8.5 Durian Tree Phenology and the Control of Phytophthora Diseases of Durian Using Phosphonate Trunk Injection

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Abstract

We have identified phenological patterns of mature durian trees grown in the north of Queensland, Australia, and monitored the distribution of phosphonate following trunk injection at three distinct phenological periods, to identify the injection period which results in maximum uptake in all tree organs. Durian cultivars Gumpun, Parung and Gob Yaow were injected with 16 g a.i. phosphonate at each of three injection periods (early flowering fruit/fruit-set, mid-fruit-set, and immediately after harvest). In northern Queensland, durian shoot and root development appears to be active throughout the year despite the relatively cool conditions that occur during winter. Shoot-flushing activity often occurs in parts of the tree rather then uniformly over the canopy. Phosphonate was detected within two days of injection in all organs sampled and reached a peak between four and eight days after injection. The highest levels of phosphonate were recorded in leaves and flowers (mean value of 60 and 40 µg/g dry weight). Phosphonate levels either declined or increased with sampling date, depending on organ and injection time, but persisted in all tissues for at least 128 days. Phosphonate trunk injection trials were also carried out on local durian varieties in Vietnam. Under moderate disease pressure, annual injections of 16 g a.i. per tree gave superior control of canker compared with recommended sprays of metalaxyl or Aliette. Under high disease pressure, 48 g a.i., injected at 3 three-monthly intervals, gave the best disease control. Results presented in this paper demonstrate the efficacy of phosphonate in controlling phytophthora diseases in durian when applied as a trunk injection.

Introduction

In all regions where durian is grown, it is seriously threatened by diseases caused by *Phytophthora palmivora* Butl. This disease generally occurs on mature fruit-producing trees. Symptoms include initial leaf-yellowing and leaf loss from the top of the canopy, with further loss of leaves occurring through the canopy at varying rates. New shoots may appear following initial severe defoliation, but further development and growth is unusual. Tree death generally occurs in 4–12 months from the initial onset of symptoms.

Attempts at controlling phytophthora diseases in durian have included repeated foliar sprays, or painting the cankered trunk with metalaxyl and phosphonate (salts or esters of phosphonic acid). These methods of application are expensive and the results highly variable under monsoonal conditions. Phosphonate is systemic and mobile in both xylem and phloem, and injection of the

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compound directly into the tree trunk has proved highly effective in controlling phytophthora diseases in a range of other tropical crops, including avocado, cocoa and coconut (Guest et al. 1995; Whiley et al. 1988).

Work in avocado has shown that, during periods of high vegetative flush and low root activity, phosphonate is carried up into the leaves rather than into the roots where it is required for the amelioration of *P. cinnamomi* (Whiley et al. 1995). Hence, the timing of injections in relation to tree phenology may be crucial to determining the distribution of the phosphonate within the durian tree and hence control of *P. palmivora*.

The experiments described in this chapter had three major objectives:

- to identify tree phenological activity under north Queensland environmental conditions with particular reference to the possibility of *P. palmivora* disease control using phosphonate injections;
- to monitor the distribution of phosphonate following trunk injection at three distinct phenological periods
- to identify the injection period which results in maximum uptake in all tree organs.

Finally, phosphonate was injected at a range of rates during different seasons into durian trees growing under a range of disease pressures in commercial orchards in Vietnam, to determine optimal application rates and timing.

Materials and Methods

Phenology monitoring

Three commercial farms and the Queensland Department of Primary Industries' (QDPI) South Johnstone research station, on the wet tropical coast of north Queensland, Australia, were selected as phenology recording sites. The sites were located within a region that extends from Bellenden Ker (16.5°S) in the north to an area south of Tully (18°S) a distance of approximately 100 km. Five groups of mature trees (i.e. had flowered previously), each consisting of three trees of each of two cultivars (Luang and Montong), were chosen for monitoring depending on availability at each site. Tree phenology (shoot, root, flowering and fruiting activity) was monitored monthly for 30 months from January 2000 until June 2002. The monitoring sites and the sampling schedule are listed in Table 8.5.1.

Shoot activity was rated on a whole tree basis as a percentage of new, hardening or mature shoot (Figure 8.5.1). Flowering was rated on a scale of 0 to 3, with 0 = no flowers present, 1 = 1–20 flowers, 2 = 20–60 flowers and 3 = > 60 flowers present. Fruiting was also rated on a scale of 0–3 with 0 = no fruits, 1 = 1– 10 fruits, 2 = 11–20 fruits and 3 = more than 20 fruits present. Harvest dates were recorded where applicable.

Figure 8.5.1 Durian flush standards, from left to right (new, maturing, mature).

Surface root activity was monitored through the use of 'root windows' (Figure 8.5.2a). The root windows consisted of a Perspex sheet (600 mm × 400 mm × 6 mm) installed on the SE side of each tree at a distance from the trunk equal to half the radius of the canopy. The perspex sheet was placed on a slope (5–35°) dependent on site topography, following soil removal and associated drainage. This process removed existing surface roots in the area. Before placing the

Table 8.5.1 Phenology monitoring sites, root window installation dates and sampling schedule

Farm	Variety	Install date	Sampling period during which monthly observations were made
CWTA	Luang	4/11/99	Jan 2000–June 2002
CWTA	Montong	14/12/99	Jan 2000–June 2002
Kuradui	Montong	23/11/99	Jan 2000–June 2002
Jensen	Montong	14/12/99	Jan 2000–June 2002
Zappala	Luang	11/11/99	Jan 2000–June 2002

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perspex sheet, the face of the slope was covered in a fine layer of sterilised potting mix. The perspex sheet was held in place using steel pegs affixed to each corner. Each sheet was etched with corner markers to allow the placement of two A4 overhead projector acetate sheets. At each sampling, if unsuberised roots were present the overhead sheets were placed on the perspex sheet and root growth traced using a permanent marking pen. Between recording periods the perspex sheets were covered with newspaper, shade cloth and bags filled with hay to stop light penetration and insulate the roots from incident solar radiation. Root activity was assessed qualitatively. The qualitative method consisted of an activity rating of 0–2, where 0 = dormant roots, 1 = slight new growth and 2 = active new growth.

Figure 8.5.2 Root window installed under durian tree.

Phenology rating data were compiled and mean ratings were calculated per site and variety combination as well as across all varieties and sites. Variation is described by standard error. Climate data were collected at all four sites. Because of the similarity between climate data sets, only data collected at the South Johnstone research station are shown.

Phosphonate injection (Queensland)

An injection trial was carried out at the South Johnstone research station on the durian variety block. The block of 14-year-old trees consists of 14 cultivars, each cultivar replicated three times. The block is one of the few in north Queensland that has not been treated (injected or sprayed) with phosphonate. Although *P. palmivora* had been recorded on the trial site, trees showed no symptoms of the disease.

Injection times selected included:

- EFF – early flowering/fruit-set (7 October 2000), with the aim of getting phosphonate into developing fruit, particularly fruit rind. Shoots and roots are also targeted
- MFS – mid-fruit-set (8 January 2001), with the aim of protecting all parts of the tree (shoot, root and possibly some protection to fruit)
- PH – immediately after harvest (26 March 2001), with the aim of avoiding direct flow of phosphonate to fruit, and distributing phosphonate to tops and possibly to roots during the last active phase of root development before root dormancy.

Three replicate trees were used per injection time, comprising three cultivars, Gumpun, Parung and Gob Yaow (all replicates of these varieties flowered and fruited during the 1998–99 season). Tree phenology was similar, and replicate trees of the same three varieties were used at each of the above injection times. The injection rate utilised was four 20 mL Chemjet® syringes of Foli-R-Phos® 200, which is equivalent to 16 g a.i. of phosphonate. Injections were administered in the early morning.

Sampling regime

All trees were sampled pre-injection on 21 September 2000. Post injection samples were obtained at 2, 4, 8 16, 32, 64, 96, 128, 192, and 256 days. At each sampling date the following tree material was sampled:

- leaves (from lower, mid and upper canopy)
- composite bark and wood sample (lower, mid and upper trunk)
- flower/fruit samples (lower, mid and upper trunk) – where and when available
- root samples (0–15 cm depth) – eight per tree were subsampled and then bulked.

The leaf, bark/wood and flower/fruit samples were oven-dried at 40˚C. Root samples were washed to remove all traces of soil before oven-drying at the above temperature. Following drying (2–3 days), samples were ground in a plant mill. A minimum of 5.0 g of dried ground material of each sample was packaged in labelled perspex containers and the collective samples were then air freighted to the University of Melbourne for analysis. Injection times and sampling dates are shown in Table 8.5.2.

Analysis

Phosphonate residues were measured by gas chromatography with a detection limit of 0.5 µg/g dry weight (dw).

Effect of phosphonate injection on disease in Vietnam

Phosphonate field trials were established on commercial orchards in the Mekong Delta and the Ba Ria–Vung Tau regions of Vietnam. In the Mekong

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Delta, the efficacy of potassium phosphonate at different concentrations was compared with Aliette (aluminium tris-*O*-ethyl phosphonate) and Metalaxyl in 1–12 year-old durian cv. Kho qua xanh. Trunk injection was compared with foliar spray. Canker severity was measured on a scale of 0 (no canker) to 3 (trunk girdling more than 70%, or tree dead).

In Ba Ria–Vung Tau, the results of trunk injection with different concentrations of potassium phosphonate were compared with canker painting with Aliette in 4 or 7-year-old durian cv. Sua Hat Lep Ben Tre. Canker severity was measured on a scale of 0 (no canker) to 5 (canker more than 50 cm^2 or tree dead).

Results

Climate monitoring (Queensland)

Monthly maximum and minimum temperature, rainfall and evaporation totals and average shortwave solar radiation inputs are shown in Figure 8.5.3.

Over the 973-day period recorded there were 179 days where the maximum temperature was less then 25˚C and 134 days where the minimum temperature was less than or equal to 15˚C, with 26 days on which the recorded temperature was 10˚C or less. The lowest temperature recorded was 7˚C. The range in average temperature was from 14.5 to 31˚C. These conditions are substantially cooler then durian trees experience in their native environment where the average temperature ranges from 24 to 30˚C (Nanthachai 1994).

Total rainfall was 10,173 mm over 545 wet days, of which 53 days had rainfall equal to or above 50 mm. The corresponding total evaporation for the same period was 4889 mm. The driest months (monthly totals less then 50 mm) were July and September 2000 and May, July, August and December 2001 and June 2002, when the respective rainfall recordings were 42, 24 and 36 and 37, 36, 43 and 16 mm. The wettest months (monthly totals greater then 500 mm) were December 1999, February, March, April and November 2000 and February 2001 when 505, 1121, 612, 948, 804 and 858 mm were recorded. These conditions, particularly during the first 24 months, are wetter then that experienced by the crop in its native environment where average rainfall ranges from 1600 to 4000 mm per year (Nanthachai 1994).

Energy inputs as measured by short wave solar radiation (SWSR) indicate that energy inputs varied across seasons. The average daily SWSR during the 973-day monitoring period was 18.6 $MJ/m^2/day$, with a maximum daily influx of 29 MJ/m^2 /day and a minimum 6 $MJ/m^2/day$. Monthly averages ranged from 12 to 24 $MJ/m^2/day$. These variations are in part due to seasonal variation in day length and to a greater degree due to rainfall and associated cloud cover which occurs during the wet season. In general, clear days during the months September to October result in the highest incident SWSR.

In summary, the climate in the major north Queensland durian-growing areas is cooler and wetter then the climate in the natural growing environment of the fruit.

Phenology monitoring

Shoot activity was high throughout the monitoring period (Figure 8.5.4). The means, for all trees, show that during the 30-month monitoring period there were 10 months in which new shoot flush occurred on 40% or more shoots. Shoot growth occurred throughout the year, but the highest activity was generally recorded in the months leading up to summer (September–December). Flush activity during the winter months was generally below 40% and occurred in discrete patches within the canopy.

Table 8.5.2 Phosphonate injection and sampling schedule.

Days (pre/post injection)	1st injection	2nd injection	3rd injection
Pre injection sample	21/9/00	21/9/00	21/9/00
Injection date	7/10/00	8/01/01	26/3/01
2	9/10/00	10/1/01	28/03/01
4	11/10/00	12/01/01	30/03/01
8	15/10/00	16/01/01	3/04/01
16	23/10/00	24/01/01	11/04/01
32	8/11/00	9/02/01	27/04/01
64	10/12/00	13/03/01	29/05/01
96	11/01/01	14/04/01	30/06/01
128	12/02/01	16/05/01	1/08/01
192	17/04/01	19/07/01	4/10/01
256	20/06/01	21/09/01	7/12/01

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Trees at individual sites exhibited similar flushing patterns.

Flower and fruiting activity varied between seasons (Figure 8.5.5). In the 2000 season, the spread of flowering was relatively short and intense, with a peak from September to October.

In the 2001 season, flowering at three of the five sites occurred over a longer period (May 2001–January 2002), continuing until May 2002 at one of the sites. The longer flowering period in 2001 may have been due to the drier conditions (Figure 8.5.3), which occurred from July 2001 to December 2001. fruit-set and growth closely followed flowering, with fruit harvest occurring from January 2001 to March 2001 in the 2000–2001 season and from January 2002 to May 2002 in the 2001–2002 season. fruit-set at one site (SJ-Monthong) was particularly poor in the 2001–2002 season.

In trees monitored in north Queensland root activity varied greatly between sites (Figure 8.5.6). Peaks in activity tended to occur during summer, but some

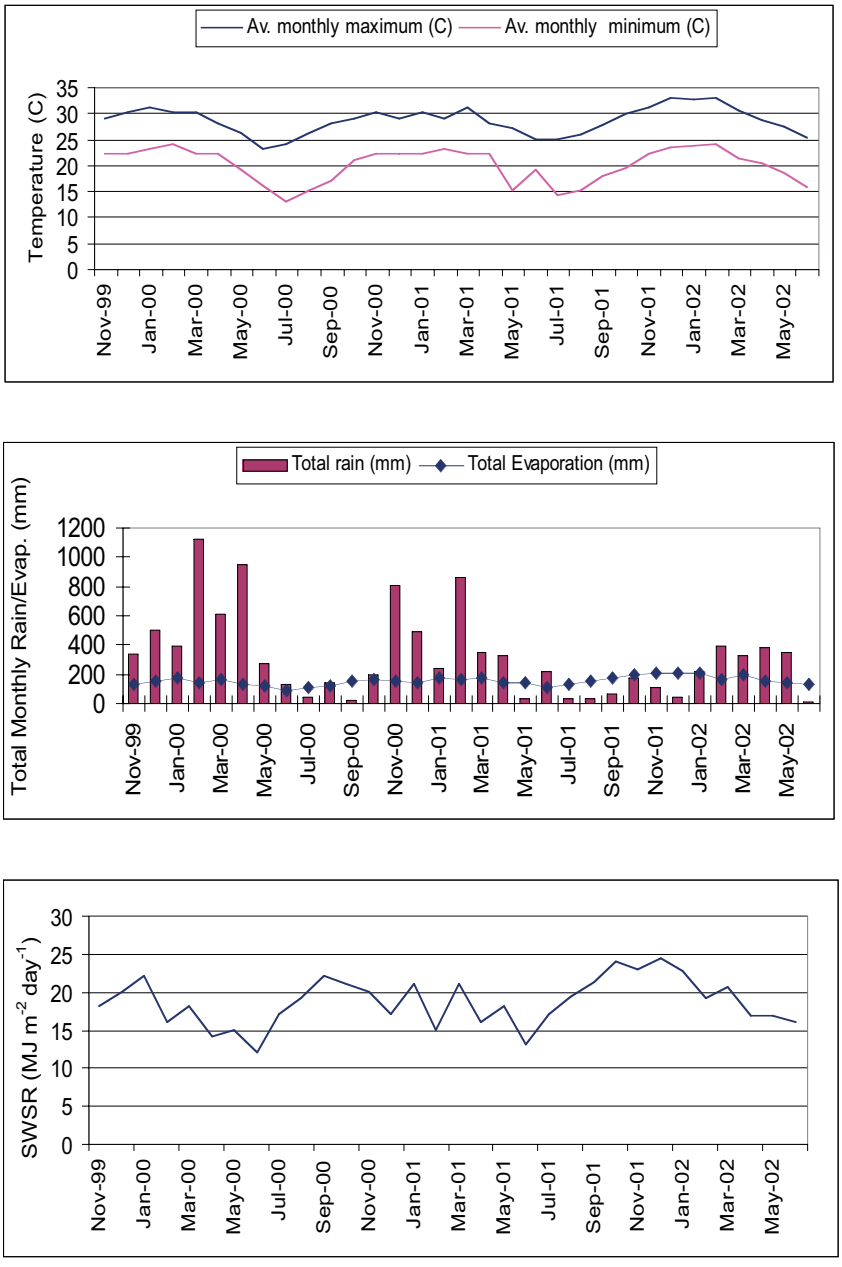

Figure 8.5.3 Mean monthly maximum and minimum temperature (°C), total monthly rain (mm) and evaporation (mm) and mean monthly shortwave solar radiation (MJ m^2/day) recorded at South Johnstone, northern Queensland, during the phenology monitoring period.

activity was noted throughout the year. The one period noted for a lack in activity in four of the five sites (May 2000–August 2000) corresponded with consistent cool conditions.

Translocation of phosphonate

Phosphonate concentration data from three injection periods have been analysed (early flowering/fruit-set, mid-fruit-set and postharvest). Phosphonate was not detected in any of the pre-injection samples of tissue, but was detected in all tissues within 2 days of injection (Figure 8.5.7). The concentration of phosphonate in organs was highest between 4 and 16 days after injection and generally fell below 10 μg/g dry weight 65 days after injection. Phosphonate concentrations increased in bark/wood samples from 96 to 256 days after the early flowering/fruit-set injection, whereas they remained relatively high following the mid-fruit-set injection.

The highest concentrations of phosphonate were recorded in leaves and bark wood (mean values of 134 and 105 μg/g, respectively) within 8 days of injection at the postharvest injection. However, there were little differences in the concentration between organs as the variability within the leaf samples was very high (Figure 8.5.7), with no detectable residue in some samples and more than 200 μg/g dw in others. In trees injected during mid-fruit-set, mean phosphonate concentrations never exceeded 30 μg/g dw. Variability within organs was lower, but a peak in phosphonate concentrations (8 days after injection) was discernible only in the leaf samples. Mean phosphonate concentration in roots was generally low ($\leq$ 10 μg/g dw), but in the postharvest injection treatment, concentrations in roots ranged from 21 to 44 μg/g dw from 4 to 32 days after injection.

Effect of phosphonate injection on disease in Vietnam

At sites of moderate disease pressure in the Mekong Delta Region, canker healing was observed within 4 months of injecting trees with 16 g a.i. phosphonate (applied as a single injection in April). Cankers continued to heal over the following 8 months until they had a canker rating of less than 1. Canker healing was achieved in other sites in the Mekong Delta Region with 32 g a.i. phosphonate (applied in two injections of 16 g a.i. with a 5-month interval). Under heavy disease pressure, 48 g a.i. per tree, along with pruning, improved drainage and orchard hygiene, gave the best disease control.

Phosphonate (0.2 or 0.4 g a.i./L), Aliette (1.6 g a.i./L) or metalaxyl (1.6 g a.i./L) significantly reduced preharvest fruit rot when applied as foliar/fruit sprays 1 month before harvest in the Mekong Delta. However, sprays of phosphonate applied at 0.4 g a.i./L or Aliette at 1.6 g a.i./L gave significantly superior control (Table 8.5.3).

Table 8.5.3 Average fruit yield and preharvest rot from 6-year-old durian trees in Vung Tai–Ba Ria, Vietnam, one year after treatment; n = 20. Values within columns are shown to be significantly different by ANOVA, P = 0.05

Treatment	Average yield (kg/tree)	Percentage fruit rot
Water injection	11.4a	43.7a
Phosphonate injection 12 g	25.5b	10.5c
Phosphonate injection 18 g	26.7b	13.5b
Phosphonate injection 24 g	27.3b	12.0bc

In Vung Tau–Ba Ria, canker healing was achieved in 4-year-old trees with either one or two applications of 8 g a.i. phosphonate per tree per year, while canker painting did not significantly reduce cankers (Figure 8.5.8). In 6-year-old trees 3 injections at 3-month intervals with 8 g a.i. or 2 injections (6-month interval) of 8 g a.i., gave superior control to a single injection of 12 g a.i. All of the above treatments resulted in a significantly higher yield of healthy fruit. Excellent control was also achieved in 7-year-old trees with 3 injections totalling 16, 24, 32 g a.i. of phosphonate per tree per year, compared with Aliette 80 WP 1% paint, with 32 g a.i. treatment the most effective.

Discussion

Flushing, flowering and fruiting patterns of durian recorded in north Queensland are similar to patterns observed in Malaysia and Thailand. Higher rates of leaf flushing occur during the wet season, while flowering normally occurs during or near the end of the dry spring months, and fruit development and harvest during the wet summer months (Subhadrabandhu and Ketsa 2001). Thai researchers report that the ideal temperature range for durian production is from 24˚C to 30˚C (Nanthachai 1994, Subhadrabandhu and Ketsa 2001). This study has revealed that active vegetative growth can occur under relatively cool conditions (three months where mean temperatures range from 18.5˚C to 20˚C and seven months where mean temperatures were >20˚C and less than 24˚C) as experienced in north Queensland. Surprisingly, root growth also continues during this period. In north Queensland, observations on durian root distribution agree with data presented by Masri (1991) showing that the durian root length density decreased horizontally

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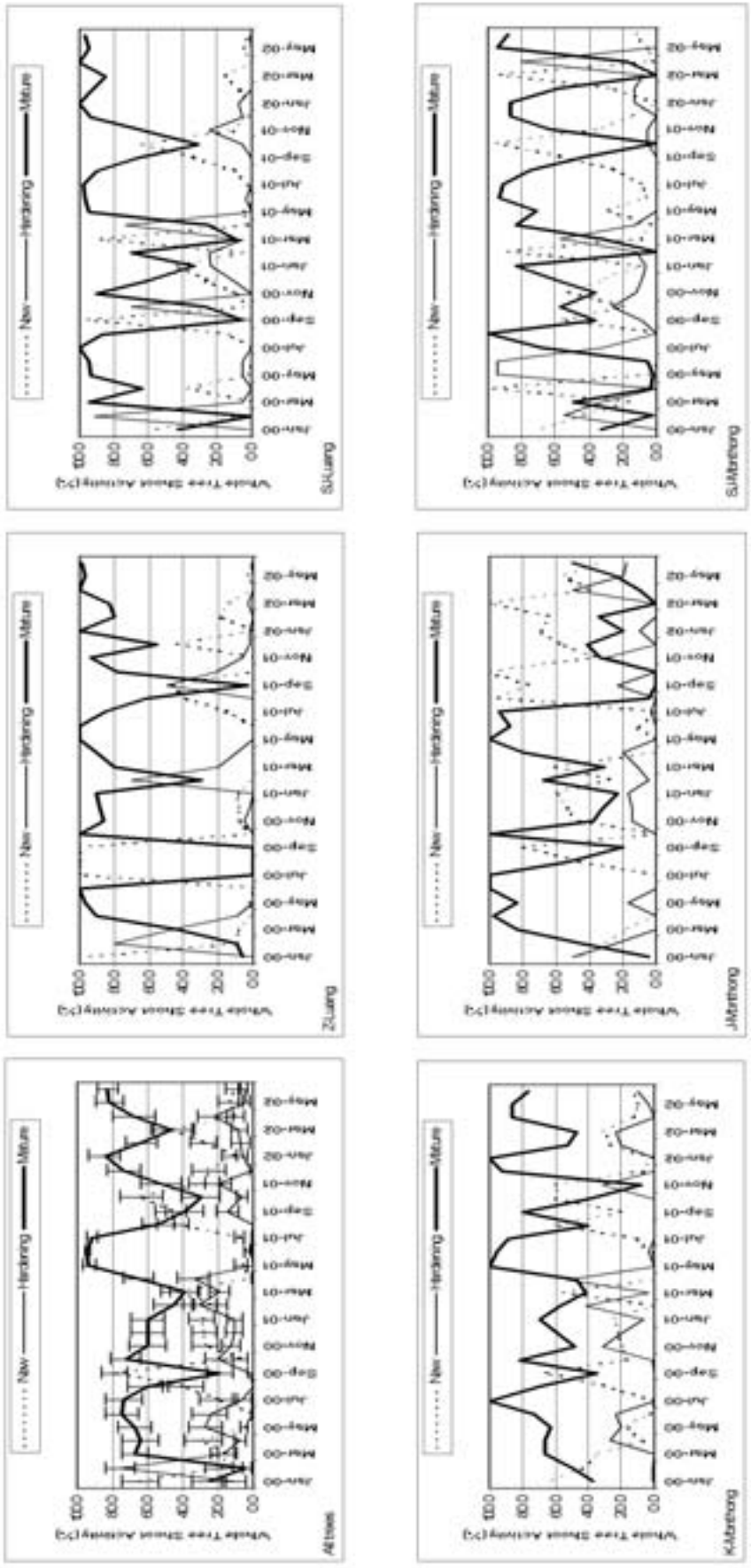

Figure 8.5.4 Whole tree shoot phenology (%) for individual farm sites (Z-Luang, SJ-Luang, K-Monthong, J-Monthong, SJ Monthong) and all trees plus standard error bars.

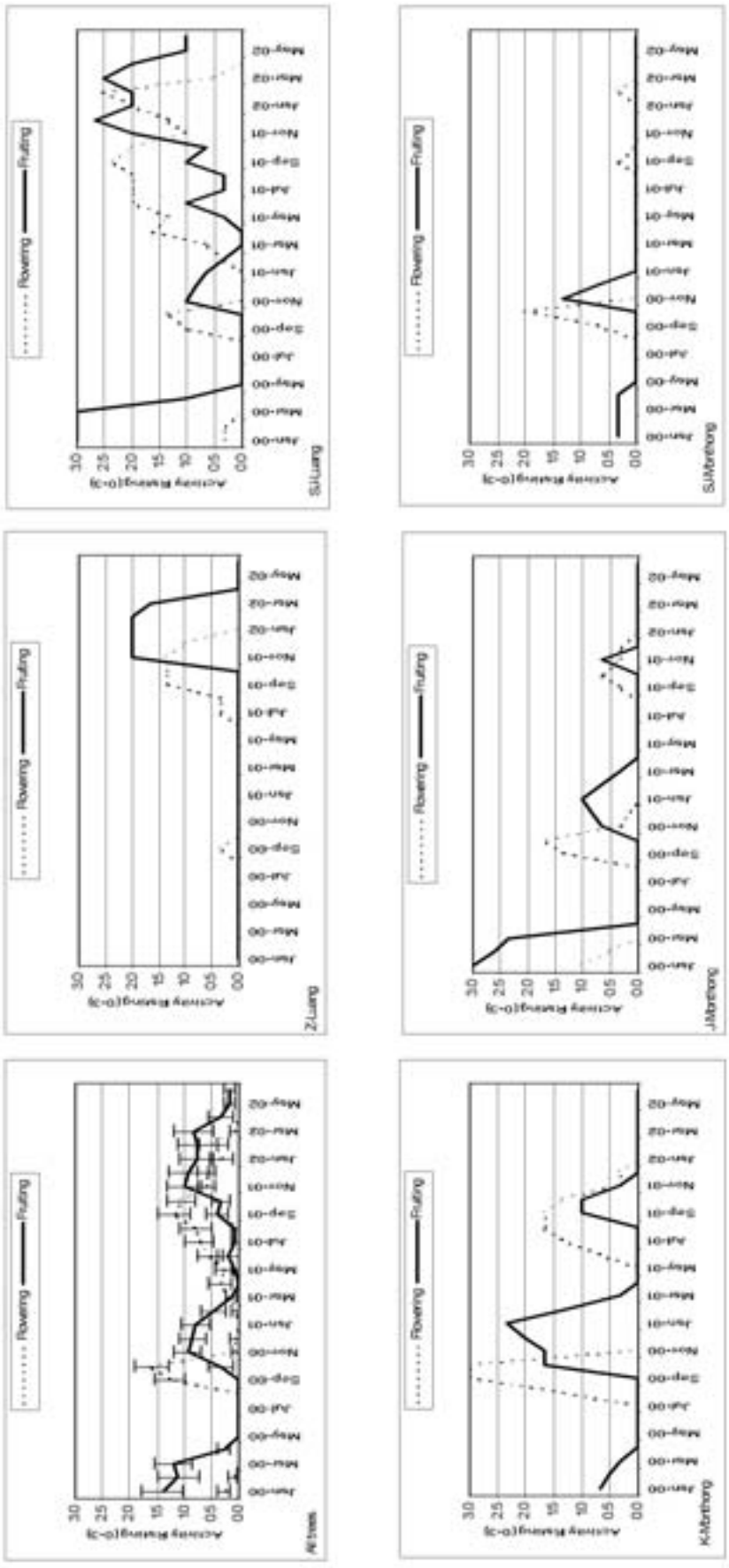

Figure 8.5.5 Flowering and fruit-set activity rating for individual farm sites (Z-Luang, SJ-Luang, K-Monthong, J-Monthong, SJ Monthong) and all trees plus SE bars.

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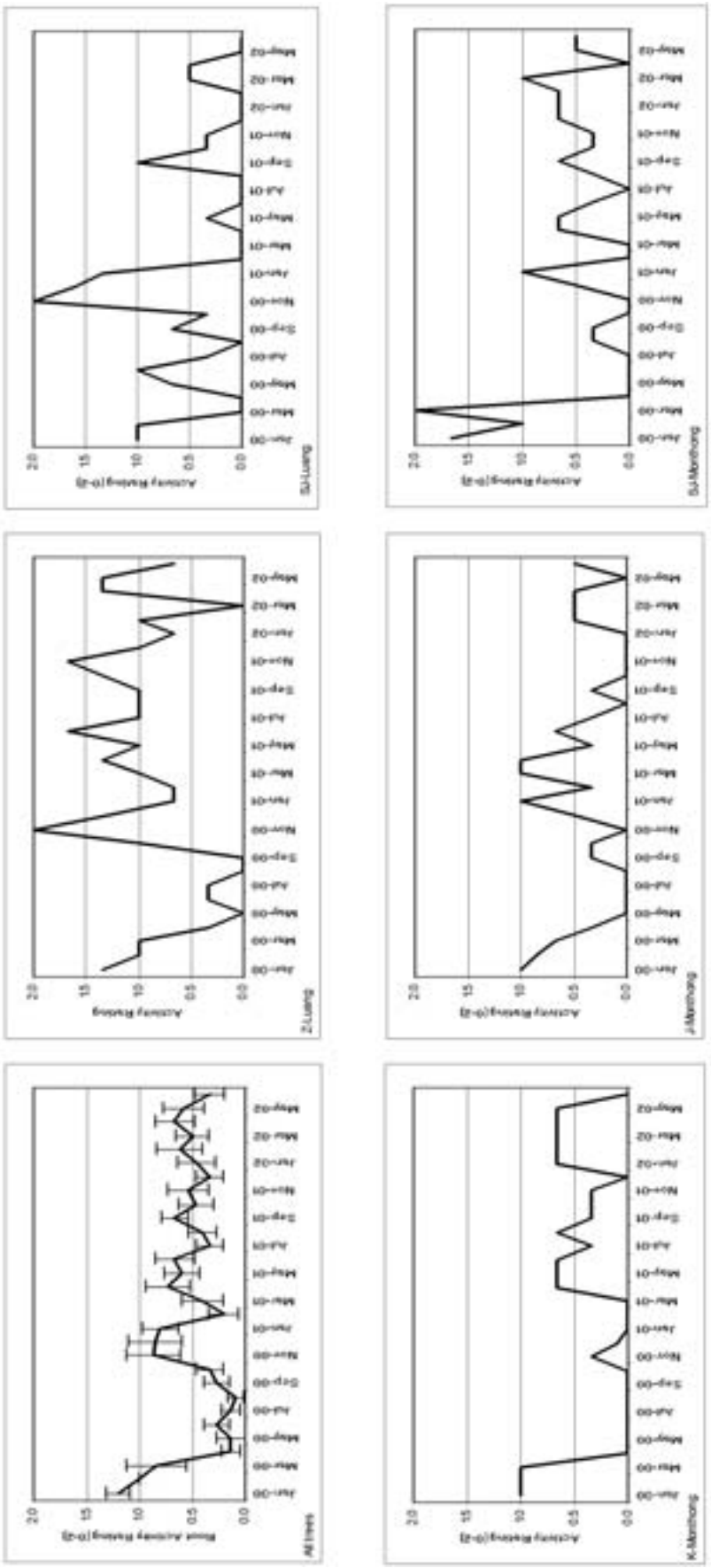

Figure 8.5.6 Root growth activity rating for individual farm sites (Z-Luang, SJ-Luang, K-Monthong, J-Monthong, SJ Monthong) and all trees plus SE bars.

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from the crown and vertically with soil depth but no data have been found that document root flushing activity.

The continuous growth of shoots and roots observed in durian differs from avocado where shoot and root activities have two distinct growth stages with the root growth following shoot growth (Whiley et al. 1988). Our data suggest that new shoot and root activity in durian occur simultaneously or are only slightly offset.

Phosphonate concentrations recorded in durian in this trial are lower than those observed in similar studies conducted in avocado (Whiley et al. 1995). In avocado, concentrations of phosphonate were as high as 80 µg/g fresh weight (fw) and 25 µg/g fw in shoots and roots, respectively. Equivalent fresh weight maximum concentrations in durian were 24 µg/g and 2.3 µg/g for shoots and roots.

The phenological patterns observed suggest that shoot and root growth occurs throughout the year, albeit at higher levels during the summer months. This suggests that translocation of phosphonate to all developing meristems is possible regardless of the time of injection, unlike the situation in avocado where maximal levels in roots could be achieved only if injections followed the maturity of the spring shoot growth (Whiley et al. 1995). Surprisingly, phosphonate levels in durian generally remained low in roots (less than 10 μg/g dw). This suggests that either the root sink strength is low or the

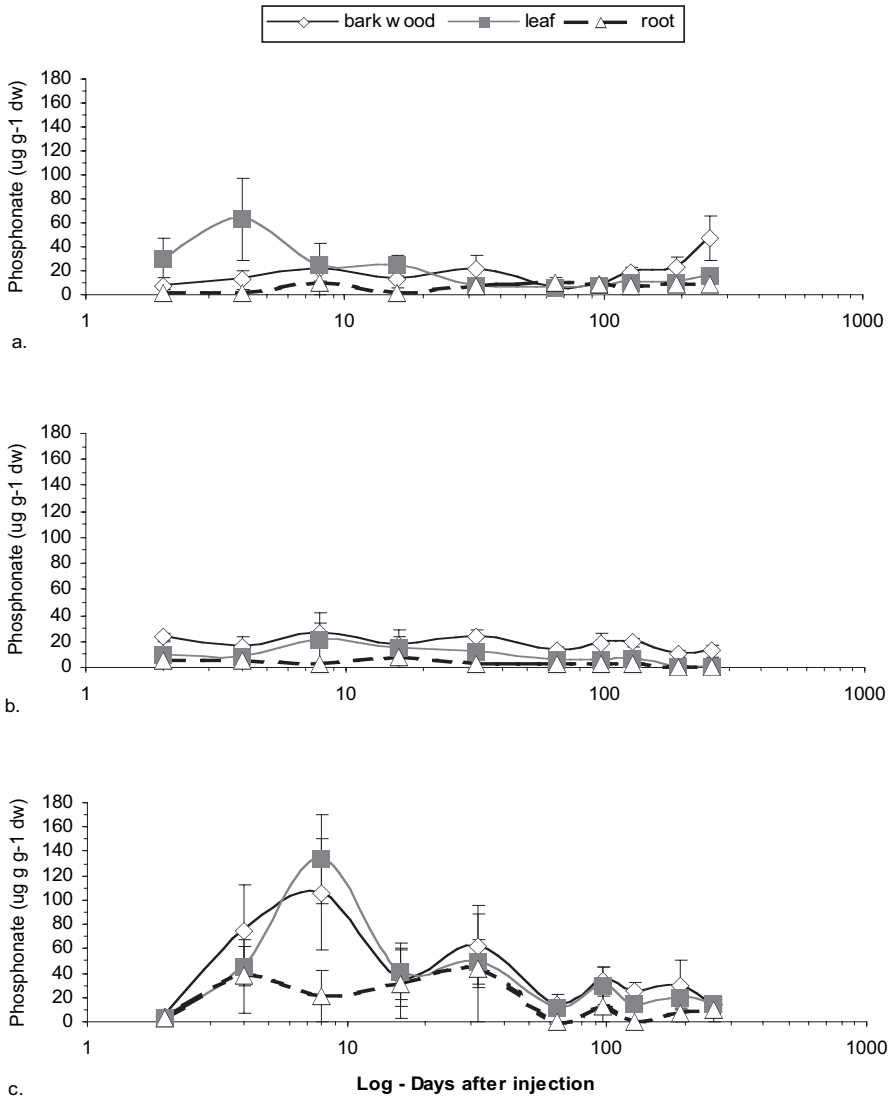

Figure 8.5.7 Phosphonate concentrations in durian tissue following injection after a) early flower and fruit-set, b) mid fruit-set and c) immediately post harvest with 16 g a.i. phosphonate.

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concentration of phosphonate injected is inadequate to supply all organs simultaneously. Concurrent work in Vietnam has shown that the concentrations used in this experiment are sufficient to halt the development of stem canker. In this study, the phosphate concentrations were highest in the bark/wood samples following the mid-fruit-set injection. There were, however, no symptoms of bark canker observed in the trees before or during the sample period in north Queensland.

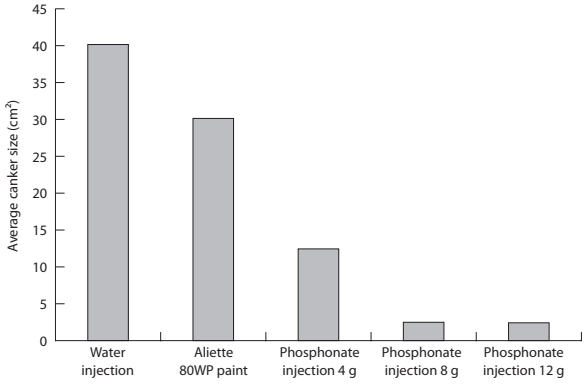

Figure 8.5.8 Severity of canker symptoms on 4-year-old trees in Vung Tau–Ba Ria, Vietnam, 1 year after treatment; $n = 20$.

Phosphonate trunk injections effectively and consistently control durian trunk canker in trials conducted under high disease pressure in Vietnam, and lead to increased healthy fruit yield, as they do in cocoa and coconut. When they are used in conjunction with improved orchard hygiene, canopy management, drainage and preharvest foliar sprays of either phosphonate or Aliette, one could expect greater control of fruit rot. The optimal rate of application depends on disease severity and disease pressure. Trials conducted over 5 years on cocoa in Papua New Guinea using trunk injections of potassium phosphonate increased healthy pod yield and decreased the incidence of Phytophthora pod rot when compared with untreated trees or trees sprayed with recommended doses of Ridomil 250 EC or trunk injected with Aliette CA (Guest et al. 1994). A single annual injection of 15 g a.i. per tree controlled Phytophthora disease on mature cocoa trees, with the optimal dose depending on tree size, initial disease severity and disease pressure.

In conclusion, durian shoot and root growth remains relatively active throughout the year. This may be beneficial in terms of Phytophthora disease control via the mechanism of phosphonate trunk injection because sink strength remains active in all growing organs throughout the year. However, because of the absence of disease in north Queensland where we monitored the effect of phenology on tissue concentrations of phosphonate, we can only infer that these concentrations are adequate to explain the excellent level of disease control achieved in the trials conducted in Vietnam.

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