sprayed with a combination of 2500 mg l^{-1} thiourea and 30000 mg l^{-1} dextrose and irrigated, to induce synchronized leaf flushing

Experimental design

The experiment was arranged in a randomized complete block design, with seven single-tree replicates. Water was withheld from 14 November 1997 (onset of the dry season), until a desired visual wilting response was exhibited by the trees. At 2 weeks (29 November 1997) after the onset of stress period, there was a single 10 mm rainfall. The following were the desired level of visual wilting responses that were observed.

Response I: last internode of the terminal shoot beginning to wilt.

Response II: last internode noticeably wilted and the last pair of leaves bent slightly downward.

Response III: last internode and the last pair of leaves exhibiting more severe wilting symptoms than in response II, and shrinkage of the stem of the last internode clearly observable.

When the desired tree response was attained, two different irrigation regimes were applied. In Regime 1, irrigation was applied every third day until flowering. The irrigation rate was 1.85 times the total daily evaporation that occurred during the two intervening days. For example, if the daily evaporation for day 1 was 2 mm and 3 mm for day 2, the evaporation for the two intervening days was 5 mm. The amount of irrigation applied on the 3rd day was 1.85 x 5 mm/tree. Irrigation for Regime 2 consisted of a single application of 35 to 40 mm/tree followed by half of that amount (17.5-20 mm) applied at 7-day-intervals until flowering. Unstressed trees were first irrigated on November 21 and were irrigated throughout the experiment. When flowering was observed, irrigation with 80% of daily evaporation from a class A evaporation pan was applied every 2 days for flowers to develop to anthesis.

The experiment consisted of the following treatments.

Treatment 1: Response I trees + 1.85 times the daily evaporation irrigation applied every 3rd day until flowering.

Treatment 2: Response I trees + 35 to 40 mm/tree and half of the first irrigation amount applied at 7-day-intervals until flowering.

Treatment 3: Response II trees + 1.85 times the daily evaporation irrigation applied every 3rd day.

Treatment 4: Response II trees + 35 to 40 mm/tree and half of the first irrigation amount applied at 7-day-intervals

Treatment 5: Response III trees + 35 to 40 mm/tree and half of the first irrigation amount applied at 7-day-intervals

Treatment 6: Unstressed control consisted of trees irrigated twice a week with 1.85 times the total daily evaporation.

Measurements

Plant vigor was visually rated initially based on leaf vigor (color and size) and damage due to the major pests. Canopy structure, healthy and damaged branches, were included in the evaluation (visual rating: 1 = trees with very poor health and damage from pests on more than 50% of total leaf area; 5 = trees healthy and damage from pests less than 5% of total leaf area). Age (weeks) of the apical buds was recorded from the time the last pair of leaves began emergence until the time when water was withheld, and to when the desired stress symptom was attained. The length of the stress period was then calculated from this data. Midday leaf water potential was determined for 4 terminal leaves from the outer canopy of each tree using the pressure chamber technique (Scholander *et al*., 1965) when the desired visual response was attained. The total amount of water (mm/tree) applied during the period between the onset of irrigation and flowering (date of appearance of flower buds) was determined. Number of days to full bloom of the entire tree after appearance of the first flower buds was also noted. The interval (days) from the onset of the stress period (last rainfall) until the first flower bud appeared as well as the interval (days) between the onset of irrigation and appearance of the first flower bud were recorded. Percentage of leaf drop after irrigation and fruit number per tree were also recorded. Analysis of variance, *F* test and least significant differences (LSD) calculated at P = 0.05, were used in the statistical analysis.

RESULTS

Tree performance and leaf xylem water potential

The vigor rating of mangosteen was 3.6 to 3.7 at the onset of the stress period (Table 1). Emergence of apical buds associated with the latest flush occurred at 10.4 to 11.7 weeks prior to exposure to the stress conditions (Table 1). The stress period was about 3 weeks to for trees to exhibit Response I, 6 weeks to exhibit Response II and about 7 weeks for Response III (Table 1). When the desired stress response (Response I) was attained, and the last internode began to wilt in Treatments 1 and 2, leaf xylem potential (leaf WP) was –0.71 and –0.86 MPa, respectively (Table 2). Leaf WP was –0.93 and –1.08 MPa in Treatment 3 and 4, respectively, when the trees exhibited a greater stress response (Response II). Leaf WP of unstressed trees was –0.56 MPa. Leaf WP in Treatment 5 for trees with the most severe water stress treatment was –1.12 MPa (Table 2).

Flowering and yield responses

When stressed trees with leaf WP of –0.71 (Treatment 1) and –0.93 MPa (Treatment 3) were irrigated at 1.85 times of daily evaporation every 3rd day, the first flower buds were observed 54 days (12 Jan) after the last rainfall, or about 31 days after the onset of irrigation for Treatment 1, and 8 days after the onset of irrigation for Treatment 3 (Table 2). Trees received a total amount 202.1 mm/tree of water in Treatment 1 and 67.3 mm/tree in Treatment 3, before flowering was observed. Stressed trees with a leaf WP of –0.86 (Treatment 2) and –1.08 MPa (Treatment 4) produced the first flower 52 and 53 days after the last rainfall or about 33 days (Treatment 2) and 7 days (Treatment 4) after the onset of irrigation. The total amount of water applied was 105.2 and 36.2 mm/tree in Treatments 2 and 4, respectively. Trees which experienced the severest stress had leaf WP of –1.12 MPa (Treatment 5) and produced the first flower 76 days (2 Feb) after the last rainfall or 25 days after the onset of irrigation. Total amount of water applied was 107.4 mm/tree. Unstressed trees produced the first flower 85 days (12 Feb) after the last rainfall and received 414.5 mm/tree of irrigation over 10 weeks. Although mangosteen trees were exposed to various degrees of water stress, days to full bloom (anthesis) from the appearance of the flower buds was in the same range as that of unstressed trees (30 to 34 days) (Table 2). After irrigation was applied to stressed trees, the highest percentage of leaf drop (10.2%) was observed on trees stressed to –1.12 MPa (Table 2). Leaf drop in the unstressed trees was only 1.7%. Fruit number for trees that attained leaf WP of –0.93 and

–1.08 MPa was significantly greater (1267 and 1073 fruit/tree, respectively) than trees exposed to greater or lower water stress (Table 2). Unstressed trees produced 214 fruit/tree.

DISCUSSION

Poonnachit *et al*. (1996) suggested that three principal factors are involved in flowering of mangosteen. They are duration of water stress, age of apical buds, and plant vigor, which is expressed by the following multiple linear regression model.

Percentage of flowering	=	3.84 (apical bud age) + 1.87 (plant vigor) -0.35 (drought period) –129.26
r^2	=	0.83**
percentage of flowering	=	proportion of flowering shoots to total shoots
apical bud age	=	age of apical buds in weeks after the emergence of the latest flush
plant vigor	=	degree of vigorous vegetative growth (%)
drought period	=	days of exposure to continuous dry period

If these three factors are in place, an appropriate water management can trigger flower development.

The present study supports the conclusions of Poonnachit *et al*. (1996). Vigor ratings showed that trees had vigorous vegetative growth, and apical buds were at least 10-weeks-old when trees were exposed to stress conditions. Since stressed trees produced more fruit number per tree, which is a consequence of a corresponding number of flowers per tree, these results indicate that mangosteen flowering was stimulated by water stress. After the emergence of the floral buds, 80% of daily evaporation from a class A evaporation pan was applied to stimulate normal development to anthesis.

It appears that a threshold level of water stress followed by an appropriate irrigation regime can stimulate greater flowering. Trees that attained a leaf WP of –0.93 to –1.08 MP were irrigated with 67.30 and 36.24 mm/tree, respectively, to promote the first flower. However, trees exposed to less stress (>–0.93 MPa) or more severe stress (< –1.08 MPa) received a higher amount of irrigation before flowering was observed. Although trees were exposed to different stress and irrigation regimes, they produced the first flower on nearly the same day (non-significant $P \leq 0.05$), but a lower number of flowers and fruits developed on trees subjected to lower (-0.93 MPa) or more severe stress (-1.08 MPa). The current study showed that a threshold level of followed by water stress followed by irrigation was crucial for increased floral initiation and development in mangosteen. Exceeding the threshold stress resulted in less flowering.

It was discovered that water stress can cause the breakage of mangosteen latex vessels and latex glands, which are found throughout the tree including branches, leaves, and flowers (S. Sadudee *et al*., unpublished). In the present study, trees subjected to water stress had leaf WP of –1.12 MPa were severely wilted and were exposed to a stress period of 11 weeks. Breakage of latex vessels and latex glands at the shoot apex might have occurred and damaged cells which resulted in less flowers and fruits/tree compared to trees subjected to an optimum degree of water stress. When factors in the model proposed by Poonnachit *et al*. (1996) are considered together with the results of the present study, it appears that once the 3 factors are in place, an optimum level of stress will stimulate greater production of flower buds. Also irrigation is critical for emergence of the floral buds.

Poonnachit *et al*. (1996) suggested that age of apical buds after the emergence of the latest flush influences mangosteen flowering. Bernier (1988) and Bernier *et al*. (1981) proposed that since not all shoot meristems respond to conditions that promote flowering, the target meristematic cells must be competent or have the capability to respond to floral inductive conditions. After competency is achieved and the meristems respond to the inductive signal(s), cells will continue along a new course of development. In mangosteen a competent apical meristem should be is at least 10 to 11 weeks-old following the emergence of the latest flush.

The size of the mangosteen apical meristem at 9 weeks of age, prior to exposure to water stress, was about 14.0 μm wide and 5.6μm in height. At the end of exposure to a threshold level of stress, the meristem increased to about 77.0 μm in width and height increased to 18.5 μm and became dome shaped (S. Salakpetch and U. Poonnachit, unpublished data). An optimum level of water stress followed by irrigation could promote flower development within 7 days after irrigation (Treatment 4). If the stress period was interrupted by irrigation and less stress occurred, flowering was observed at a later period after the onset of irrigation. In the trees subjected to severe stress (Treatment 5) floral buds emerged about 25 days after irrigation with a large amount of water. It appears that a large amount of irrigation was required to rehydrate the buds and resume further growth and development if trees are not exposed to an optimum level of stress.

Ethylene evolution generally increases in stressed tissues and dormant buds (Abeles, 1973) and decreases when dormancy has been broken (Fuchigami and Nee, 1987; Schuch *et al.*, 1992). Severe water stress can lead to defoliation of trees. It is possible that elevated ethylene levels promoted leaf abscission in the highly stressed trees and might explain why the percentage of leaf drop after irrigation of the severely water-stressed trees was greater when compared to the less severely stressed and unstressed trees.

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Table 1. Plant vigor and age of apical buds in mangosteen trees exposed to soil moisture stress conditions.

Treatment[a] No.	Plant vigor rating	Apical bud age (weeks) at onset stress	Apical bud age (weeks) at onset irrigation	Stress period (weeks)
1	3.64	10.97	14.31	3.34
2	3.71	11.71	14.43	2.72
3	3.71	10.97	17.53	6.56
4	3.64	11.28	17.85	6.57
5	3.57	10.42	17.67	7.25
6	3.68	-	12.10	-
LSD at $P \leq 0.05$	NS	NS	7.70	0.56

[a]Treatment

1 = last internode beginning to wilt + 1.85 times total daily evaporation irrigation every 3rd day.
2 = last internode beginning to wilt + 35 to 40 mm/tree followed by half of that amount at 7-day-intervals.
3= last internode noticeably wilted and last pair of leaves bent slightly downward + 1.85 times total daily evaporation irrigation every 3rd day.
4 = last internode noticeably wilted and last pair of leaves bent slightly downward + 35 to 40 mm/tree followed by half of that amount at 7-day-intervals.
5 = the severe wilting symptoms + 35 to 40 mm/tree followed by half of that amount at 7-day-intervals.
6 = unstressed

Table 2. Effects of soil moisture stress and irrigation treatments on flowering and yield of mangosteen.

Treatment[a]	Leaf water potential (MPa)	Irrigation before flowering (mm/tree)	Days between onset of irrigation and appearance of flowers	Days to 1st flower after the last rainfall	Flowering date	Days to full bloom	No. fruits./tree	Leaf drop after irrigation (%)
1	-0.71	202.11	30.62	54	12 Jan 98	30.29	850.48	9.29
2	-0.86	105.22	32.96	52	10 Jan 98	32.29	784.29	9.52
3	-0.93	67.30	8.08	54	12 Jan 98	32.29	1266.93	7.86
4	-1.08	36.24	7.01	53	11 Jan 98	33.71	1073.37	9.76
5	-1.12	107.43	25.25	76	2 Feb 98	34.00	753.29	10.24
6	-0.56	414.52	85	85	12 Feb 98	32.41	214.33	1.67
LSD at $P \leq 0.05$	**0.07**	**22.32**	**4.59**	**18.24**		**NS**	**234.09**	**2.36**

[a] **Treatment**

1 = last internode beginning to wilt + 1.85 times total daily evaporation irrigation every 3rd day.
2 = last internode beginning to wilt + 35 to 40 mm/tree followed by half of that amount at 7-day-intervals.
3 = last internode noticeably wilted and last pair of leaves bent slightly downward + 1.85 times total daily evaporation irrigation every 3rd day.
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