Report AH-01-59: Water and nutrient management for high quality fruit

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Objectives:

1. To determine the effects of mulching and organic amendment, irrigation method and scheduling and N management on performance of a young fruiting block of Braeburn/M.9 (Naches site).
2. To determine the effects of irrigation system, mulching and organic amendment and N management on tree performance and fruit quality, the vertical and horizontal distribution of soil moisture, indicators of plant water stress, and to create water, N and P budgets for young year-old Braeburn/M.26 (Summerland site).
3. To investigate the use of polyacrylamide gel (PAM) on soil moisture retention in relation to irrigation management and mulching.
4. To determine the feasibility of using plant sensors to measure tree response to water stress.
5. To complete the fifth year of a trial (4^{th} fruiting year) comparing N and P fertilization effects on fruit yield and to investigate the link between P and fruit quality.
6. To determine the effects of timing of foliar Ca sprays and soil Ca applications on fruit quality.

Significant findings:

1-1 Overall, alfalfa straw mulch with drip irrigation was the most successful treatment in overcoming growth and
yield limitations in Braeburn/M.9 growing on replant affected soils, but mow and blow with sprinkler was effective in 2004.
1-2 Soil moisture distribution, but not content was affected by drip emitter placement and flow rate. Trees in soil
with greater moisture content at 0-20cm depth and wider lateral spread were less stressed.
2-1 Braeburn/M26 (Summerland) had more growth and yield than Braeburn/M.9 (Naches) 2002-2004. Trees receiving the biosolids amendment had the highest fruit number and yield (2002, 2003) and also had more consistently firm and sweet fruit than other treatments in all years. These effects may be attributable to higher P availability in the biosolids treatment
2-2 Although soil moisture fluctuates greatly on a daily basis, it is relatively constant over the growing season, and is higher under microsprinkler than drip at all locations in the herbicide strip except closest to the row. In-field water balances were constructed and demonstrated that atmometer scheduling in both drip and microsprinkler meets tree requirements well.
2-3 Movement of N through the root zone was driven by N applications and amount of water applied. There were
no effects of large applications of N on leaf N concentration, growth or yield and tree uptake could not explain the large amount of unaccounted for N in the high N treatment. N sequestration likely occurred in the soil microbial biomass.
3-1 Shredded paper mulch was more beneficial than PAM in promoting growth of newly planted Silken/M.9.
4-1 Sap flow gages were more responsive, had a clearer signal and were less sensitive to disturbance than strain gage dendrometers in measuring tree response to diurnal fluctuations in temperature, light and water availability
5-1 *Effects described in section 5 were measured across all cultivars.*
Leaf N concentrations decline during the season as fruit sizes. Thus, minimum leaf N concentrations are measurable just prior to harvest.

5-2 Lowest leaf N concentrations were measured in 2003 after an early freeze the end of October the year previous (2002), followed by a spring bloom frost and low crop in 2003.
5-3 Maintaining a high N fertilizer regime increased leaf N concentration (<10%) and fruit N concentration (10-20%) but consistently decreased fruit firmness and to a lesser extent percent red color.
5-4 Changing the timing of applications of N-fertilizer altered leaf and fruit N concentration but had few consistent effects on fruit quality or yield.
5-5 A single application of 20g of P per tree just after bloom was highly effective at increasing leaf and fruit P concentration compared to trees receiving N only during time A.
5-6 The P treatment described in 5-5 was the most impressive treatment in this experimental block with highest cumulative yield of all treatments. Fruit harvested from this treatment could have reduced incidence of water core and improved membrane stability as well as reduced susceptibility to browning when cut.
6-1 Five weekly $CaCl_2$ sprays applied early, commencing the first week of June and ending the first week of July, substantially reduced and often eliminated incidence of bitter pit at harvest.
6-2 In years of severe Ca deficiency and large fruit, this early season spray regime alone was insufficient to prevent development of surface lenticel pitting.
6-3 Achieving fruit with maximum Ca concentration at harvest, as might be the goal for optimizing fruit storage quality where no obvious Ca disorders are present, is best achieved by applying $CaCl_2$ close to harvest.
6-4 Soil Ca thiosulphate applications and foliar applications of acidified calcium carbonate compounds were less effective for improving fruit Ca nutrition.
6-5 Water core and Braeburn browning were not affected by Ca – treatments.

Methods:
1. Four year-old Braeburn/M.9 at Allan Orchards, Naches, WA received atmometer-scheduled drip irrigation either at total evaporative demand or reduced to account for mulch effect or ABS-sprinkler (grower schedule). N was fertigated at a low or high N concentration from May – Sept in 2002-2003. N and I treatments were discontinued in 2004 as they had shown little effects n 2002-03. New treatments comprised the same amount of water being applied either twice daily (I1), every two days (I2) , through 2 x 4-L/h emitters at 30cm either side of the tree in the row (E1) or 4 x 2-L/h drippers placed either side of the tree at 30 cm within and perpendicular to the row (E2). Minimally composted dairy solids were applied at 50 tons/acre and alfalfa straw mulch was applied at the rate of 56 tons/acre in May 2002 and 'topped up in May 2003 and 2004. Electronic monitoring of water flow to each treatment, atmometer evaporation and soil temperature was carried out. Tree growth, leaf and fruit nutrient content, fruit yield and quality and tree water status measurements were made.
2. Two year-old Braeburn/M.26 at Summerland received either atmometer-scheduled drip irrigation (2/tree) or micro-sprinkler irrigation (40in ~1m throw one/tree). There were six replicates and five treatments: 1. fertigated low N (28ppm) 2. fertigated high N (168 ppm) 3. treat1+ spray on mulch 4. treat 1+ municipal compost 5. treat 1 + mulch +compost. Tree growth, leaf and fruit nutrient content, fruit yield and quality and tree water status measurements were made. To collect temporal and spatial water and nutrient balance data: 1. Hourly soil moisture measurements were made in treatments 1 and 3 using TDR, and 2. Passive capillary wick samplers were used to collect drainage beneath treats 1,2,3, and 5. 3.Soil samples for N and P analysis were collected.
3. Silken/M.9 apples were planted in 2003, in a coarse sand soil at PARC, Summerland, with irrigation supplied by 2.8 gpm sprinklers, 45min every second day. PAM was pre-mixed in the planting trench (0.4% dw) and compared with shredded paper mulch and control treatments in a four replicate experiment.
4. In 2004, trees were fitted with strain-gage dendrometers and heat balance sap flow sensors (DynaMax Inc.) to test diurnal patterns in voltage in response to light, temperature and moisture stress. Young peach trees were planted in 14 inch diameter pots filled with peat/soil/perlite

commercial potting mix. Pots were weighed daily and watered to weight either daily (well-watered) or every three days (stressed).

5. The same eight different fertilizer treatments applied through drip irrigation lines were maintained over the past 3 growing seasons in a fruiting experimental block planted at a high density in April 1998 at 3ft. within row by 10ft. between rows involving five newer cultivars (Gala, Fuji, Cameo, Ambrosia and Silken). Pertinent to this report were treatments involving high (target soil solution concentration 168 ppm) and low N regimes (target soil solution concentration 28ppm) each applied at 3 different times including time A (0-4 weeks post bloom), time B (4-8 weeks post bloom) and time C(8-12 weeks post bloom). In order to minimize water stress, irrigation was applied according to evaporative demand as calculated daily by an atmometer. An additional treatment usually involved a one time annual application of 20g of phosphorus per tree as ammonium polyphosphate (10-34-0) soon after bloom in a high early N, time A treatment (see results and discussion for 2004 methods). Detailed monitoring for each cultivar and treatment included multiple leaf samples for nutrient analysis throughout the growing season and at harvest, fruit nutrient analysis, soluble solids, titratable acidity, firmness and percent solid red color (for red cultivars), and incidence of fruit disorders. Total fruit numbers and harvest weight were also recorded. All data were statistically analyzed to determine the effects of rate and timing of nitrogen fertilization and the effects of a single large application of phosphorus early in the spring. A P-injection treatment was applied for two years at a site in Quincy Washington with fine-textured soil and buried irrigation lines.

6. For the past 3 growing seasons an experiment has been conducted in a block of 'Braeburn' apple trees on M.9 rootstock to compare the effects of various Ca application strategies on fruit Ca accumulation and bitter pit development. Treatments included 1) an unsprayed control, 2) early season calcium chloride applications (5 weekly sprays commencing the first week of June), 3) mid-season $CaCl_2$ (5 weekly sprays commencing the first week of July), 4) late season $CaCl_2$ (5 weekly sprays commencing the first week of August). Three additional treatments compared foliar application of two calcium carbonate compounds and soil applications (120 US gal/acre within the tree row in late spring) of calcium thiosulphate. Fruit Ca concentration and incidence of physiological disorders were measured each year at commercial harvest.

<u>Results and Discussion</u>:

1. Water and nitrogen management – Braeburn/M.9 at Naches

This experiment was initiated in 2001, to determine the effects of conservative water (drip/mulch/atmometer scheduled irrigation) and nutrient (fertigation/organic amendments) management on productivity of a Braeburn/M.9 planting. In 2002, it was determined that this site was replant affected (Mazzola replant test) which was confirmed by increased numbers of plant parasitic nematodes in some treatments (Forge WTFRC report 2003). Consequently, maintaining vegetative growth on a cultivar/rootstock combination which tends to promote intense spur production has been challenging.

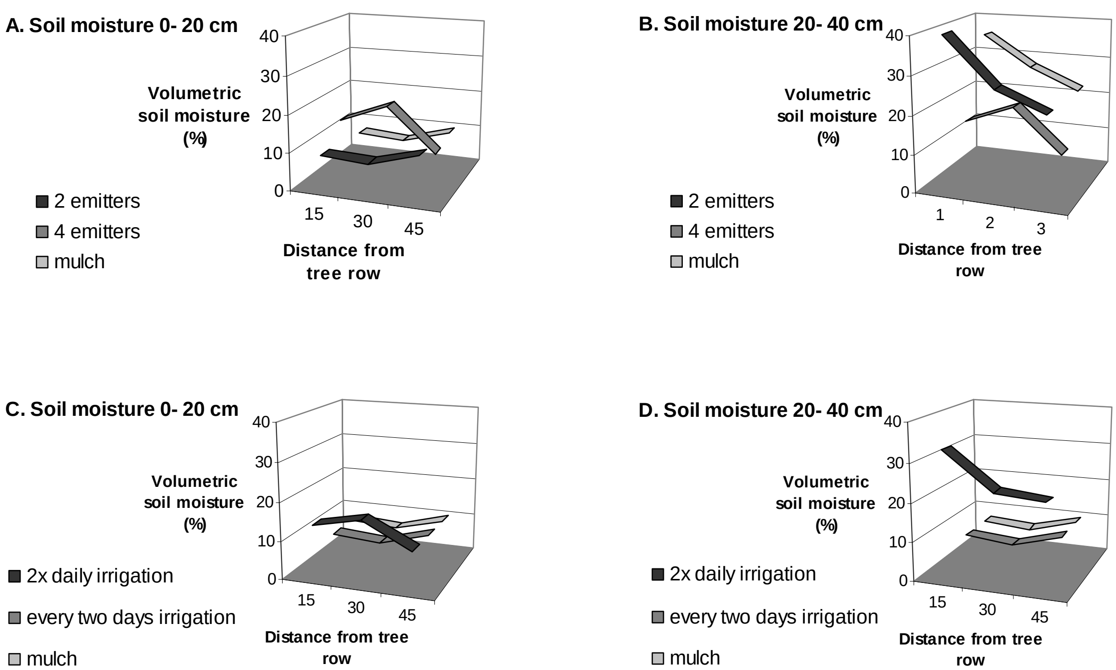
Table 1.1 Tree and fruit responses to irrigation, nitrogen, alfalfa straw mulch and dairy manure amendments for Braeburn/M.9 at a replant site in Naches, WA.

Year	Treatment	TCSA cm^2	Yield MT/ha	Fruit size (g)	Fruit No.	Colour (% red)	Soluble solids %	Firmness lbs	Starch Index
2002	low N I1	5.14bc	12.0c	207	19	84	12.9	20.7b	2.69b
	low N I2	4.9c	13.6abc	206	21	89	13.2	20.8b	2.82ab
	High N I1	4.96c	13.6bc	210	21	84	13.2	20.9b	2.84ab
	High N I2	5.25bc	13.6bc	207	21	84	13.2	20.6b	3.28ab
	Mulch I1	6.3a	16.7a	215	25	84	12.9	20.9b	2.85ab
	Mulch I2	6.35a	13.9abc	222	20	81	13	22a	3.42a
	Amendment	5.4bc	14.8abc	201	23	81	13.1	21.2b	3.23ab
	M + A	5.98ab	15.8ab	209	24	83	12.6	20.7b	3.06ab
	I3	5.25bc	15.1ab	200	24	72	12.7	21.1b	2.99ab
		***	*	ns	*	ns	ns	**	*
2003	low N I1	5.69c	10.7c	192bc	14b	24	16.6	20.6a	5.5bcd
	low N I2	5.69c	12.9c	185bc	17aqb	90	16.4	19.5cd	5.1cd
	High N I1	5.77c	12.9c	180c	19ab	84	16.7	20.1abc	5.5bcd
	High N I2	5.96c	12.9c	190bc	16ab	90	16.7	20.1abc	4.7d
	Mulch I1	7.45a	18.9ab	209ab	21a	84	16.9	19d	6.4a
	Mulch I2	7.13ab	20.8a	190bc	24ab	86	16.9	19.6abcd	5.8abc
	Amendment	5.9c	14.2bc	188bc	15b	79	16.6	19.9abcd	5.5bcd
	M + A	6.87ab	15.5abc	217a	17ab	82	16.7	19.4cd	6.2ab
	I3	6.37bc	12.3c	214a	14ab	87	15.7	20.5ab	3.8e
		***	**	**	**	ns	ns	**	**
2004	Emitter 1 I1	6.55d	20.8b	189d	38ab	84abc	13	20.6	2.55bc
	Emitter 1 I2	6.52d	16.7b	189d	31b	89a	13.3	20.6	2.33c
	Emitter 2 I1	6.74dc	13.9b	206bcd	25b	81bcd	12.9	21.1	2.97ab
	Emitter 2 I2	6.8dc	13.9b	216bcd	23b	86abc	13.6	20.5	3.21a
	Mulch I1	8.93a	22.4b	231abc	37ab	80cde	12.8	20.4	3.12ab
	Mulch I2	8.27ab	15.1b	206cd	28b	74e	13.2	20.8	2.9abc
	Amendment	6.88cd	16.4b	211bcd	29b	79cde	13	20.4	2.95abc
	M + A	8.01ab	18.9b	233ab	31b	75de	13. 3	20.3	3.42a
	I3	7.67bc	34.1a	241a	51a	88ab	12.9	20.7	2.95abc
		***	**	***	*	***	ns	ns	***

Means significantly different at 1% (*) or 0.01% (***) level of probability or not significantly different (ns). Means followed by different letters significantly different at the probability level indicated.

Tree growth was highest under alfalfa straw mulch (Mulch I1, I2 treatment, Table 1.1). High N applications did not result in increased growth. Until 2004, yield, fruit size and fruit number were also highest in the alfalfa straw mulch treatment, but in 2004, trees receiving impact sprinkler irrigation (I3 - less frequent, but higher total applications than drip) and 'mow and blow' mulch had the highest yield of all treatments and comparable fruit number and size to the mulch treatment. It is uncertain at this point whether increased yield and fruit number were due to water management, beneficial effects from decomposing grass clippings or whether the trees are in biennial bearing as this treatment had a low yield and fruit number in 2003 (Table 1.1). Fruit quality effects varied from year to year. Mulch treatment apples consistently had a high starch index, and in 2002 and 2003, lower firmness. Effects amongst other treatments were not as consistent. In 2004, apples from mulched or amended plots were less red. Apple soluble solids content was unaffected in all years. The stressed appearance of this planting has always been of interest. In 2002, there were no significant effects of treatments on plant gas exchange measurements and all trees appeared slightly stressed (minimum stem water potential ~ -1.2MPa) throughout the growing season (data not shown). At two of four measurement periods, stem water potential was higher (less stressed) for trees receiving mulch or sprinkler irrigation (data not shown). In 2003, 'Sprinkler' trees were less stressed than 'drip' trees having higher stomatal conductance and higher stem potential readings. In 2004, treatments were changed to improve spatial distribution of irrigation water. The same amount of water was applied either twice daily (I1), every two days (I2) , through 2 x 4-L/h emitters at 30cm either side of the tree in the row (E1) or 4 x 2-L/h drippers placed either side of the tree at 30 cm within and perpendicular to the row (E2). There were no significant effects of 2004 treatments on growth, yield or fruit quality, but these may be apparent in 2005. A detailed assessment of soil moisture was made with measurements at 15, 30 and 45 cm (6-18 inches) perpendicular to the row at 0- 20 and 0-40 cm depth (0-8, 0-16 inches). Averaged over the whole soil volume there were no significant differences in soil moisture content sampled at the driest point in the irrigation cycle in early August. Water distribution within the profile differed however.

Figure 1.1 Soil moisture distribution in response to emitter placement, irrigation frequency and mulch



Soil moisture was higher in the surface 20 cm (8 inches) for E2 (4 emitters) compared with mulch and E1 (2 emitters) treatments, but lower between 20-40 cm. Watering twice daily maintained a higher soil moisture content at both soil depths (Fig. 1.1). Plants receiving water every two days were more stressed (stem water potential = -1.63MPa) than those receiving twice daily watering (stem potential =-1.5MPa). The least stressed were those plants receiving twice daily watering through four emitters (-1.32MPa) or under mulch (-1.42MPa), which suggests that higher moisture content in the upper part of the soil profile, well distributed laterally increases water availability.

2. Water and nitrogen and phosphorus management – Braeburn/M.26 at Summerland

This experiment was established in 2001, with conservative water and nutrient management practices similar to the Naches experiment, but comparing drip and microsprinkler (radius 1.02m (40in.), no over-lap). The use of a less dwarfing rootstock and the absence of replant problems has resulted in more growth and greater yield in three years at Summerland (Table 2.1) than in four years at Naches (Table 2.1). Consistently, spray-on paper mulch increased growth more than the other treatments, and in 2002-3 trees under drip were larger than trees under microsprinkler irrigation. Trees receiving the biosolids amendment (Ogogrow) had the highest number of apples and yield (significant in 2002, 2003) of all treatments. Fruit colour was unaffected by treatments in all three years.

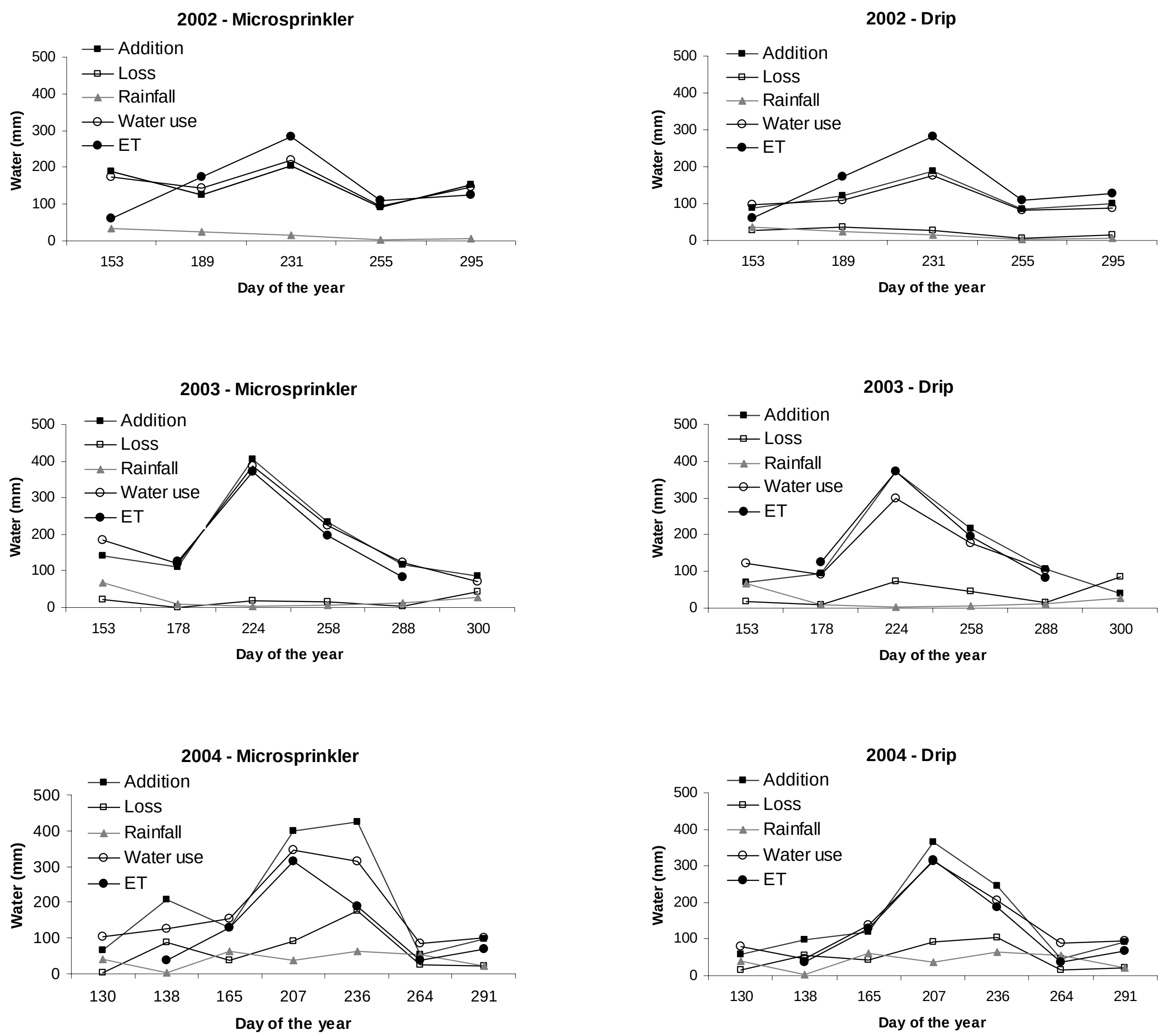
Table 2.1 Tree and fruit responses to irrigation, nitrogen, spray-on mulch and composted biosolids amendments for Braeburn/M.26 at Summerland, B.C.

Year	Treat.	TCSA mm2	Yield MT/ha	Fruit size (g)	Fruit No.	Colour (% red)	Malic acid (ml/100ml)	Soluble solids %	Firmness lbs
2002	Low N	6.19b	8.2	285b	9a	88	1.06b	14.7ab	23.9ab
	High N	6.1b	7.5	295b	8b	89	1.13a	14.9a	23.6b
	M	6.66ab	5.6	319a	6b	84	1.06ab	14.3b	24.6a
	A	6.11b	7.9	299ab	9ab	83	1.05b	14.7ab	24.2ab
	M+A	7.1a	5.5	301ab	6b	86	1.05b	14.3b	24.2ab
	Sign.	**	ns	*	*	ns	*	*	*
	Drip	6.7a	7.6a	299	8	87	1.08	14.8a	23.9
	Micro.	6.16b	6.3b	300	6	85	1.08	14.3b	24.4
	Sign.	*	**	ns	*	ns	ns	*	ns
2003	Low N	8.42b	17.2abc	271	16ab	79	0.99	13.3b	22.4c
	High N	8.37b	15.0c	264	14bc	77	1	13.6ab	22.2c
	M	10.07a	14.1c	278	12c	85	1.01	13.8a	23.6a
	A	8.42b	20.9a	282	20a	79	1	13.5ab	23.0ab
	M+A	10.23a	18.8ab	273	17ab	86	0.99	13.2b	22.6bc
	Sign.	***	***	ns	***	ns	ns	*	***
	Drip	9.18	18.7	273	18	80	0.95b	13.2b	22.6
	Micro.	9.04	15.8	274	17	83	1.04a	12.7a	22.9
	Sign.	ns	**	ns	ns	ns	*		ns
2004	Low N	10.88b	24.4	265	29	83	0.79	11.8b	24.1b
	High N	10.55b	24.9	253	30	82	0.77	12.0ab	23.9b
	M	13.48a	22.7	271	28	83	0.8	11.9ab	24.6ab
	A	11.1b	24.9	288	28	85	0.78	12.3a	24.9a
	M+A	14.11a	26.1	272	31	82	0.8	11.9b	24.4ab
	Sign.	**	ns	ns	ns	ns	ns	*	*
	Drip	11.75	25.1	277	29	86	0.77	12	24.5
	Micro.	12.28	24.1	263	29	80	0.8	12	24.2
	Sign.	ns	ns	ns	ns	*	ns	ns	ns

Apples from mulched trees were firmer than from other treatments, but mulch effects on malic acid and soluble solids content were ambiguous. In all years, trees receiving Ogogrow had firmer, sweeter apples than other treatments. Trees receiving drip irrigation had lower malic acid content in 2003, and redder fruit in 2004. It is possible that some of the benefits from Ogogrow, may be attributed to P availability as leaf P content was higher in all three years (data not shown). There were few effects of treatments on plant water relations.

Detailed analysis has been made of water budgets, nutrient availability and movement in this experiment. Continuous soil moisture measurements have indicated that although soil moisture fluctuates greatly on a daily basis, it is maintained at a relatively constant level over the growing season, and the amount of moisture in the soil is dependent on treatment and on position with respect to the water source - drip emitter or microsprinkler. Microsprinklers generally maintained higher soil moisture content than drip except closest to the row. Similar results were found in all three years, although soil drying away from the emitter was more pronounced in the drought year, 2003. Losses of water beneath the root zone followed the same spatial pattern as soil moisture distribution in response to treatments i.e. higher near the emitter for drip and higher away from the dripper for micro-sprinkler. Because soil water remained relatively constant, a water budget was constructed using water inputs, losses to PCAP samplers and compared to ET measured with an atmometer. In general, water losses were relatively low compared to the magnitude of additions (Fig. 2.1). Water added matched ET determinations reasonably well –some exceptions were either due to ET measurements not being available early in the year (2002) or due to unscheduled additions due to system failure and heavy rainfall (day 236, 2004). These data confirm that atmometer scheduled irrigation promotes conservative use of water to meet plant demand. Nutrient budgets are more difficult to construct, as microbial cycling of nutrients may sequester considerable amounts of N and P. The relative availability of N and P at different times in the year in response to treatments can be assessed from losses to the PCAP samplers. All trees received the same amount of N with the exception of the high N treatment. For 2004 , as for all years, losses of N were highest in the high N treatment and were driven by both high water inputs and high N inputs (data not shown). Nevertheless, the difference between N added and lost for the high N treatment was large (78g), suggesting either high tree N uptake, high microbial sequestration or high gaseous losses. As there were no significant effects of N treatment on leaf N content , growth or yield, it seems likely that a large portion of added N is tied up in the microbial biomass and available for future mineralisation. In all years, P movement and availability was highest in trees receiving composted biosolids (Ogogrow)as indicated by P accumulation in the PCAP samplers & leaf P concentration (not shown).

Figure 2.1. In-field water balance for atmometer scheduled microsprinkler and drip irrigation



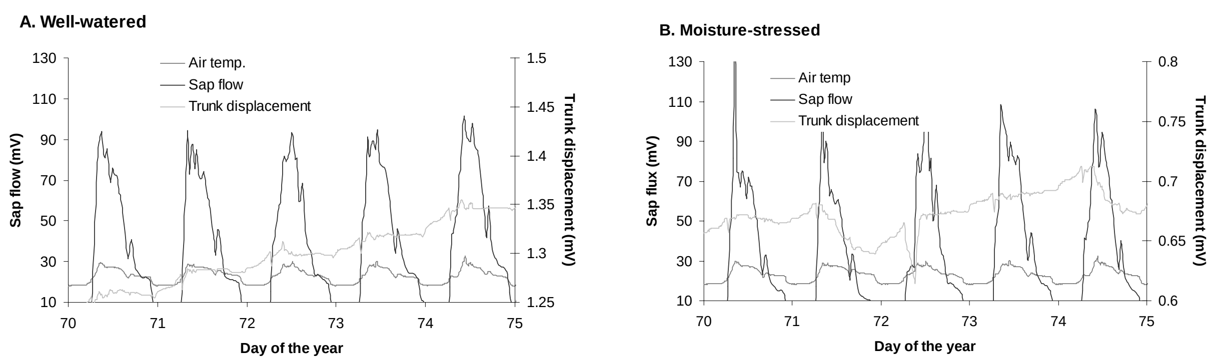
3. Effects of polyacrylamide gel (PAM) on growth on apple.

There were no beneficial effects of PAM on young apple trees grown with sprinkler irrigation in a coarse-textured soil. In contrast, shredded paper mulch resulted in more shoot growth and greater trunk cross-sectional area. A companion study with beans grown under drip, however, indicated that under an imposed moisture deficit, PAM and PAM + compost, more than doubled plant growth compared with the control.

4. Plant sensors

In 2004, strain-gage dendrometers and heat balance sap flow sensors (DynaMax Inc.) were tested for their ability to sense diurnal changes in plant response to temperature and moisture stress in the greenhouse. An attempt to test dendrometers in the field in 2003 was unsuccessful due to extreme sensitivity and electronic 'noise'. Both gages responded to diurnal changes in temperature, light and water availability (Fig 4-1). However, sap flow gages had a larger and clearer signal than the dendrometers and did not have the disadvantages of sensitivity to movement, upward trend in signal (well-watered) and unclear signal (stressed) that were displayed by the dendrometers. Estimates of total sap flux made from sap flow measurements were linearly related to transpiration measured by weighing (weight = 1.2 sapflux - 0.053; R^2 = 0.95)

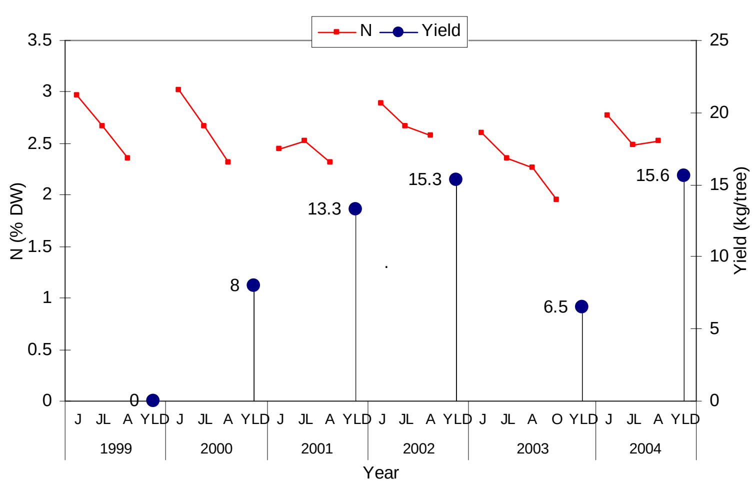
Figure 4.1 Response of sap flux and trunk displacement sensors to soil moisture, and diurnal light and temperature



5. Long term Nitrogen and Phosphorus experiment

As illustrated for the 'Fuji' cultivar over the whole experimental period, leaf N concentration declines regardless of fertilizer treatment during the growing season as the annual crop sizes (Fig. 5-1). Lowest leaf N concentration by the end of time C was measured in 2003 when annual yield was lowest due to a late October freeze in 2002 and a frost during bloom in May 2003. An extra leaf sample on Oct.29, 2003 indicates leaf N concentrations averaging below 2% by season's end. The rebound in leaf N concentration and yield without changing N treatments is indicated for 2004.

Figure 5-1 Average leaf N concentration for Fuji/M.9 throughout the experimental period



Nitrogen Rate

Leaf and fruit N concentrations were generally increased across all cultivars at the high rate of N (Table 5-1). Despite the 6-fold difference between low and high N rates, leaf N concentration increases were generally less than 10% at high N and somewhat higher (about 10-20%) for fruit N indicating an inefficient use of the extra N. Fruit quality characteristics most affected by N-fertilization were fruit firmness and percent solid red color (Table

5-2). The high N regime, despite the rather inefficient uptake of N described, had significantly reduced firmness annually of between ½ and 1 pound, averaged across all cultivars (Table 5-2). In 2004, red coloration of all red apples fertilized at high rates of N in time A had only 77.6% solid red compared to 88.2% solid red when fertilized at low N rates at the same time. In 2002 and 2003, higher percent red color was always observed on apples receiving the low rate of N although the differences just failed to make statistical significance. Collectively this data indicates that detrimental effects of high N-fertilizer rates are more apparent on fruit firmness than red coloration which presumably can be affected by other factors such as light exposure.

Harvest fruit firmness was strongly affected by cultivar with Fuji consistently firmest and Silken often softest. Highest red coloration was measured in Cameo and lowest in Fuji (data not shown).

Nitrogen Timing

Leaf and fruit N concentrations were strongly affected by the timing of N fertilization. Leaf N concentrations late in the growing season (August) were lowest for trees which had received their N four weeks post bloom (time A) (Table 5-1). Similarly, lowest fruit N was consistently measured for trees fertilized this early. There were few differences in N concentration of apples fertilized in time B or C.

Table 5-1 Effects of N rate and timing on late (12 weeks post bloom (pb)) leaf N and harvest fruit N concentration, 2002-2004. Unless otherwise indicated averages over all cultivars (Ambrosia (A), Cameo (C), Fuji (F), Gala (G), or Silken (S).

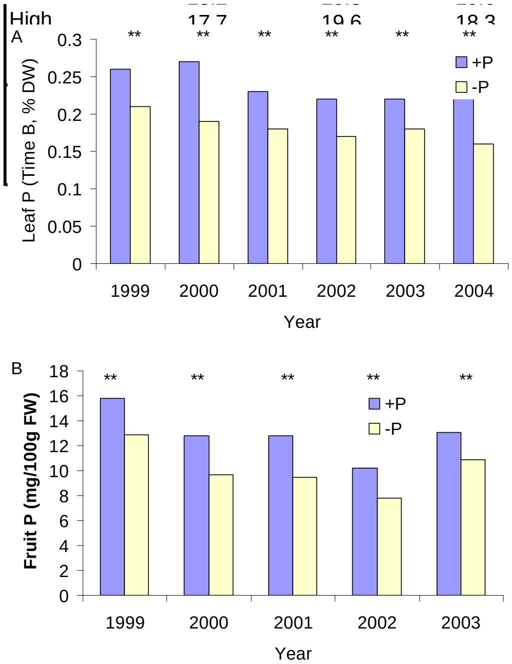
	Leaf N (%DW)					Fruit N (mg/100g FW)						
	8-Aug-02			5-Aug-03	3-Aug-04	2001				2002		2003
N Rate	F	G	S	All	All	A	C	G	S	All		All
Low	2.47	2.27	2.33	2.01	2.25	39.30	36.10	41.70	47.50			47.60
High	2.64	2.48	2.47	2.20	2.51	42.80	43.00	46.40	58.00			52.30
	***	**	**	***	***	**	***	*	****			***
N Timing										Low	High	
A (4 wk pb)	2.37	2.22	2.30	1.99	2.26	37.70	36.70	43.40	47.90	38.60	46.70	47.80
B (8 wk pb)	2.65	2.41	2.39	2.18	2.49	43.10	41.10	45.60	58.70	44.20	48.70	51.00
C (12 wk pb)	2.66	2.50	2.59	2.15	2.50	42.40	40.80	43.20	51.90	45.70	49.50	51.10
	***	**	***	***	****	****	*	*	***	*	*	*

Table 5-2 Effects of N rate and timing on harvest fruit firmness and solid red color averaged over all cultivars, 2002-2004.

				Solid Red Color (%)			
				2002	2003	2004	
				83.3	83.9		
High	17.7	19.6	18.3	80.7	80.8		
				ns (p=0.06)	ns (p=0.08)	Low N	High N
				82.5	80.3	88.2	77.6
				82.0	83.5	74.8	75.6
				81.5	83.4	79.7	75.4
				ns	ns	*	

In contrast, timing of N application had few consistent affects on the fruit quality characteristics of firmness and percent solid red color (Table 5-2) and did not affect yield. Thus, high rates of application of N fertilizer were more detrimental than the actual timing of N application.

Fig 5-2 A) Leaf P at time B 1999-2004 and B) Fruit P 1999-2003 at harvest as affected by single P application near bloom. Averaged for all cultivars.



Phosphorus

The phosphorus application treatment consistently and significantly increased leaf and fruit P concentration throughout the study for all cultivars (Fig 5-2) when compared to trees receiving N only during time A. This effect persisted in 2004 when P was applied as ammonium polyphosphate with no additional N in time A. For the second year in a row higher average leaf P was measured at Quincy as a result of applying 15g P/tree as phosphoric acid on June 8, 2004.

Applying phosphorus resulted in trees producing the greatest number of fruit and highest yield, as indicated by cumulative harvests over the first 5 fruiting seasons of the planting (Table 5-3). Trees fertilized with high rather than low rates of N also had significantly greater production but values were not as large as for the phosphorus treatment. The timing of N-application did not affect fruit number or yield. Over the 5 year period, overall fruit size was unaffected by any treatment although effects could be observed some years (data not shown). Cultivar had a highly significant effect on yield with Fuji producing most fruit and highest yield and Silken and Cameo having lowest yield (Table 5-3). No yield effects were measured in 2004 in a year when yield production recovered to pre 2003 levels after weather related yield reductions in the 2003 growing season (data not shown).

Table 5-3 Cumulative fruit numbers, harvest yield and average fruit size for treatments and cultivars for the first 5 fruiting seasons, 1999-2003.

Treatment	Cultivar	Cumulative Fruit Numbers (n/tree)	Cumulative Yield (lbs/tree)	Average Fruit Size (oz.)
High N time A	All			
+P		239a	107.6a	7.0
- P		203b	89.6b	6.8
		*	*	ns
Time A, B and C	All			
Low N		196b	85.4b	6.8
High N		210a	91.5a	6.8
		*	*	ns
Low and High N	All			
Time A		202	89.3	6.8
Time B		206	88.6	6.7
Time C		201	87.5	6.8
		ns	ns	ns
All treatments				
	Ambrosia	208b	96.4b	7.2a
	Cameo	181c	83.6c	7.1a
	Gala	216b	98.6c	7.1a
	Fuji	250a	105.1a	6.5b
	Silken	173c	70.2d	6.4b
		****	****	****

Means significantly different at 1% (*) or 0.01% (****) level of probability or not significantly different (ns). Means followed by different letters significantly different at the probability level indicated.

In contrast to negative effects on fruit quality associated with moving from a low to high N fertilizer regime, application of P was associated with beneficial effects on fruit quality as summarized in Table 5-4. These effects included reductions in incidence of water core and reduced browning of cut surfaces which seemed to imply more stable membranes for high P fruit.

Table 5-4 Summary of beneficial effects of single annual P application on fruit quality, 2001-2004 seasons.

Year	Statistically significant effect
2001	reduced incidence of water core Silken, Fuji
2002	reduced incidence of water core, all culitvars
	*reduced browning of cut surfaces, all cultivars
2003	*reduced browning of cut surfaces, all cultivars
	*reduced membrane leakage Silken
2004	increased soluble solids, all cultivars

* only measured in years indicated

6. Timing of Ca sprays and soil Ca application

Fruit size was unaffected by any Ca treatment throughout the study with size being particularly large in 2003, averaging above 300g over all treatments (Table 6-1). Fruit Ca concentration was significantly affected by treatments in 2001 and 2002 but not in 2003 when fruits were largest. For $CaCl_2$ sprays, the later $CaCl_2$ was applied during the growing season the higher fruit Ca concentration was (Table 6-1). Spraying liquid calcium thiosulphate within the tree row on the soil surface did not increase fruit Ca concentration relative to unsprayed fruit in the two years this treatment was applied. Similarly, foliar calcium carbonate sprays were generally ineffective at increasing fruit Ca concentration although fruit from the foliar Micronashade treatment had higher fruit Ca than unsprayed fruit in 2002.

Throughout the experiment, harvest fruit disorders observed on ‘Braeburn’ apple in the experimental block

Table 6.1 Average fruit size and Ca concentration at harvest as affected by Ca treatment, 2001-2003.

	Fruit Size (g)			Fruit Ca concentration (mg/100gFW)		
Treatment	2001	2002	2003	2001	2002	2003
1. Control (no Ca)	244	246	298	3.6b	3.4d	3.5
2. Early Season foliar $CaCl_2$	229	225	290	3.3bc	3.7cd	3.4
3. Mid Season foliar $CaCl_2$	238	222	305	4.2a	4.9b	3.3
4. Late Season foliar $CaCl_2$	253	220	283	4.4a	5.7a	3.8
5. Soil Ca applications	Na^z	230	309	Na^z	3.5d	3.2
6. Foliar $CaCO_3$ suspension	272	230	313	2.8c	4.0cd	3.8
7. Foliar Micronashade	255	226	304	3.1bc	4.3c	3.9
Significance	ns	ns	ns	****	****	ns

ns, **** Non-significant or significantly different at p=0.0001 (****) level of probability.

^{z} This treatment not applied 2001.

included bitter pit (all 3 years), lenticel pit, core browning (2 years each) and water core (1 year) (Table 6-2). Of these disorders, only bitter pit and lenticel pit were affected by experimental Ca treatments. Over all years, the lowest incidence of bitter pit was observed after application of $CaCl_2$ early in the season. This effect was observed even though this treatment did not have a large influence on harvest fruit Ca concentration. Also in 2003, when fruit size was largest and the highest incidence of bitter pit and lenticel pit occurred, early $CaCl_2$ sprays did not eliminate bitter pit and did not result in the lowest incidence of lenticel pit.

Table 6.2 Incidence of major fruit disorders of 'Braeburn' apple when occurring at commercial harvest as affected by Ca treatment.

	Incidence of disorder (%)							
	Bitter Pit			Lenticel Pit		Core browning	Water core	
Treatment	2001	2002	2003	2001	2003	2001	2002	2003
1. Control (no Ca)	2b	12a	3b	2	23ab	2	3	18
2. Early Season foliar $CaCl_2$	0b	0c	6d	0	18ab	0	2	24
3. Mid Season foliar $CaCl_2$	0b	0c	9cd	0	4b	0	8	36
4. Late Season foliar $CaCl_2$	3b	2bc	15bcd	0	4b	0	0	16
5. Soil Ca applications	NA[y]	10a	24abc	NA[y]	38a	NA[y]	3	27
6. Foliar $CaCO_3$ suspension[z]	15a	8ab	26ab	0	30ab	8	7	23
7. Foliar Micronashade[z]	10ab	2bc	24abc	7	42a	5	5	10
Significance	*	**	**	ns	ns (p=0.06)	ns	ns	ns

[z]Applied as late season, 2001-02 and early season 2003.

[y]This treatment not applied 2001.

ns, *, ** Not significantly different or significantly different at p=0.05 (*) or p=0.01 (**) level of probability, respectively.

Budget:

Project duration: 2002-2004 **Project total (3 years):** $159,000

Year	Year 1 (2002)	Year 2 (2003)	Year 3 (2004)
Total	53,000	53,000	53,000

Current year breakdown:

Item	Year 1 (2002)	Year 2 (2003)	Year 3 (2004)
Salaries			
Research technician – field	30K	30K	30K
Technical support – lab	17K	17K	17K
Technical assistance (D. Faubion/Yakima)	2K	2K	2K
Materials/Supplies/Travel	4K	4K	4K
Total	53K	53K	53K

MII match – This project was supported by matching investment initiative funds (MII, 50/50) provided through the Canadian government (53 K annually for 3 years). These funds have been used to hire summer students, supplies and equipment.