Chapter 4

RESULTS AND DISCUSSION

4.1 Field Experiment

4.1.1 Responses to Boron Fertilizer

4.1.1.1 Shoot Length

Shoot length increased with increasing B application (Table 4.1). At 4W and 20W, shoot lengths reached maximum in B80 trees. By contrast, at 8W, 12W and 16W, shoot lengths of B160 tree were greatest. The changing responses of shoot length to B supply during tree development may be attributed to the rapid increase in B requirement due to rapid shoot growth after 4W (Table 4.1). In addition, at 20W, the lack of difference of shoot length between B80 and B160 may be attributed to the fact that shoot growth in B160 reached maximum at 16W. Shoot length in B160 trees reached maximum 4 weeks before that in B80 trees.

Table 4.1 Effect of borax application on shoot length in Golden Delicious apples. Values are means of 4 replications.

Borax	Sampling time				
(g tree^{-1})	4W	8W	12W	16W	20W
0	19.7o	36.1k	43.9h	46.3f	47.0ef
40	21.0n	38.7j	45.0g	47.4e	47.7e
80	22.6m	41.4i	48.7c	49.9b	50.9a
160	23.1m	44.0h	50.1b	51.3a	51.4a

4W, 8W etc. refer to 4 weeks after full bloom, 8 weeks after full bloom etc.
Means followed by the same letter are not significantly different at 5% level.

4.1.1.2 Fruit Drop

Most fruit dropped before 3W. However, the difference of the percentage of fruit drop among different borax rates was not observed before 3W (Table 4.2). Then, the heavy fruit dropping and the lack of B response of fruit drop at early fruit development may have been due to insufficient photosynthate. The percentage of dropped fruit during the period of 3W-8W decreased with increasing B application. The percentage of dropped fruit during 3W-4W and 4W-8W reached a minimum in B80 trees. At the end of June drop, fruit in B80 and B160 were thinned to 25% of the potential number of fruit set. After thinning, numbers of retained fruit in B0, B40 B80 and B160 trees were 17%, 22%, 25% and 25 % of fruit set, respectively. Thus, B deficiency increased number of shed fruit in B deficiency trees after influence of limiting photosynthate ceased. However, there was no difference of the percentage of dropped fruit at pre-harvest drop among B treatments.

Table 4.2 Effect of borax application on percentage of abscised fruit during fruit dropping time in Golden Delicious apples. Values are means of 4 replications.

Borax	Pea-size drop		June drop	Pre-harvest drop
(g tree^{-1})	1W-3W	>3W-4W	>4W-8W	14W-18W
0	50a	12a	21a	5a
40	49a	11a	18a	4a
80	51a	6b	12b	3a
160	50a	4b	10b	5a

1W, 3W etc. refer to 1 week after full bloom, 3 weeks after full bloom etc.
Means in a column followed by the same letter are not significantly different at 5% level.

4.1.1.3 Fruit Size

Fruit length increased with increasing B application (Table 4.3). Similar to shoot length, at 4W and 20W, fruit lengths reached maximum in B80 trees whereas during 8W-16W, the greatest fruit lengths were obtained in B160 trees.

Table 4.3 Effect of borax application on fruit length (cm) and fruit diameter (cm) in Golden Delicious apples. Values are means of 4 replications.

Fruit size	Borax rate	Sampling time				
	(g tree^{-1})	4W	8W	12W	16W	20W
Fruit length	0	1.70n	3.70k	4.78h	6.05e	7.15b
	40	1.79n	3.78k	4.93h	6.15e	7.19b
	80	1.99m	4.04j	4.89g	6.28d	7.31a
	160	2.01m	4.26i	5.10f	6.48c	7.59a
Fruit diameter	0	1.22k	3.17h	4.76f	6.06d	7.19b
	40	1.25jk	3.22h	4.83f	6.12d	7.24b
	80	1.48ij	3.65g	5.13e	6.48c	7.81a
	160	1.51i	3.75g	5.16e	6.57c	7.86a

4W, 8W etc. refer to 4 weeks after full bloom, 8 weeks after full bloom etc.
Means followed by the same letter of fruit length or fruit diameter are not significantly different at 5% level.

In contrast with shoot and fruit length, fruit diameter reached maximum in B80 trees at all stage of fruit development (Tables 4.3).

The above results may suggest that the B requirement for maximum shoot length and fruit length were higher than that for maximum fruit diameter and fruit shedding.

It can be concluded that the growth rates of shoot and fruit in B80 trees were slower than those in B160. However, at harvest, maximum shoot length and fruit size were obtained in B80 trees.

4.1.1.4 Yield and Yield Components

Fruit were harvested at 150 days after full bloom when 50% of fruit skin area in B0 trees was yellow. At this time, fruit in B40, B80 and B160 trees were 2, 5 and 10 days, respectively, beyond the same stage of ripening (Table 4.4).

Table 4.4 Effect of borax application on time when the skin color of 50% of fruit surface changed from green to yellow in Golden Delicious apples, fruit weight, number of fruit per tree and yield. Values are means of 4 replications.

Borax ($g\ tree^{-1}$)	Time [A]	Fruit weight ($g\ fruit^{-1}$)	Number of fruit $tree^{-1}$	Fruit yield ($kg\ tree^{-1}$)
0	150a	159a	335b	50c
40	148ab	165a	381a	60b
80	145b	176b	392a	69a
160	140c	181b	395a	72a

[A] The days after full bloom.
Means in column followed by the same letter are not significantly different at 5% level.

Fruit weight, number of fruit $tree^{-1}$ and yield increased with increasing B application. Similar to shoot length and fruit size at harvest, maximum fruit weight and yield were obtained in B80 trees (Table 4.4). By contrast, with high percentage of dropped fruit in B40, maximum number of fruit was obtained in B40 trees (Table 4.4). This is attributed to the fact that fruit numbers of fruit in B80 and B160 trees were reduced by thinning to 25 % after June drop. Therefore, low fruit yield in B40 was due to low fruit weight. In B0 trees, low fruit yield was attributed to both low fruit weight and number of fruit tree^{-1}. Thus, B deficiency decreased apple yield through decreasing the number of retained fruit and the fruit weight.

4.1.1.5 Fruit Quality

With increasing B application, total sugar increased but fruit firmness, titratable acidity and soluble solids decreased (Table 4.5). When trees were applied with 80 g borax tree^{-1}, total sugar was maximized. Thus, applying 80 g borax tree^{-1} was sufficient for maximum fruit size and total sugar. However, borax application had no effect on vitamin C content in apple fruit.

Table. 4.5 Effect of borax application on firmness, total sugar (TS), soluble solids (SS), titratable acidity (TA), vitamin C (V.C) and number of seed per fruit in Golden Delicious apples at harvest. Values are means of 4 replications.

Borax (g tree^{-1})	Firmness (kg cm^{-2})	TS (%)	SS (%)	TA (% malic acid)	V. C (mg/100g fresh fruit)	Number of seed fruit^{-1}
0	12.7c	9.7b	13.7a	0.315a	2.3a	9.0b
40	11.9b	9.8b	13.3b	0.295b	2.2a	9.5b
80	11.7b	10.2a	12.9b	0.273c	2.3a	11.5a
160	10.3a	10.2a	12.6c	0.235d	2.2a	12.3a

Means in column followed by the same letter are not significantly different at 5% level.

4.1.1.6 Seed Number per Fruit

Similar to yield and yield quality, with increasing B application, number of seeds $fruit^{-1}$ increased (Table 4.5). In addition, when trees were supplied with 80 g borax $tree^{-1}$, number of seeds $fruit^{-1}$ were 11.5 being maximum.

4.1.1.7 Tissue Boron Concentration

A. Boron Concentrations in Plant Parts before Imposing Boron Treatment

At 5 days before imposing B treatments, B concentrations in flower, YOL and young shoot were not different among B treatments trees(Table 4.6). The order of plant parts having B concentration from high to low were as following: young shoot, central flower, border flower and YOL. Thus, it may suggest that under comparable conditions, trees with B concentrations at full bloom in YOL, border and central flowers and shoot, respectively equal to or lower than 24, 28, 32 and 37 mg kg^{-1} dry wt. will probably experience B deficiency at the later stage leading to low yield unless B fertilizer is applied.

Table 4.6 Boron concentrations (mg kg^{-1} dry wt.) in flower, youngest open leaf and young shoot in Golden Delicious apples at five days before borax application. Values are means of 4 replications.

Plant part	B0	B40	B80	B160	Mean
Border Flower	29c	28c	27c	28c	28
Central Flower	33b	31b	32b	31b	32
Youngest open leaf	23d	24d	23d	25d	24
Young shoot	39a	36a	36a	37a	37

B0, B40 etc. refer to 0g borax $tree^{-1}$, 40 g borax $tree^{-1}$ etc.

Means followed by the same letter are not significantly different at 5% level.

B. Boron Concentrations in Plant Parts after Imposing Boron Treatment

B.1 Shoot Boron Concentration

Higher B application led to higher B concentrations in shoots except at 4W in B40 trees (Figure 4.1a.). Changes with time of B concentrations in shoots in all B treatments showed the same pattern. Boron concentrations in the shoots slightly decreased from 4W to 8W, then slightly increased up to 12W and declined until 20W.

At 4W, supplying 40 g borax $trees^{-1}$ increased shoot growth without change of shoot B concentration (Table 4.1 and Figure 4.1 a). This may be attributed to the fact that in low B soil, for each additional increment of B absorbed by the trees, there was a corresponding increment of additional shoot growth so that the amount of B per unit mass of tissue remained approximately constant. However, supplying 80 g borax $trees^{-1}$ increased both shoot growth and shoot B concentration (Table 4.1 and Figure 4.1 a) suggesting that 80 g borax $trees^{-1}$ increased B content in shoot at a higher rate compared with increasing shoot growth. Applying 160 g borax $trees^{-1}$ increased shoot B concentration without change of shoot growth suggesting that B deficiency was no longer a limiting factor.

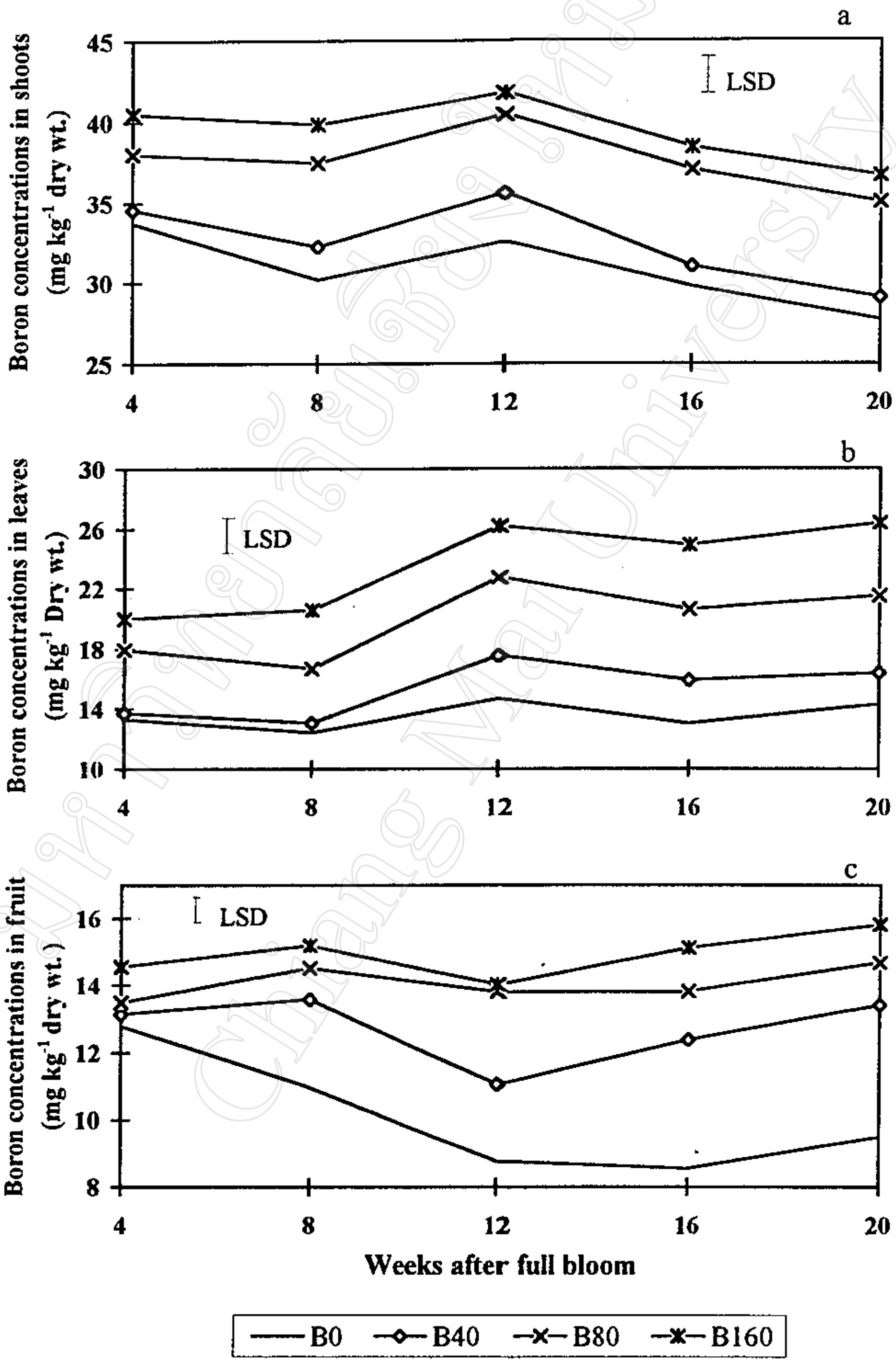

Figure 4.1 Effect of borax application on boron concentrations in shoots (a), youngest fully expanded leaves (b) and fruit (c) in Golden Delicious apples. B0, B40 etc. refer to 0 g borax tree^{-1}, 40 g borax tree^{-1} etc.

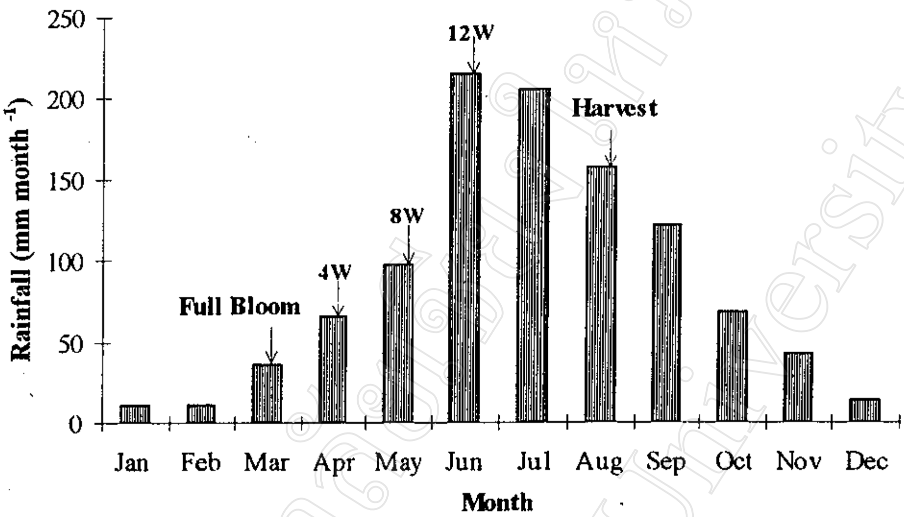

Figure 4.2 Rainfall in Dabaiqiao Horticultural Farm, Kunming in 1996. 4W, 8W etc. refer to 4 weeks after full bloom, 8 weeks after full bloom etc.

B.2 Leaf Boron Concentration

Leaf B concentrations in high B trees were higher than those in low B trees at 4W except in B40 trees (Figure 4.1b). Similar explanation in B.1 can also be applied for leaf B concentration. Changes with time of leaf B concentrations in all B treatments showed the same pattern. During 4W-8W, leaf B concentrations were relatively stable. Then, leaf B concentrations increased up to 12W and were stable until 20W. Increasing B concentrations in shoot and leaf during 8W-12W may be attributed to increase in availability of soil B due to markedly increasing rainfall after 8W (Figure 4.2). The increasing leaf B concentration after rain were also observed in black gram (Noppakoonwong *et al.*, 1997) and barley (Gupta, 1979).

Since B80 trees had the highest yield, it may suggest that in trees grown under comparable conditions, high yield may be obtained when leaf B concentration is equal to or higher than leaf B concentrations in B80 trees being 18±1.6, 17±1.3, 23±1.0, 21±1.7 and 23 ± 1.4 mg kg^{-1} dry wt. at 4W, 8W, 12W, 16W and 20W, respectively (Figure 4.1b).

B.3 Fruit Boron Concentration

Fruit B concentrations in high B trees were higher than those in low B trees except in B40 and B80 trees at 4W (Figure 4.1c). Changes with time of fruit B concentrations in different B treatments showed different patterns. In B0 trees, during 4W-12W, B concentrations in fruit decreased. During 12W-20W, B concentrations in B0 fruit were relatively constant. In B40 trees, during 4W-8W, B concentrations in fruit were relatively constant. During 8W-12W, B concentrations in fruit decreased then increased until 20W. In both B80 and B160 trees, B concentrations were relatively constant during fruit development suggesting that B content in fruit in high B treatment increased at the same rate as increasing fruit dry weight during fruit development.

During 8W-12W, B concentrations in leaves increased whereas B concentrations in fruit were stable in high B trees or even decreased in low B trees. This difference may be attributed to the fact that fruit size rapidly increased during this period (Table 4.1) whereas leaf size grew at a slower rate and tended to reach maximum size at about 12W.

Since B80 trees had the highest yield, it may suggest that in trees grown under comparable conditions, high yield may be obtained when fruit B concentration is equal to or higher than fruit B concentrations in B80 trees being 13.6±0.4, 14.6±0.9, 13.8±0.5, 13.8±1.2 and 14.7±0.7 mg kg^{-1} dry wt. at 4W, 8W, 12W, 16W and 20W, respectively (Figure 4.1c).

B.4 Boron Concentrations in Retained and Dropped Fruit

At pea-size drop, the highest B concentration in dropped fruit of all B treatments was 12.4 mg kg^{-1} dry wt., being equal to or lower than 12.8 mg kg^{-1} dry wt., the minimum B concentration of retained fruit (Table 4.7). Similarly, at June drop, the highest B concentration in dropped fruit of all B treatments was 8.7 mg kg^{-1} dry wt. being equal to or lower than 8.8 mg kg^{-1} dry wt., the minimum B concentration of retained fruit. Thus, fruit tended to drop when the fruit B concentrations was less than 12.8 and 8.8 mg kg^{-1} dry wt. at pea-size drop and June drop, respectively.

Table 4.7 Effect of borax application on boron concentrations (mg kg^{-1} dry wt.) in retained and dropped fruit at pea-size drop, June drop and pre-harvest drop in Golden Delicious apples. Values are means of 4 replications.

	Pea-size drop[A]		June drop		Pre-harvest drop	
Borax rate (g $tree^{-1}$)	Retained fruit	Dropped fruit	Retained fruit	Dropped fruit	Retained fruit	Dropped fruit
0	12.8a	10.2a	8.8a	7.0a	8.4a	7.1a
40	13.1ab	10.3a	11.1b	8.0b	12.1b	8.1b
80	13.6b	11.7b	13.8c	8.6c	13.3c	10.3c
160	14.5c	12.4c	14.0c	8.7c	14.7d	11.8d

[A]Pea-size drop, June drop and Pre-harvest drop refer to 4, 8 and 16 weeks after full bloom, respectively.
Means in a column followed by the same letter are not significantly different at 5% level.

By contrast, at pre-harvest drop, B concentrations of dropped fruit in B80 and B160 trees, 10.3 and 11.8 mg kg^{-1} dry wt. respectively, were higher than 8.4 mg kg^{-1} dry wt., the minimum B concentration of retained fruit (Table 4.7). The dropping of high B fruit at late reproductive stages may be attributed to other factors, such as insufficient photosynthate; the requirement for photosynthate in B80 was higher than that of B40 trees because fruit weight and yield in B80 trees was higher than that of B40 trees (Table 4.4). However, the limiting photosynthate may have little or no effect on fruit drop after 3W when its effect ceased (Table 4.2).

B.5 Boron Concentrations in Fruit Parts

At harvest, B concentrations in the skin, outer cortex, inner cortex , and core increased with increasing B application rates (Figure 4.3). Fruit core had the highest B concentration compared with other fruit parts ($p<0.05$). Moreover, differences of fruit core B concentrations among treatments were the greatest compared with other fruit parts.

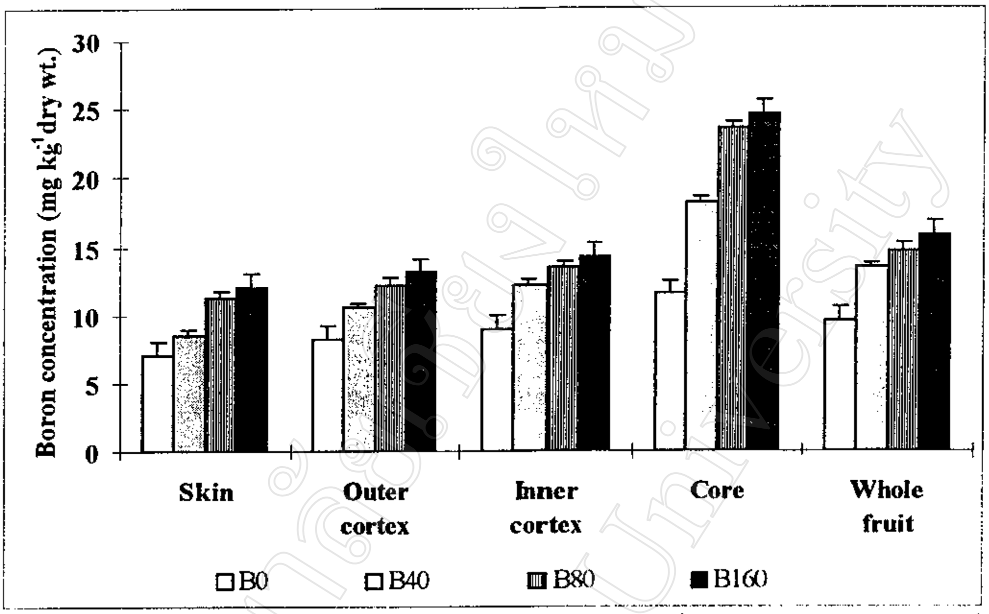

Figure 4.3 Boron concentrations in skin, outer cortex, inner cortex, core and whole fruit in Golden Delicious apples at harvest. B0, B40 etc. refer to 0 g borax tree^{-1}, 40 g borax tree^{-1} etc. Vertical bar refers to standard error.

4.1.2 Prognosis

4.1.2.1 The Relationships between Yield or Fruit Total Sugar at Harvest and Leaf Boron Concentration at 4 Weeks after Full Bloom

Trees can be separated into 2 groups with respect to leaf B concentration at 4W and yield (Figure 4.4 a). In group 1, leaf B concentrations were equal to or higher than 16 mg kg^{-1} dry wt. and yield was about 68 kg tree^{-1} whereas those in group 2 were equal to or lower than 14 mg kg^{-1} dry wt. and 63 kg tree^{-1}, respectively. This suggested that increasing leaf B concentrations increased yield. However, in group 1, yield did not increased with increasing leaf B concentration suggesting that B was little or no longer a limiting factor. By contrast, in group 2, yield increased with little or no change of leaf B concentration. It may be concluded that yield will reach maximum when leaf B concentration at 4W is equal to or higher than 16 mg kg $^{-1}$ dry wt. whereas yield will be low if leaf B concentration at 4W is equal to or lower than 14 mg kg^{-1} dry wt.. Thus, from this experiment, it is suggested that a critical leaf B concentration for prognosis of maximum fruit yield at 4W should be higher than 14 mg kg^{-1} dry wt. but lower than 16 mg kg^{-1} dry wt..

Trees can be separated into 2 groups with respect to leaf B concentration and total sugar. Leaf B concentrations in group 1 were equal to or higher than 16 mg kg^{-1} dry wt. but that in group 2 were lower than 14 mg kg^{-1} dry wt. (Figure 4.4 b). In group 1, total sugar was higher than those trees of group 2 and constant with increasing leaf B concentration suggesting that in group 1 trees, B deficiency was no longer a limiting factor. In group 2, total sugar rapidly increased with small increasing their leaf B concentration. Thus, critical leaf B concentration for prognosis of maximum total sugar at 4W should be higher than 14 mg kg^{-1} dry wt. but lower than 16 mg kg^{-1} dry wt..

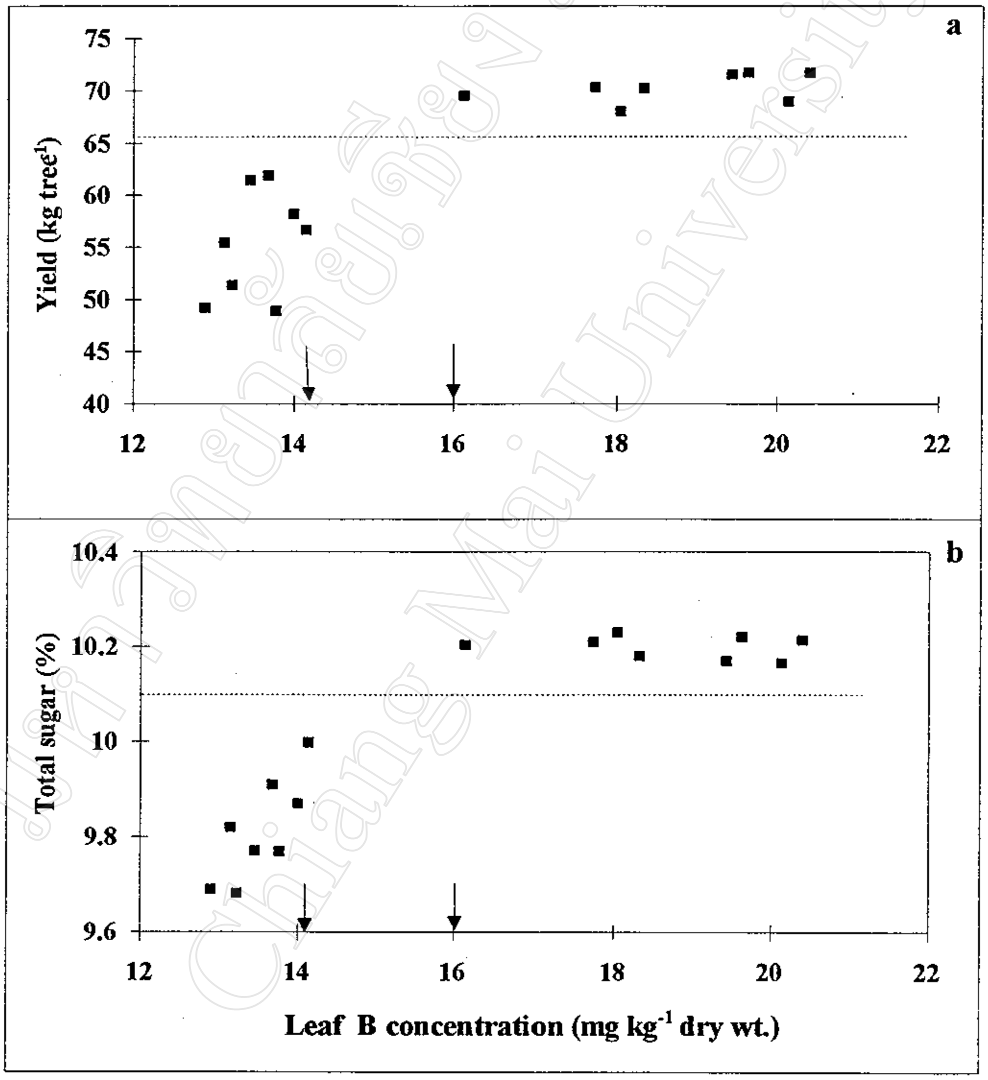

Figure 4.4 The relationships between yield (a) or fruit total sugar (b) at harvest and leaf boron concentrations at 4 weeks after full bloom. Broken line (----) is mean yield or fruit total sugar in B80 minus the LSD; it is used to distinguish between yield or fruit total sugar at boron sufficiency and deficiency. B80 refers to 80 g borax tree^{-1}.

4.1.2.2 The Relationships between Yield or Fruit Total Sugar at Harvest and Fruit Boron Concentration at 4 Weeks after Full Bloom

When fruit B concentration was lower than 13.5 mg kg^{-1} dry wt. at 4W, fruit yield and total sugar rapidly increased with increasing fruit B concentration (Figure 4.5). When fruit B concentration was higher than 13.5 mg kg^{-1} dry wt., fruit yield and total sugar reached maximum and did not change further. Thus, critical fruit B concentration for maximum yield and total sugar should be about 13.5 mg kg^{-1} dry wt. similar to mean of fruit B concentration in B80 trees at 4W (Figure 4.1 c).

At early reproductive stage, both leaf and fruit B concentration are good indicators for prognosis of B deficiency.

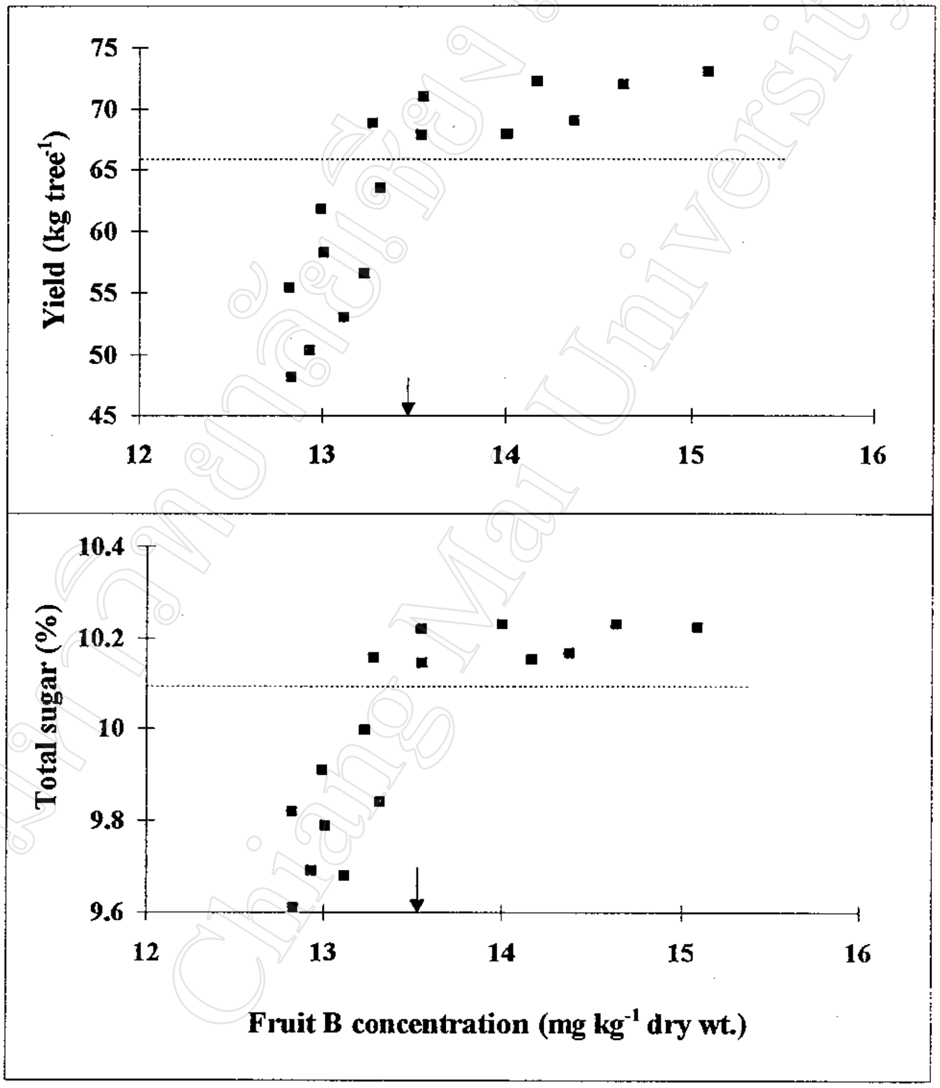

Figure 4.5 The relationships between yield or fruit total sugar at harvest and fruit boron concentrations at 4 weeks after full bloom. Broken line (----) is mean yield or fruit total sugar in B80 minus the LSD; it is used to distinguish between yield or fruit total sugar at boron sufficiency and deficiency. B80 refers to 80 g borax tree^{-1}.

4.1.3 Diagnosis

4.1.3.1 The Relationships between Yield or Fruit Total Sugar and Leaf B Concentration at 20 Weeks after Full Bloom (harvest)

Trees can be separated into 2 groups with respect to leaf B concentration at harvest. Leaf B concentrations in group 1 were equal to or higher than 21 mg kg^{-1} dry wt. but that in group 2 were equal to or lower than 17 mg kg^{-1} dry wt. (Figure 4.6). In group 1, yield and total sugar was higher than those trees of group 2 and constant with increasing leaf B concentration suggesting that in group 1 trees, B deficiency was no longer a limiting factor. In group 2, yield and total sugar rapidly increased with small increases in their leaf B concentration. Critical leaf B concentration for maximum of fruit yield and total sugar at harvest should be higher than 17 mg kg^{-1} dry wt. but lower than 21 mg kg^{-1} dry wt. (Figure 4.1b). This range of leaf B concentrations (17-21 mg kg^{-1} dry wt.) is lower than 21-40 mg kg^{-1} dry wt., the reported adequate range of leaf B concentration and quite similar to the range of 15-20 mg kg^{-1} dry wt. being the marginal range of leaf B concentration in apple at late reproductive stage (Robinson, 1986). Thus, the range of critical value for diagnosis of B deficiency in apple in southern China should be 17-20 mg kg^{-1} dry wt. and can be used to access B status under field conditions.

The exact leaf B diagnostic values at harvest could not be obtained from the present experiment due to lack of data points in the marginal range between B40 to B80. Thus, in order to obtain the leaf diagnostic value, a further B rate experiment should include 60 g borax $tree^{-1}$ treatment.

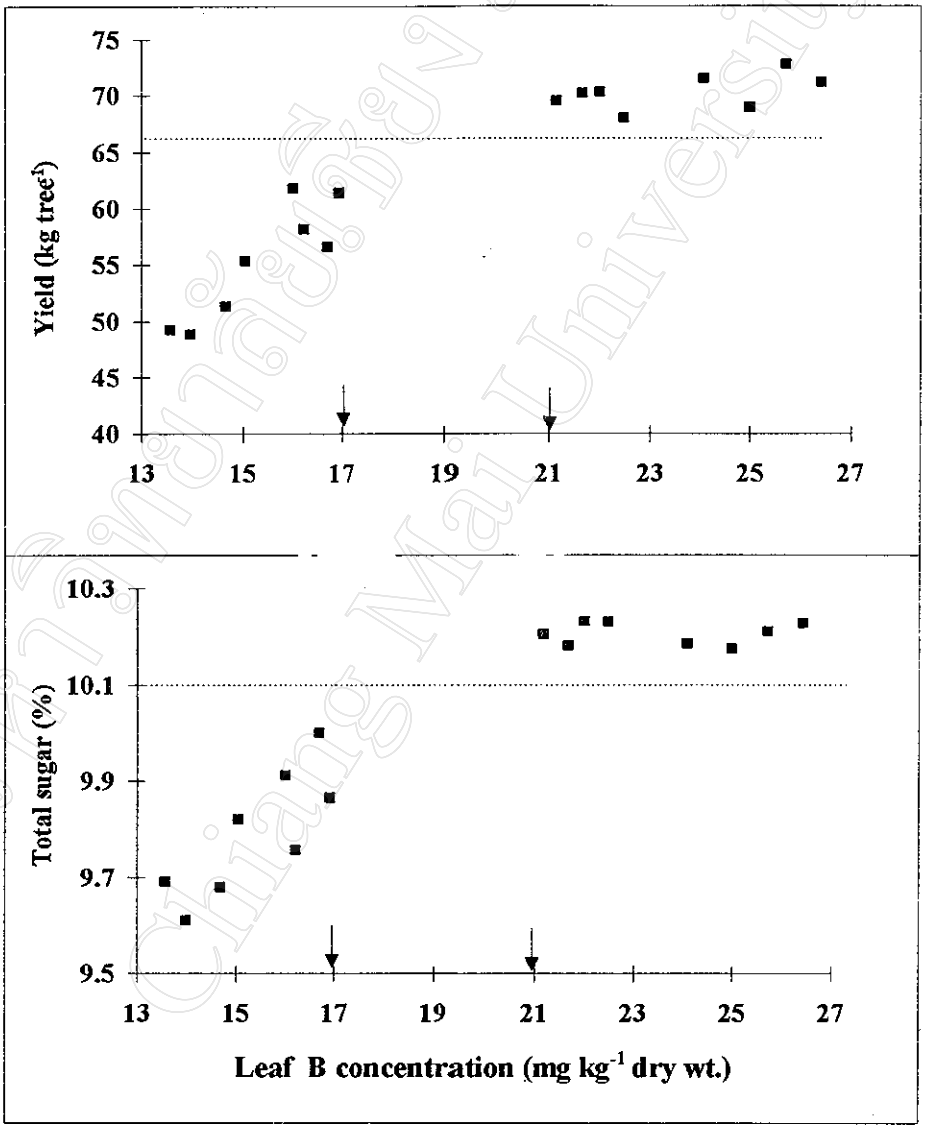

Figure 4.6 The relationships between yield or fruit total sugar and leaf boron concentrations at 20 weeks after full bloom (harvest). Broken line (----) is mean yield or fruit total sugar in B80 minus the LSD; it is used to distinguish between yield or fruit total sugar at boron sufficiency and deficiency. B80 refers to 80 g borax tree^{-1}.

4.1.3.2 The Relationships between Yield or Fruit Total Sugar and Fruit Core Boron Concentration at 20 Week after Full Bloom (harvest)

Fruit yield and total sugar rapidly increased with increasing fruit core B concentration when fruit core B concentrations were lower than 22 mg kg^{-1} dry wt. (Figure 4.7). By contrast, when fruit core B concentrations were higher than 22 mg kg^{-1} dry wt., fruit yield and total sugar did not increase with increasing fruit core B concentration suggesting that B deficiency was no longer a limiting factor. Thus, critical fruit core B concentration for maximum yield and total sugar at 20W should be about 22 mg kg^{-1} dry wt..

4.1.3.3 The Relationships between Yield or Fruit Total Sugar and Fruit Boron Concentration at 20 Weeks after Full Bloom (harvest)

Yield and total sugar increased in a linear relationship with increasing fruit B concentration (Figure 4.8). Thus, critical B concentration can not be obtained. The differences of leaf and fruit core B concentrations compared with fruit B concentration regarding their correlation to yield and total sugar will be discussed later in 5.3 section.

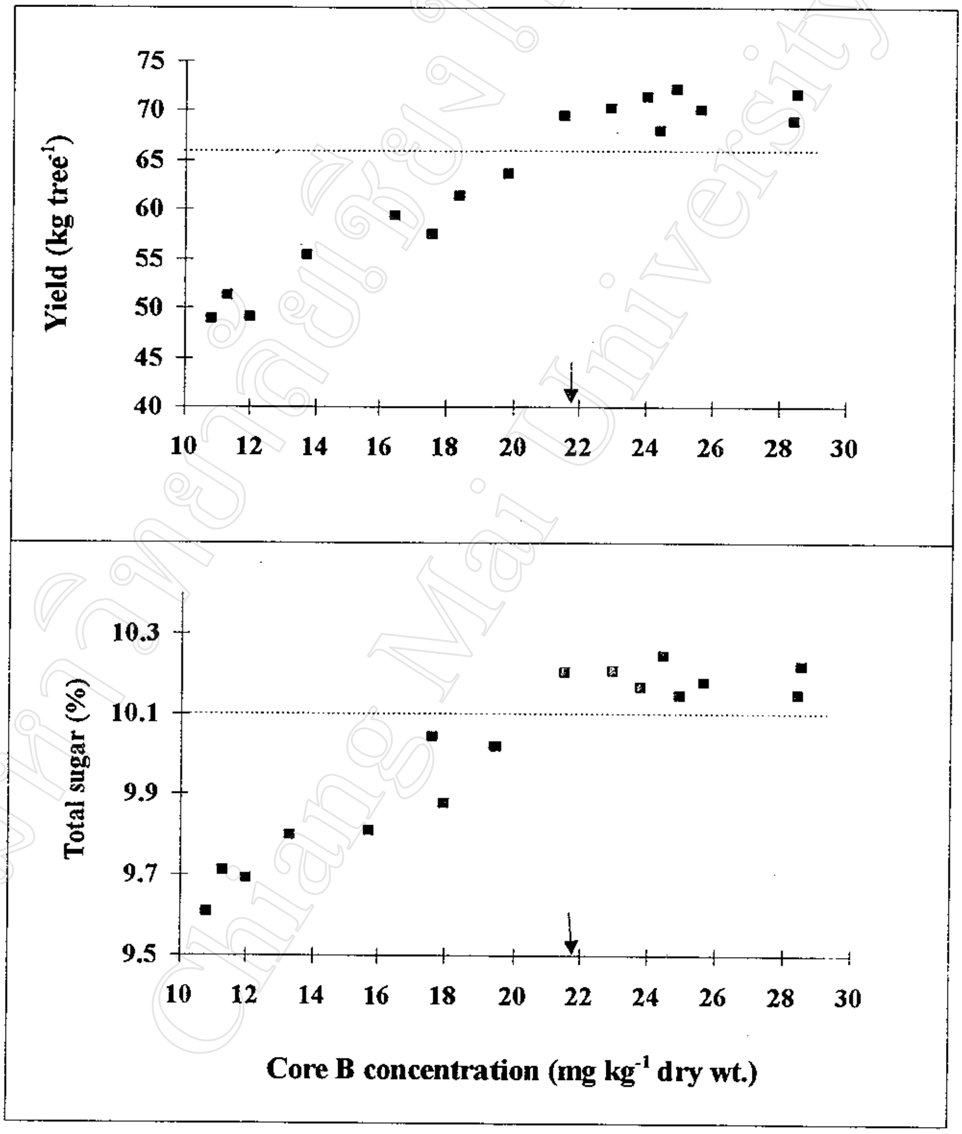

Figure 4.7 The relationships between yield or fruit total sugar and fruit core boron concentrations at 20 weeks after full bloom (harvest). Broken line (----) is mean yield or fruit total sugar in B80 minus the LSD; it is used to distinguish between yield or fruit total sugar at boron sufficiency and deficiency. B80 refers to 80 g borax tree^{-1}.

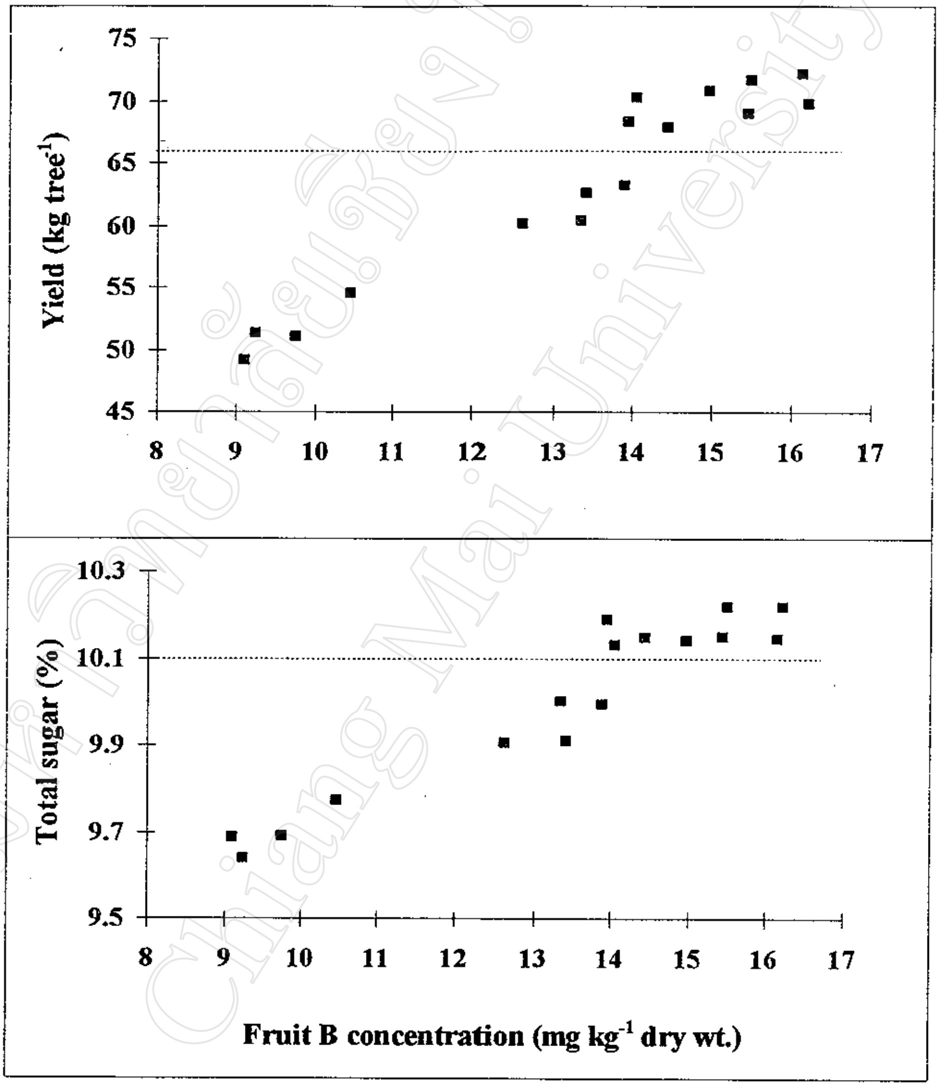

Figure 4.8 The relationships between yield or fruit total sugar and fruit boron concentrations at 20 weeks after full bloom (harvest). Broken line (----) is mean yield or fruit total sugar in B80 minus the LSD; it is used to distinguish between yield or fruit total sugar at boron sufficiency and deficiency. B80 refers to 80 g borax tree^{-1}.

4.1.4 Effect of Storage Time and Low Temperature on Fruit Quality

Total sugar and soluble solids of fruit at harvest were lower than those stored for 25 days after harvest, but fruit firmness, titratable acidity and vitamin C were higher (Table 4.8). Thus, fruit became sweeter and softer when they were kept longer. Compared with fruit kept at low temperature, soluble solids in fruit kept in high temperature was higher whereas vitamin C was lower. However, total sugar, titratable acidity and firmness of fruit kept under different storage temperatures had no difference. These results reflect well characterized physiological changes in apple fruit in storage and during post-storage ripening: softening, conversion of starch to sugar and metabolism of organic acids (Esmacil, *et al.*, 1985; Kaushal and Sharma, 1995).

Table 4.8 Effect of storage time and temperature on fruit quality of Golden Delicious apple trees supplied with 160 g borax per tree. Values are means of 4 replications.

Quality parameters	Fruit at harvest	Fruit kept 25 days after harvest	
		20 ^{0}C	4-5 ^{0}C
Soluble solids(%)	12.6c	13.8a	13.3b
Total sugar(%)	10.16c	11.10ab	11.30a
Firmness (kg cm^{-2})	10.3a	8.0b	8.8b
Titratable acidity (% malic acid)	0.235a	0.220b	0.203b
Vitamin C (mg/100g fresh fruit)	2.2a	1.7c	1.9b

Means in a row followed by the same letter are not significantly differently different at 5% level.

4.1.5 Economic Benefit

Applying 80 g borax tree^{-1} clearly increased both gross income and net income (Table 4.9). Applying 160 g borax tree^{-1} did not further increase gross and net income, but the rate of return markedly decreased. Similarly, the highest borax efficiency was obtained from B80 trees. Therefore, the highest rate of return and borax efficiency were obtained from B80 trees.

Table 4.9 Economic consideration of different treatments. Values are means of 4 replications

Borax (g tree^{-1})	Gross income[A]	Costs[B]	Net income	Increasing net income	Cost of borax	Rate of return	Borax efficiency[C]
	Yuan tree^{-1}						
0	82.4c	25	57.4c	0	0		
40	157.0b	27	130.0b	72.6b	2	36.3b	200a
80	310.5a	29	281.5a	224.1a	4	56.0a	180a
160	321.8a	33	288.8a	231.4a	8	28.9c	100b

[A] Gross income = yield x price (The sale price of fruit in B0, B40 B80 and B160 tree was 1.5, 2.5, 4.5 and 4.5 yuan kg^{-1}, respectively. B0, B40 etc. refer to 0 g borax tree^{-1}, 40 g borax tree^{-1} etc. 1 Yuan = 0.125 Dollar).

[B] Costs of apple production including cost of labor, irrigation management, pesticide and fertilizer.

[C] Borax efficiency = Increased yield (g) from BO treatment divided by g borax tree^{-1}.

Means in column followed by the same letter are not significantly different at 5% level.

4.2 Field Survey

4.2.1 Fertilizer Management in Apple Orchards in Yunnan

In general, fertilizer management of apple production in Zhaotong, Lijian and Kunming are quite similar (Table 4.10). Fruit growers used urea, calcium superphosphate and potassium sulphate as sources of N, P, K. There were 7 tapes of fertilizers application used by fruit growers. Sixty percent, 23% and 10% of fruit growers used 60-30-30, 30-15-15 and 30-15-0 (kg N ha^{-1} - kg P ha^{-1} - kg K ha^{-1}) respectively. The rest 7% did not supply any fertilizer. Animal manure was only applied by most fruit growers who applied N, P, K fertilizer and these accounted for 77% of total fruit growers. Micronutrient was applied by fruit growers who applied the highest rate of N, P, and K fertilizer and animal manure and it accounted for 8.3 % of total fruit growers.

4.2.2. The Relationships between Weight, Length, Diameter, Firmness, Soluble solids of Fruit or Seed Number per Fruit or and Leaf boron Concentrations at Harvest

Similar to the field experiment, weight, length and diameter of fruit, and seed number $fruit^{-1}$ increased with increasing leaf B concentration whereas fruit firmness and soluble solids decreased (Figure 4.9). However, although leaf B concentrations were higher than 21 mg kg^{-1} dry wt., weight, length and diameter of fruit and seed number $fruit^{-1}$ did not reach maximum. This may be attributed to the fact that under the variable field environment conditions, other factors apart from B deficiency affected fruit growth and fruit quality.

4.2.3 The Relationships between Weight, Length, Diameter, Firmness, Soluble solids of Fruit or Seed Number per fruit and Fruit Boron Concentrations at Harvest

Similar to field experiment, weight, length and diameter of fruit and seed number fruit^{-1} increased with increasing fruit B concentration whereas fruit firmness and soluble solids decreased (Figure 4.10).

Table 4.10 Types of fertilizer management in Zhaotong, Lijiang and Kunming orchards. Number in parenthesis is percentage

	Types						
	1	2	3	4	5	6	7
N(kg ha^{-1})	60	60	60	30	30	30	-
P(kg ha^{-1})	30	30	30	15	15	15	-
K(kg ha^{-1})	30	30	30	15	15	-	-
Animal manure (x1000 kg ha^{-1})	2-3	2-3	-	2-3	-	-	-
Micronutrient (kg ha^{-1})	10	-	-	-	-	-	-
Zhaotong (n=20)	2 (10)	7 (35)	1 (5)	4 (20)	1 (5)	3 (15)	2 (10)
Lijiang (n=20)	0 (0)	11 (55)	1 (5)	3 (15)	1 (5)	2 (10)	2 (10)
Kunming (n=20)	3 (15)	11 (55)	0 (0)	5 (25)	0 (0)	1 (5)	0 (0)
Total (n=60)	5 (8.3)	29 (48.3)	2 (3.3)	12 (20)	2 (3.3)	6 (10)	4 (6.6)

n refer to number of orchards

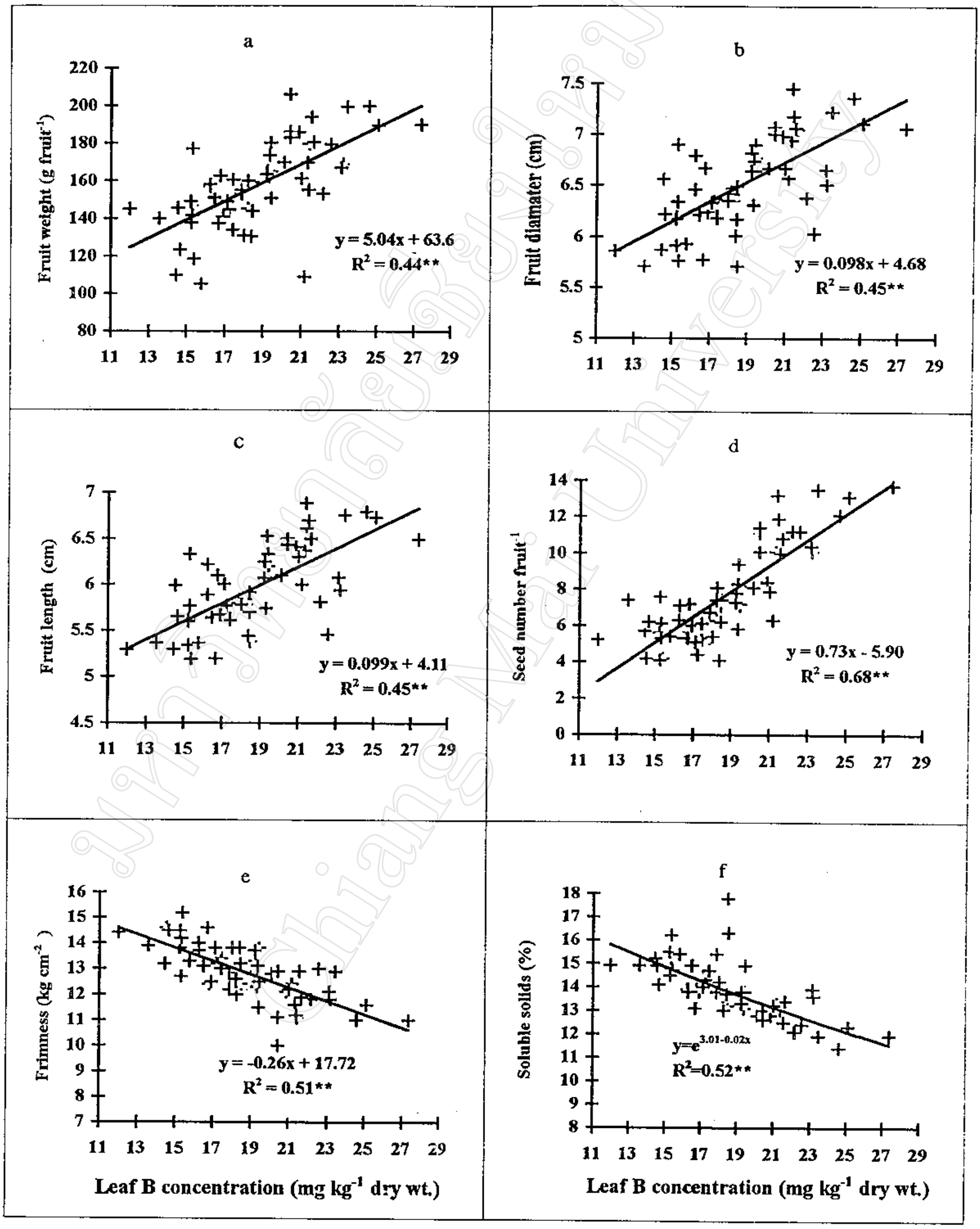

Figure 4.9 The relationships between fruit weight (a), diameter (b), length (c), seed number per fruit (d), firmness (e) or soluble solids (f) and leaf boron concentrations at harvest.

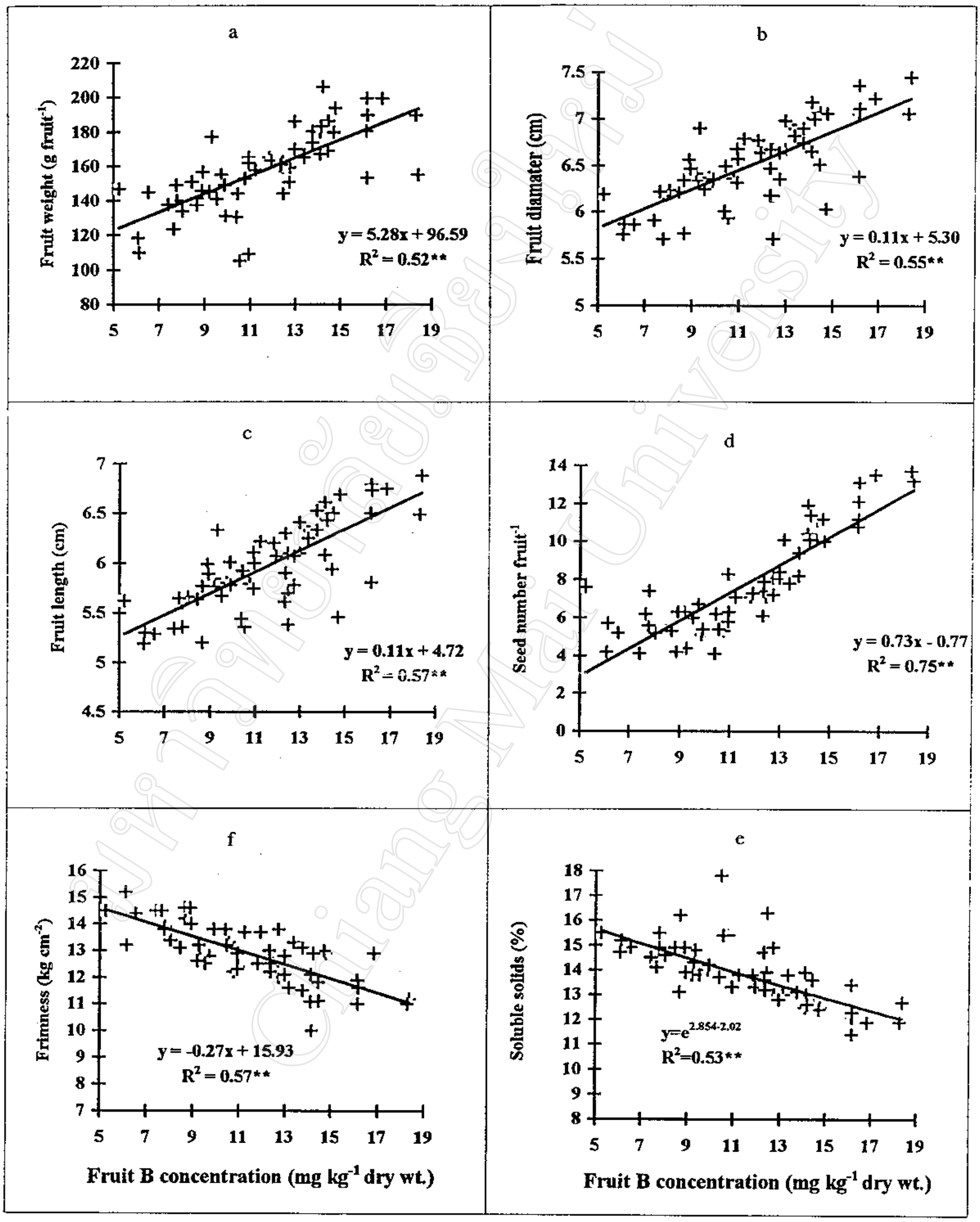

Figure 4.10 The relationships between fruit weight (a), diameter (b), length (c), seed number per fruit (d), firmness (e) or soluble solids (f) and fruit boron concentrations at harvest.

4.2.4 Distribution and Severity of Boron Deficiency in Apple Growing Areas in Yunnan

The field experiment results suggest that at harvest, when leaf B concentration was equal to or higher than 21 mg kg^{-1} dry wt., B was not a limiting factor for maximum yield and quality but when leaf B concentration equal to or higher than 17 mg kg^{-1} dry wt., B deficiency decreased yield and its quality.

Thus, surveyed orchards were separated into 3 groups based on their leaf B concentrations (Table 4.11).

In Lijiang, the two sites were identical in the level of severity of B deficiency. In Zhaotong, Ludian was more severely B deficient than Shayi. Xishan in Kunmimg was least affected B deficiency.

In three areas, ranking of the B deficiency distribution and severity from the high to low are as following: Ludian (Zhaotong), Guaidu (Kunming), Taian (Lijiang), Baisha (Lijing), Shayi (Zhaotong), Xishan (Kunming).

Table 4.11 Leaf boron concentrations in three surveyed areas at harvest. Number in parenthesis are percentage.

Leaf B concentration (mg kg^{-1})	Locations						Total
	Lijiang		Zhaotong		Kunming		
	Taian	Baisha	Ludian	Shayi	Guaidu	Xishan	n=60
≤ 17	4(20)	4 (20)	6 (30)	3 (15)	6 (30)	0	23 (38)
>17 - <21	5(25)	5 (25)	3 (15)	4(20)	3(15)	4(20)	24 (40)
≥ 21	1(5)	1(5)	1 (5)	3(15)	2(10)	5(25)	13 (22)

In these surveyed areas, 22%, 40% and 38% of total samples had leaf B concentration equal to or higher than 21 mg kg^{-1} dry wt., within the range of 17-21 mg kg^{-1} dry wt. and equal to or lower than 17 mg kg^{-1} dry wt., respectively (Table 4.11).

Therefore, at least 38 % of apple growing areas had low B soil causing low apple yield and quality. Apple yield and quality in these areas can be improved by application of B fertilizer. However, the long term fertilizer rate experiments need to be conducted in these 3 areas before providing B fertilizer recommendations to fruit grower.