

**CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)**

**FINAL REPORT
July 2007**

Project Title Determination of nursery crops yields, nutrient content, and water use for improvement of water and fertilizer use efficiency

Project Location UC Davis. **Project Duration** 4 years

Project Leaders:

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OBJECTIVES

1. Determine the NPK uptake of 75 container-grown ornamental crops at commercial maturity.
2. Measure water use of these crops at key stages of development and relate values to reference evapotranspiration.
3. Estimate and prepare recommendations for overall crop water and fertilizer needs based on values obtained from preceding objectives.

ABSTRACT

Ornamental nursery crop producers in California face pressure to reduce leaching and runoff of agricultural chemicals, and many also face local pressure to reduce water consumption. More efficient management of water and nitrogen fertilizer cannot be achieved without knowing the amount of nitrogen and water required by crops. For container-grown plants, the huge diversity of crops (including ornamental trees and shrubs, herbaceous perennials, bedding plants, and greenhouse-grown potted flowering and foliage plants) precludes highly involved studies of the fertilizer and water requirements of all of the important crops. We grew 75 woody and herbaceous nursery crops that represent common species and growth habits in the nursery trade and measured total NPK uptake and water use over the cropping period. Water use and nutrient uptake varied widely among crops. There was less variation in the ratio of nutrient and water uptake, which gives a reasonable estimate of the required concentration for a liquid feed. In most cases, woody species should receive adequate nutrition from a liquid feed containing 50 mg N/l, 20 mg P/l, and 50 mg K/l. Most herbaceous species require about 100-150 mg N/l, 20 mg P/l, and 120-150 mg K/l. Average daily water use was less than 250 ml (about 8 oz.) for all crops.

INTRODUCTION

There is increasing interest in the development of fertilizer and irrigation best management practices for commercial nurseries. Some of the information necessary for the development of BMPs for nurseries is available. For example, some information about water and nitrogen requirements of 1-gallon container nursery stock has been published, and a few studies have addressed questions about the effects of fertilizer N form, concentration, and frequency of delivery, and the effects of plant development on nutrient uptake. Although such studies yield much useful information, they are not well suited to provide general guidelines for fertilizer management of the immense range of nursery crops in California. This project was undertaken to provide the nursery industry with basic information about the quantities of nitrogen, phosphorus, potassium, and water needed by their crops.

WORK DESCRIPTION

A total of 75 different woody and herbaceous nursery crops were grown in the Environmental Horticulture outdoor nursery and greenhouse on the UC Davis campus. Plants were fertilized with a complete controlled-release fertilizer or with a complete liquid feed fertilizer at two rates, as described below. Fresh and dry weights and NPK contents of the roots and shoots of propagules and finished crops were determined. Evapotranspiration was monitored gravimetrically throughout crop production. Experiments took place between 2003-2007, and all followed the same set of tasks:

Task 1: Purchase and plant nursery stock.

Task 2: Determine dry weight and NPK content of propagules.

Task 3: Maintain plants in nursery and monitor evapotranspiration and nitrogen leaching. Task 4: Harvest plants and analyze results.

RESULTS AND DISCUSSION

Year 1

Two irrigation systems were constructed in March 2003, one in the outdoor nursery and the other in the adjoining saran shade house. Pressure-compensated drip emitters were used, and the systems had distribution uniformity values of 0.86 to 0.89. We encountered delays in obtaining the nursery stock designated by industry representatives as important varieties. Plant material was not available until late May 2003. The species listed in Table 1 were purchased and planted into 1-gallon containers during the first week of June 2003.

Immediately after planting of the liners, additional representative plants of each species were separated into roots and shoots. Roots were washed free of soil, then all plant parts and soil were dried and analyzed for N, P, and K content. Results are presented in Table 2.

Table 1. Species selected for testing in Year 1.

<i>Acorus</i> 'Ogon'	<i>Lantana</i> 'Pink Caprice'
<i>Aucuba japonica</i> 'Variegata'	<i>Lavandula dentata</i>
<i>Azalea</i> 'Pink Lace'	<i>Ligustrum x vicaryi</i>
<i>Berberis thunbergii</i> 'Kobold'	<i>Miscanthus sinensis</i> 'Purpurescens'
<i>Camellia</i> x 'Winter's Star'	<i>Nandina domestica</i>
<i>Dietes vegeta</i>	<i>Pennisetum</i> 'Little Bunny'
<i>Euonymus japonicus microphylla</i>	<i>Phalaris</i> 'Strawberries and Cream'
<i>Hemerocallis</i> x 'Stella de Oro'	<i>Pyracantha coccinea</i> 'Mohave'
<i>Hydrangea macrophylla</i> 'Nikko Blue'	<i>Raphiolepis indica</i>
<i>Imperata</i> 'Red Baron'	<i>Spiraea x vanhouttei</i>
<i>Juniperus scopulorum</i> 'Moonglow'	<i>Thuja</i> x 'Green Giant'
<i>Lagerstroemia</i> 'Tuscarora'	<i>Weigela florida</i> 'Variegata Nana'

A controlled release fertilizer (18-4-16) was applied at low and high recommended rates, resulting in additions of 2.7 g and 5.4 g of N per pot. Establishment of some species was difficult because of the extremely hot weather in June-July. Many plants suffered severe leaf necrosis. This was probably due to high salt concentrations in the container medium. Release rate of the controlled-release fertilizer was high, with leachate EC in some cases exceeding 5 dS m⁻¹ with a 25% leaching fraction. Irrigation rates were increased to leach out excessive fertilizer salts. Most species survived the high temperatures during the establishment period, but 14 species were affected severely enough to be eliminated from the study. After temperatures returned to normal, the remaining species were irrigated with a leaching fraction of 0.25.

Daily water use of the sun and shade crops varied with weather conditions and crop age. Water use of plants grown in full sun did not exceed 250 mL/day on any day, and usually was less than

Table 2. Dry weight and N, P, and K content of propagules. All plants were obtained as 2-inch liners. All values include both shoots and roots.

Species	Dry weight (g)	N (mg)	P (mg)	K (mg)
<i>Acorus</i>	10.3	188	43	229
<i>Aucuba</i>	3.6	30	5	43
<i>Camellia</i>	4.1	67	10	38
<i>Dietes</i>	2.1	34	7	48
<i>Hydrangea</i>	2.1	24	4	28
<i>Juniperus</i>	5.4	105	13	58
<i>Lantana</i>	2.6	40	6	38
<i>Lavandula</i>	2.8	55	9	62
<i>Nandina</i>	1.3	25	5	21
<i>Weigela</i>	2.7	56	10	47

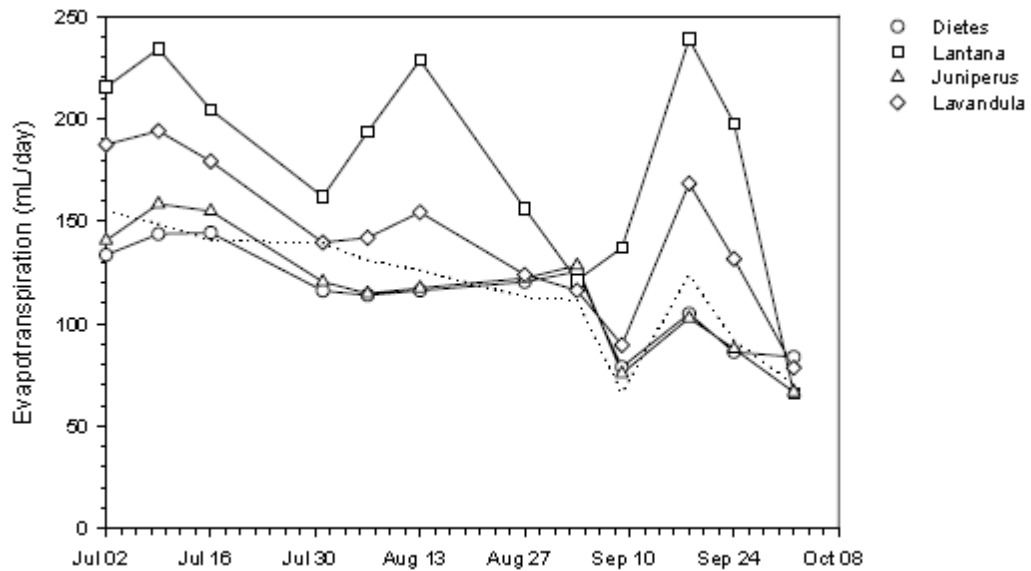


Figure 1. Water use of one-gallon shrubs grown in full sun. Dotted line represents ET based on the soil area of each pot.

200 mL/day (Figure 1). Water use of plants grown under shade cloth never exceeded 200 mL/day, and usually was less than 150 mL/day (Figure 2). The crop coefficient, k , for most sun crops was relatively constant over time (Figure 3). Values across all crops grown in full sun ranged from 0.9-1.8 (based on water use relative to ET for the soil surface area), but seasonal changes in k never exceeded 0.29 for a particular shrub species. The k values were generally lower for shade-grown species, but remained relatively constant over time for only two of the species (Figure 4). For the other shade-grown species, k increased by as much as 0.73 as plants increased in size.

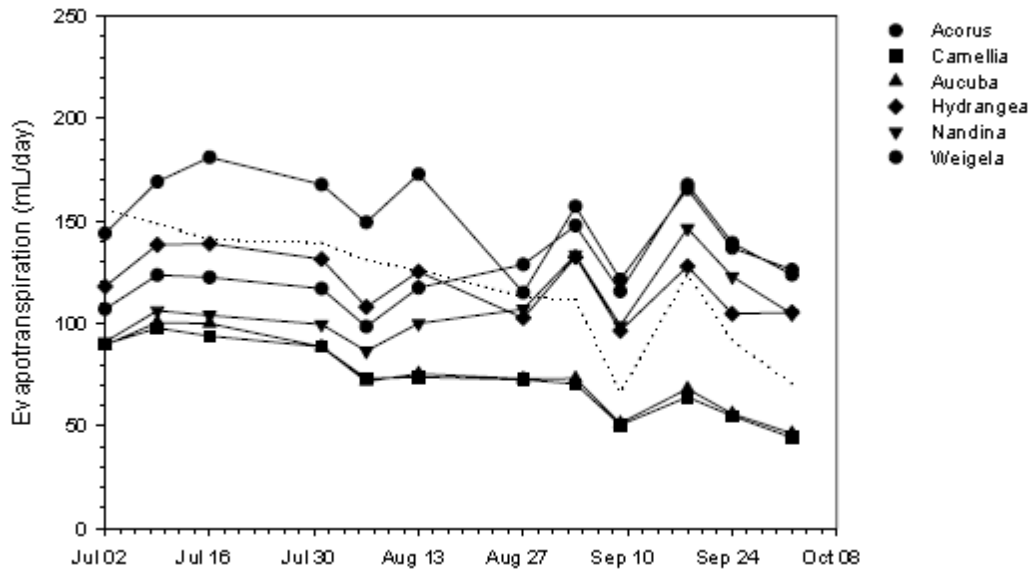


Figure 2. Water use of one-gallon shrubs grown under shade cloth. Dotted line represents ET based on the soil area of each pot.

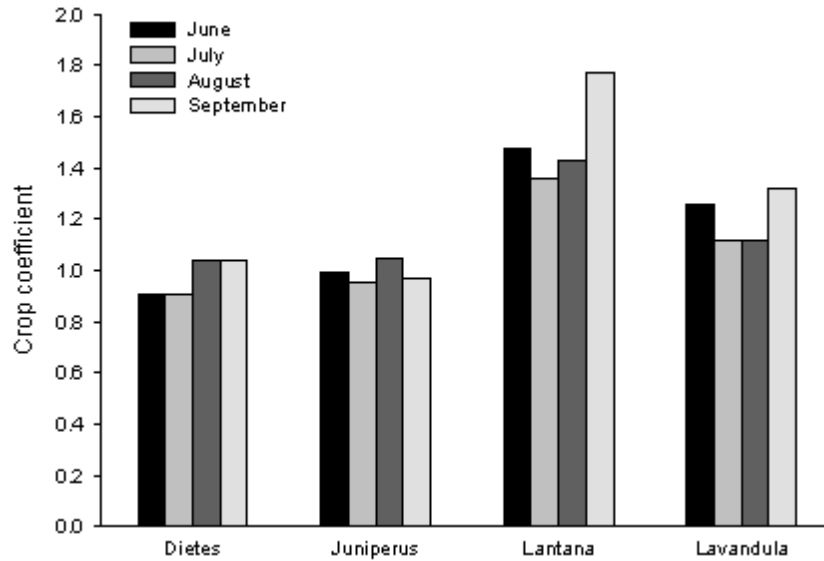


Figure 3. Monthly crop coefficient values for one-gallon shrubs grown in full sun. Crop coefficients were calculated from plant water use relative to ET for the soil surface area of each pot.

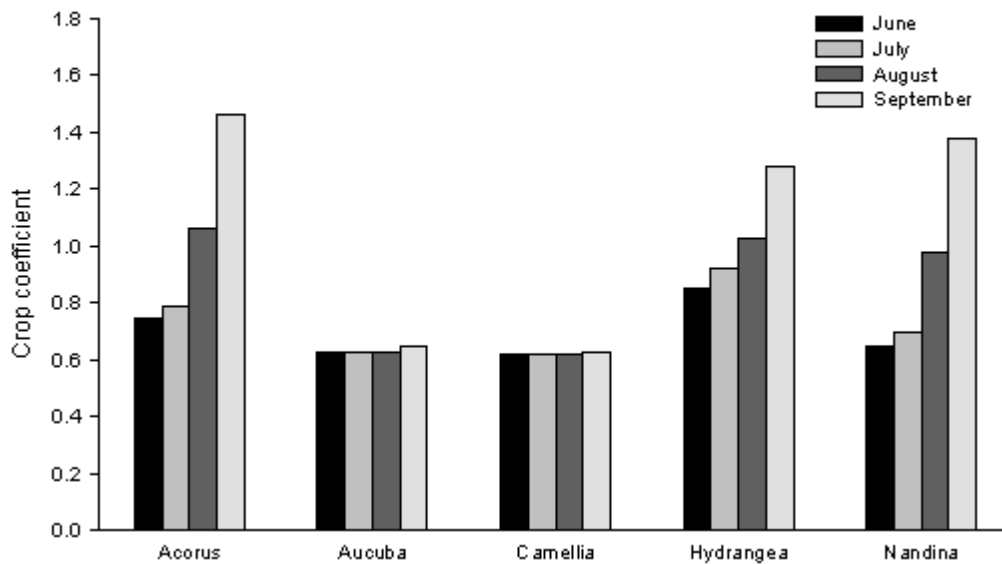


Figure 4. Monthly crop coefficient values for one-gallon shrubs grown in shade. Crop coefficients were calculated from plant water use relative to ET for the soil surface area of each pot.

Table 3. Dry weight and tissue N, P, and K concentrations in whole plants (shoots plus roots) at commercial maturity.

Species	Dry weight (g)	[N] (%)	[P] (%)	[K] (%)
<i>Acorus</i>	25.1	2.87	0.39	3.73
<i>Aucuba</i>	4.3	2.37	0.19	1.56
<i>Camellia</i>	5.2	2.07	0.15	0.64
<i>Dietes</i>	8.6	1.95	0.21	2.19
<i>Hydrangea</i>	24.0	2.20	0.23	2.12
<i>Juniperus</i>	11.6	2.12	0.15	1.45
<i>Lantana</i>	29.7	2.04	0.17	1.89
<i>Lavandula</i>	32.4	2.05	0.19	1.92
<i>Nandina</i>	26.4	1.65	0.15	1.00
<i>Weigela</i>	14.6	2.53	0.30	1.70

Applied fertilizer rate had no significant effect on yields. Dry weights and tissue nutrient concentrations are presented in Table 3. Four species (*Aucuba*, *Camellia*, *Dietes*, and *Juniperus*) grew slowly and had a relatively small dry weight gain. Tissue nitrogen concentrations were acceptable in all species, but P was low in several species and K was unusually low in *Camellia*. *Camellia* took up extremely small amounts of N and no measurable amounts of P or K during the growing season (Table 3). Among the species with more normal growth, N uptake ranged from 70 mg by *Aucuba* to 598 mg by *Lavandula* (Table 4). Most species took up 30-50 mg P, but uptake by *Aucuba*, *Camellia*, *Dietes*, and *Juniperus* was 11 mg or less. K uptake also varied widely.

The nitrogen balance sheet (Table 5) shows that 1.7-2.2 g of applied N was lost from the low fertilizer treatment and 3.5-4.3 g N was lost from the high fertilizer treatment, presumably due to

Table 4. Total N, P, and K uptake between planting and harvest.

Species	N (mg)	P (mg)	K (mg)
<i>Acorus</i>	529	53	716
<i>Aucuba</i>	70	3	22
<i>Camellia</i>	42	0	0
<i>Dietes</i>	132	11	141
<i>Hydrangea</i>	449	41	459
<i>Juniperus</i>	138	5	108
<i>Lantana</i>	565	44	525
<i>Lavandula</i>	598	54	557
<i>Nandina</i>	411	33	240
<i>Weigela</i>	311	32	196

Table 5. Nitrogen balance sheet.

Species	Fertilizer rate	Harvested plant (g)	Liner (g)	Plant uptake (g)	Residual fertilizer (g)	Soil N (g)	Applied N (g)	Nlost (g)	Relative loss (%)	Relative uptake (%)
<i>Acorus</i>	Low	0.603	0.188	0.415	0.488	0.031	2.7	1.766	65.4	15.4
<i>Acorus</i>	High	0.830	0.188	0.642	1.109	0.112	5.4	3.537	65.5	11.9
<i>Aucuba</i>	Low	0.113	0.030	0.083	0.452	0.065	2.7	2.100	77.8	3.1
<i>Aucuba</i>	High	0.084	0.030	0.054	1.176	0.117	5.4	4.052	75.0	1.0
<i>Camellia</i>	Low	0.128	0.067	0.061	0.423	0.030	2.7	2.186	81.0	2.3
<i>Camellia</i>	High	0.082	0.067	0.015	1.042	0.099	5.4	4.244	78.6	0.3
<i>Dietes</i>	Low	0.152	0.034	0.118	0.385	0.013	2.7	2.184	80.9	4.4
<i>Dietes</i>	High	0.190	0.034	0.156	0.816	0.018	5.4	4.410	81.7	2.9
<i>Hydrangea</i>	Low	0.503	0.024	0.479	0.538	0.009	2.7	1.675	62.0	17.7
<i>Hydrangea</i>	High	0.448	0.024	0.424	1.146	0.012	5.4	3.819	70.7	7.8
<i>Juniper</i>	Low	0.222	0.105	0.117	0.306	0.085	2.7	2.192	81.2	4.3
<i>Juniper</i>	High	0.263	0.105	0.158	0.796	0.163	5.4	4.283	79.3	2.9
<i>Lantana</i>	Low	0.528	0.040	0.488	0.373	0.045	2.7	1.794	66.5	18.1
<i>Lantana</i>	High	0.682	0.040	0.642	0.935	0.201	5.4	3.622	67.1	11.9
<i>Lavender</i>	Low	0.545	0.055	0.490	0.324	0.066	2.7	1.820	67.4	18.1
<i>Lavender</i>	High	0.797	0.055	0.742	0.880	0.075	5.4	3.703	68.6	13.7
<i>Nandina</i>	Low	0.349	0.025	0.324	0.428	0.030	2.7	1.918	71.0	12.0
<i>Nandina</i>	High	0.522	0.025	0.497	1.300	0.073	5.4	3.530	65.4	9.2
<i>Weigela</i>	Low	0.402	0.056	0.346	0.536	0.008	2.7	1.810	67.0	12.8
<i>Weigela</i>	High	0.331	0.056	0.275	1.213	0.026	5.4	3.886	72.0	5.1

Table 6. Cumulative water use and calculated minimum liquid feed [N] (based on ratio of total N uptake and total water uptake) in Year 1 experiment.

Species	Low fertilizer rate		High fertilizer rate	
	Water use (l)	[N] (mg/l)	Water use (l)	[N] (mg/l)
<i>Acorus</i> 'Ogon'	11.6	36	13.0	49
<i>Aucuba japonica</i> 'Variegata'	7.8	11	7.2	7
<i>Camellia</i> x 'Winter's Star'	7.5	8	7.1	2
<i>Dietes vegeta</i>	11.7	10	11.1	14
<i>Hydrangea macrophylla</i> 'Nikko Blue'	12.7	38	11.1	38
<i>Juniperus scopulorum</i> 'Moonglow'	11.5	10	11.8	13
<i>Lantana</i> 'Pink Caprice'	17.9	27	18.6	34
<i>Lavandula dentata</i>	15.3	32	13.3	56
<i>Nandina domestica</i>	10.6	31	10.6	47
<i>Weigela florida</i> 'Variegata Nana'	15.4	22	15.0	18

leaching. This represents about 65-80% of the applied N. The percentage of applied N that was recovered in plants was 18% or less for all species. The high leaching losses of N are probably due to high release rates during hot weather (soil temperatures reached 50°C in the containers in full sun), and the high leaching rates that were then needed to manage salinity. Cumulative water use (transpiration plus evaporation) ranged from about 11-15 liters for most species (Table 6). The maximum ratio of N uptake to total water use was 56 mg/l, and the average value was 25 mg/l.

Year 2

The experiments in Year 2 were focused on herbaceous species and were grown in containers ranging in size from 4-inch to 1-gallon, depending on species. Plants were grown in a greenhouse (25°C day/17° night) to avoid the excessive temperatures in the outdoor nursery. An irrigation system was constructed in April 2004 in a greenhouse at the Department of Environmental Horticulture at UC Davis. "Grey Mini Flow" Spot Spitter emitters (Roberts Irrigation Products, San Marcos CA) were used that delivered 4 L/h with a distribution uniformity of 0.79. We conducted three successive experiments, in each of which eight different species were produced using two liquid fertilizers (full-strength and half-strength Hoagland's). Water use and NPK uptake were determined as in year 1.

Propagule weights and tissue NPK contents are presented in Table 7. The yields of finished plants differed significantly among species, and the applied fertilizer rate affected yields and nutrient content in *Coleus*, *Cosmos*, and *Capsicum* (pepper) plants (Tables 8 and 9). Average yield for all species fertilized at the high recommended rate was 14.1 g, compared to 13.1 g for plants fertilized at the low recommended rate.

Table 7. Dry weight and N, P, and K content of propagules. All values include both shoots and roots.

Species	Dry weight (g)	N (mg)	P (mg)	K (mg)
<i>Angelonia angustifolia</i>	1.11	17.9	4.4	32.4
<i>Calibrachoa</i> 'Superbells Red'	1.00	23.7	5.5	30.7
<i>Capsicum annuum</i> 'Sweet California Wonder'	0.79	55	8	67
<i>Caryopteris X clandonensis</i> 'Longwood Blue'	0.47	14.9	1.4	15.9
<i>Coleus</i> 'Tilt A Whirl'	1.02	40	8	45
<i>Cosmos</i> 'Sonata Pink'	0.61	69	17	78
<i>Cuphea hyssopifolia</i> 'Lavender Lace'	1.22	32.7	4.9	28.3
<i>Echinacea purpurea</i>	2.68	102.3	17.3	83.6
<i>Hedera helix</i> 'Thorndale'	1.77	45.1	6.3	49.4
<i>Iberis sempervirens</i> 'Snowflake'	1.97	64.5	7.7	79.5
<i>Impatiens hawkeri</i> 'Bonfire Orange'	1.37	67	12	65
<i>Impatiens walleriana</i> 'Double Ole Rose'	1.14	63	13	48
<i>Kniphofia</i> 'Border Ballet'	5.34	118.3	24.5	200.2
<i>Lavendula angustifolia</i> 'Munstead'	1.13	30.3	6.5	39.4
<i>Nepeta X faassenii</i> 'Dropmore'	1.50	28.8	9.0	52.9
<i>Pelargonium X hortorum</i> 'Flamingo'	2.79	108	19	140
<i>Penstemon X mexicali</i> 'Red Rocks'	0.89	17.7	3.2	25.1
<i>Perovskia atriplicifolia</i>	0.80	22.2	4.0	29.6
<i>Rudbeckia fulgida</i> 'Goldsturm'	3.26	102.9	27.1	158.6
<i>Sedum spurium</i> 'Fuldaglut'	0.49	12.7	1.9	18.9
<i>Stachys byzantina</i> 'Silver Carpet'	5.43	155.7	32.6	233.2

Table 8. Dry weight (g) of finished plants in Year 2 experiment.

Species	Low fertilizer rate			High fertilizer rate		
	Shoot	Root	Total	Shoot	Root	Total
<i>Angelonia angustifolia</i>	12.7	1.30	14.0	12.0	1.14	13.1
<i>Calibrachoa</i> 'Superbells Red'	10.6	0.69	11.3	8.0	0.52	8.6
<i>Capsicum annuum</i> 'Sweet California Wonder'	11.3	4.39	15.7	16.1	5.62	21.7
<i>Caryopteris X clandonensis</i> 'Longwood Blue'	14.4	0.85	15.3	14.6	0.69	15.3
<i>Coleus</i> 'Tilt A Whirl'	6.9	1.06	8.0	10.1	1.10	11.2
<i>Cosmos</i> 'Sonata Pink'	20.7	2.16	22.9	25.5	2.56	28.1
<i>Cuphea hyssopifolia</i> 'Lavender Lace'	4.9	1.02	5.9	4.6	0.91	5.5
<i>Echinacea purpurea</i>	12.3	3.50	15.8	11.7	3.19	14.9
<i>Hedera helix</i> 'Thorndale'	6.3	0.88	7.2	5.9	0.69	6.6
<i>Iberis sempervirens</i> 'Snowflake'	6.8	0.41	7.2	7.8	0.53	8.3
<i>Impatiens hawkeri</i> 'Bonfire Orange'	5.5	0.79	6.3	5.8	0.95	6.7
<i>Impatiens walleriana</i> 'Double Ole Rose'	7.7	0.75	8.5	7.4	0.64	8.1
<i>Kniphofia</i> 'Border Ballet'	9.4	3.59	13.0	11.5	4.05	15.2
<i>Lavendula angustifolia</i> 'Munstead'	7.0	0.55	7.6	6.1	0.63	6.7
<i>Nepeta X faassenii</i> 'Dropmore'	16.4	1.69	18.1	20.2	1.29	21.4
<i>Pelargonium X hortorum</i> 'Flamingo'	19.9	2.09	22.0	21.9	2.07	24.0
<i>Penstemon X mexicali</i> 'Red Rocks'	10.3	0.33	10.6	9.2	0.28	9.4
<i>Perovskia atriplicifolia</i>	11.7	0.79	12.5	12.3	1.04	13.4
<i>Rudbeckia fulgida</i> 'Goldsturm'	16.9	4.33	21.2	15.8	4.13	20.0
<i>Sedum spurium</i> 'Fuldaglut'	4.7	0.30	5.0	5.4	0.33	5.7
<i>Stachys byzantina</i> 'Silver Carpet'	19.4	6.98	26.4	25.4	6.73	32.2

Table 9. Whole shoot nutrient concentrations (% dry weight) of finished plants in Year 2 experiment.

Species	Low fertilizer rate			High fertilizer rate		
	N	P	K	N	P	K
<i>Angelonia angustifolia</i>	3.10	0.43	2.48	3.29	0.49	2.70
<i>Calibrachoa</i> 'Superbells Red'	3.46	0.42	3.37	3.46	0.42	3.35
<i>Caryopteris X clandonensis</i> 'Longwood Blue'	3.79	0.45	2.52	3.97	0.49	2.69
<i>Coleus</i> 'Tilt A Whirl'	3.66	0.74	4.17	3.98	0.67	4.30
<i>Cosmos</i> 'Sonata Pink'	2.26	0.46	3.13	3.65	0.57	4.34
<i>Cuphea hyssopifolia</i> 'Lavender Lace'	1.92	0.43	1.84	1.98	0.50	1.91
<i>Echinacea purpurea</i>	3.85	0.57	4.40	4.44	0.56	4.36
<i>Hedera helix</i> 'Thorndale'	2.98	0.40	2.85	3.03	0.39	2.73
<i>Iberis sempervirens</i> 'Snowflake'	2.90	0.36	3.78	3.28	0.36	3.63
<i>Kniphofia</i> 'Border Ballet'	2.90	0.32	3.90	2.96	0.34	4.69
<i>Pelargonium X hortorum</i> 'Flamingo'	2.69	0.56	3.16	2.81	0.60	3.38
<i>Impatiens walleriana</i> 'Double Ole Rose'	3.56	0.62	4.15	4.28	0.63	4.41
<i>Lavandula angustifolia</i> 'Munstead'	3.13	0.41	4.17	3.21	0.42	4.41
<i>Nepeta X faassenii</i> 'Dropmore'	3.62	0.45	3.60	3.97	0.45	3.75
<i>Impatiens hawkeri</i> 'Bonfire Orange'	3.09	0.58	3.29	3.42	0.62	3.15
<i>Penstemon X mexicali</i> 'Red Rocks'	2.89	0.49	3.17	2.93	0.50	3.03
<i>Capsicum annuum</i> 'Sweet California Wonder'	2.62	0.52	3.78	3.20	0.45	4.25
<i>Perovskia atriplicifolia</i>	3.10	0.56	3.88	3.61	0.59	4.09
<i>Rudbeckia fulgida</i> 'Goldsturm'	3.48	0.36	4.93	4.08	0.41	5.89
<i>Sedum spurium</i> 'Fuldaglut'	2.72	0.47	3.97	2.93	0.46	4.01
<i>Stachys byzantina</i> 'Silver Carpet'	2.86	0.64	4.77	3.80	0.65	5.21

Table 10. Total N, P, and K (in mg) uptake between planting and harvest for crops in Year 2.

Species	Low fertilizer rate			High fertilizer rate		
	N	P	K	N	P	K
<i>Angelonia angustifolia</i>	204	54	304	186	57	310
<i>Calibrachoa</i> 'Super Bells Red'	353	44	344	265	34	253
<i>Capsicum annuum</i> 'Sweet California Wonder'	345	61	402	654	86	679
<i>Caryopteris</i> 'Longwood Blue'	545	66	369	581	72	392
<i>Coleus</i> 'Tilt A Whirl'	220	44	241	380	61	394
<i>Cosmos bipinnatus</i> 'Sonata Pink'	388	74	537	883	130	1030
<i>Cuphea hyssopifolia</i> 'Lavender Lace'	132	19	78	130	21	73
<i>Echinacea purpurea</i> 'Magnus'	472	75	569	486	70	533
<i>Hedera helix</i>	138	22	153	110	18	126
<i>Iberis sempervirens</i> 'Snowflake'	191	17	189	231	22	218
<i>Impatiens hawkeri</i> 'Bonfire Orange'	114	22	125	148	27	128
<i>Impatiens walleriana</i> 'Double ole Rose'	468	36	271	552	35	278
<i>Kniphofia</i> 'Border Ballet'	256	17	281	391	31	470
<i>Lavandula angustifolia</i> 'Munstead'	204	26	257	186	24	228
<i>Nepeta X faassenii</i> 'Dropmore'	596	74	588	803	91	747
<i>Pelargonium X hortorum</i> 'Flamingo'	214	107	546	264	128	653
<i>Penstemon X mexicali</i> 'Red Rocks'	287	48	306	255	48	259
<i>Perovskia atriplicifolia</i>	356	65	430	445	73	517
<i>Rudbeckia fulgida</i> 'Goldsturm'	648	107	884	714	109	1018
<i>Sedum spurium</i> 'Fuldaglut'	241	20	176	283	22	206
<i>Stachys byzantina</i> 'Silver Carpet'	861	146	1029	1284	187	1467

Shoot N, P, and K concentrations were significantly different among species, and tissue N concentrations were affected by fertilizer concentration, but shoot K and P concentrations were affected only by species (Table 9). The lower N and K concentrations in plants fertilized at the low fertilizer rate could account for the lower yields observed at that fertilizer concentration, although NPK concentrations were within the published acceptable ranges for all species except *Capsicum* (pepper) (and perhaps *Cosmos*, for which no published data are available).

The highest quantity of N uptake was 1284 mg by *Cosmos* plants (Table 10). Average N uptake was 344 mg at the low fertilizer rate and 440 mg at the high rate. Fertilizing at the high recommended rate resulted in greater N uptake by *Coleus*, *Cosmos*, *Impatiens*, *Nepeta*, *Capsicum* (pepper), and *Perovskia*, but only *Coleus*, *Cosmos*, and *Capsicum* (pepper) plants responded with higher yields..

The calculated ratio of N uptake:water uptake over the course of the experiment indicates that most of these herbaceous species readily take up about 100-150 mg N/l, 20 mg P/l, and 120-150 mg K/l (Table 11). Luxury consumption of N occurs in most of the species tested.

Evapotranspiration did not exceed 250 ml/day, and usually was less than 150 mL/day. Cumulative water use ranged from 1.6 l for New Guinea impatiens (*I.hawkeri*) to 6.4 l for *Stachys* (Table 11). Only *Pelargonium*, *Cosmos*, *Nepeta*, and *Perovskia*, the crops with the greatest leaf area, exceeded ET . The crop coefficient, k , tended to increase as plants matured.

Table 11. Cumulative water use and calculated minimum liquid feed [N], [P], and [K] (based on ratio of total N uptake and total water uptake) in Year 2.

Species	Water use	N	P	K	Water use	N	P	K
	(l)	(mg/l)			(l)	(mg/l)		
<i>Angelonia angustifolia</i>	3.1	128	17	99	3.4	116	17	92
<i>Calibrachoa</i> 'Super Bells Red'	2.7	138	17	109	2.7	97	13	83
<i>Capsicum annuum</i> 'Sweet California Wonder'	2.6	133	24	155	2.9	223	29	232
<i>Caryopteris</i> 'Longwood Blue'	3.1	174	21	117	3.2	184	23	127
<i>Coleus</i> 'Tilt A Whirl'	2	112	22	123	2.1	179	29	186
<i>Cosmos bipinnatus</i> 'Sonata Pink'	3.3	119	23	164	3.5	253	37	295
<i>Cuphea hyssopifolia</i> 'Lavender Lace'	2.7	48	7	28	2.9	45	7	25
<i>Echinacea purpurea</i> 'Magnus'	5.1	93	15	112	4.3	112	16	123
<i>Hedera helix</i>	2.4	59	9	65	2.3	48	8	55
<i>Iberis sempervirens</i> 'Snowflake'	3.4	56	5	55	3.3	70	7	66
<i>Impatiens hawkeri</i> 'Bonfire Orange'	1.6	73	14	77	1.6	93	16	79
<i>Impatiens walleriana</i> 'Double ole Rose'	3.8	123	28	143	3.9	142	33	167
<i>Kniphofia</i> 'Border Ballet'	3.4	76	5	83	3.3	119	9	143
<i>Lavandula angustifolia</i> 'Munstead'	2.3	89	11	112	2.1	87	11	107
<i>Nepeta X faassenii</i> 'Dropmore'	4.1	146	18	144	3.6	224	25	208
<i>Pelargonium X hortorum</i> 'Flamingo'	2.1	103	17	126	1.7	158	21	165
<i>Penstemon X mexicali</i> 'Red Rocks'	3.1	92	15	98	2.7	93	18	95
<i>Perovskia atriplicifolia</i>	3.4	103	19	125	3.4	130	21	151
<i>Rudbeckia fulgida</i> 'Goldsturm'	6.0	108	18	147	4.6	156	24	223
<i>Sedum spurium</i> 'Fuldaglut'	2.1	114	9	83	2.1	136	11	99
<i>Stachys byzantina</i> 'Silver Carpet'	5.4	161	27	192	6.4	199	29	227

For most species, k_C did not increase dramatically until the week of harvest. Values in the first 2 weeks after planting ranged from 0.2 to 0.6 (based on water use relative to ET for the area occupied by each plant). At commercial maturity, k ranged from 0.4 for New Guinea impatiens (*I.hawkeri*) to 1.5 for *Cosmos*.

Year 3

Plants in Year 3 were grown in 1-gallon pots using UC Mix as the potting medium and fertilized with half-strength or quarter-strength Hoagland's solution with each irrigation. Yields differed among species, but the fertilizer rate only affected the yield of *Hemerocallis* (Table 12).

Shoot N, P, and K concentrations and total uptake were significantly different among species and fertilizer rates (Tables 13 and 14). The crops for which fertilizer rate affected shoot N were *Aptenia*, *Euonymus*, *Gazania*, *Hemerocallis*, *Lagerstroemia*, *Miscanthus*, *Pachysandra*, *Parthenocissus*, *Phalaris*, *Prunus*, and *Pyracantha coccinea*. The higher fertilizer rate also increased shoot P in *Pachysandra* and *Parthenocissus*, and increased shoot K in *Aptenia*, *Armeria*, *Gazania*, *Pachysandra*, and *Phalaris*.

The highest quantity of N uptake was 1.25 g, by *Hemerocallis* plants (Table 14). Average N uptake was 379 mg at the low fertilizer rate and 530 mg at the high rate. P uptake averaged 77 and 100 mg at the low and high fertilizer rates, and average K uptake was 490 and 615 mg. It is important to note, however, that only the yield of *Hemerocallis* was affected by fertilizer uptake.

Table 12. Dry weights (g) of liners and of commercially mature plants grown at two fertilizer rates in the Year 3 experiment.

Scientific name/cultivar	Common Name	Liner	Harvest DW	
			Low rate	High rate
<i>Aptenia cordifolia</i>	Heartleaf Ice Plant	3.49	21.88	26.76
<i>Armeria maritima</i>	Sea Pink	1.00	12.67	11.36
<i>Berberis thunbergii</i> 'Crimson Pygmy'	Japanese Barberry	1.60	15.32	16.04
<i>Buxus microphylla</i> 'Winter Gem'	Boxwood	3.52	16.86	18.02
<i>Euonymus fortunei</i> 'Green and Gold'	Winter creeper Euonymus	3.78	15.99	16.99
<i>Gazania</i> 'Majestic Yellow'	Gazania	1.44	18.60	19.77
<i>Hemerocallis</i> 'Stella de Oro'	Daylily	8.60	45.56	53.67
<i>Hypericum calycinum</i>	St. John's Wort	1.49	32.92	36.61
<i>Ilex aquifolium</i> 'San Gabriel'	English Holly	6.30	25.90	25.06
<i>Imperata cylindrica</i> 'Red Baron'	Japanese Blood Grass	0.92	22.62	20.62
<i>Lagerstroemia indica</i> 'Petite Orchid'	Crape Myrtle	2.42	24.58	28.37
<i>Ligustrum japonicum</i> 'Texanum'	Privet	4.36	28.57	25.69
<i>Miscanthus sinensis</i> 'Purpureascens'	Flame Grass	2.74	25.99	20.84
<i>Pachysandra terminalis</i>	Japanese Spurge	5.84	27.60	29.13
<i>Parthenocissus quinquefolia</i>	Virginia Creeper	4.27	26.53	23.95
<i>Phalaris arundinacea</i> 'Strawberries and Cream'	Ribbon Grass	1.87	26.82	29.79
<i>Prunus laurocerasus</i> 'Zabeliana'	English Laurel	0.78	18.70	23.60
<i>Pyracantha coccinea</i> 'Low Boy'	Firethorn	2.28	16.68	19.56
<i>Pyracantha koidzumii</i> 'Walden Prostrata'	Firethorn	4.64	35.64	37.14
<i>Raphiolepis indica</i> 'Pink Lady'	Indian hawthorn	2.75	35.18	29.02
<i>Rosa</i> 'The Fairy'	Rose, polyantha	2.93	25.41	24.00
<i>Rosmarinus officinalis</i> 'Prostratus'	Rosemary	0.84	31.71	31.45
<i>Spiraea japonica</i> 'Neon Flash'	Spiraea	2.18	16.66	15.82
<i>Thuja</i> 'Green Giant'	Arborvitae	4.93	15.27	20.88

Table 13. Whole shoot nutrient concentrations (% dry weight) of finished plants in Year 3 experiment.

Scientific name/cultivar	Low fertilizer rate			High fertilizer rate		
	N	P	K	N	P	K
<i>Aptenia cordifolia</i>	2.45	1.21	6.74	3.25	1.10	7.75
<i>Armeria maritima</i>	2.04	0.50	3.31	2.19	0.43	4.38
<i>Berberis thunbergii</i> 'Crimson Pygmy'	1.37	0.20	1.36	1.70	0.25	1.82
<i>Buxus microphylla</i> 'Winter Gem'	1.97	0.17	1.30	2.28	0.20	1.74
<i>Euonymus fortunei</i> 'Green and Gold'	1.85	0.23	1.64	2.49	0.30	1.99
<i>Gazania</i> 'Majestic Yellow'	2.47	0.51	4.88	3.62	0.57	6.32
<i>Hemerocallis</i> 'Stella de Oro'	2.58	0.44	3.52	3.05	0.47	3.94
<i>Hypericum calycinum</i>	1.71	0.30	2.03	1.87	0.34	2.11
<i>Ilex aquifolium</i> 'San Gabriel'	1.35	0.15	1.70	1.73	0.21	2.18
<i>Imperata cylindrica</i> 'Red Baron'	1.12	0.31	2.17	1.20	0.34	2.26
<i>Lagerstroemia indica</i> 'Petite Orchid'	2.40	0.64	2.27	3.08	0.70	2.84
<i>Ligustrum japonicum</i> 'Texanum'	1.49	0.17	1.50	1.81	0.19	1.57
<i>Miscanthus sinensis</i> 'Purpurescens'	1.15	0.25	1.51	1.73	0.27	1.72
<i>Pachysandra terminalis</i>	1.58	0.21	1.89	2.13	0.25	2.41
<i>Parthenocissus quinquefolia</i>	2.00	0.49	1.66	2.69	0.98	2.14
<i>Phalaris arundinacea</i> 'Strawberries and Cream'	3.08	0.81	4.46	4.03	0.82	5.14
<i>Prunus laurocerasus</i> 'Zabeliana'	2.18	0.43	1.98	2.68	0.44	1.82
<i>Pyracantha coccinea</i> 'Low Boy'	2.28	0.30	1.60	2.77	0.32	1.77
<i>Pyracantha koidzumii</i> 'Walderi Prostrata'	1.63	0.27	1.31	2.05	0.33	1.51
<i>Raphiolepis indica</i> 'Pink Lady'	1.42	0.26	1.61	1.66	0.29	1.83
<i>Rosa</i> 'The Fairy'	2.04	0.36	1.59	2.33	0.42	1.74
<i>Rosmarinus officinalis</i> 'Prostratus'	2.14	0.41	3.07	2.58	0.52	3.64
<i>Spiraea japonica</i> 'Neon Flash'	2.32	0.51	2.34	2.57	0.48	2.34
<i>Thuja</i> 'Green Giant'	1.30	0.24	1.58	1.61	0.28	1.64

The calculated ratio of nutrient uptake:water uptake over the course of the experiment indicates that, except for *Hemerocallis*, all of these crops achieve acceptable yields at ratios of about 50 mg N/l, 20 mg P/l, and 50 mg K/l (Table 15). *Aptenia* apparently took up K at a ratio well in excess of the concentration applied, but yield was not affected significantly in this experiment.

Phalaris had the highest average rate of water use at 398 ml/day, and the highest water use on any single day was 602 ml, by *Phalaris*. The overall average for daily evapotranspiration was 150 ml, but values ranged from 77 to 398 ml. Cumulative water use ranged from 6.3 l for *Spiraea* to 16.6 l for *Hypericum* (Table 15).

Table 14. Whole plant nutrient uptake (in mg) of finished plants in Year 3 experiment.

Scientific name/cultivar	Low fertilizer rate			High fertilizer rate		
	N	P	K	N	P	K
<i>Aptenia cordifolia</i>	439	225	1232	772	256	1805
<i>Armeria maritima</i>	257	67	404	249	53	470
<i>Berberis thunbergii</i> 'Crimson Pygmy'	219	17	210	293	39	277
<i>Buxus microphylla</i> 'Winter Gem'	295	30	191	390	38	274
<i>Euonymus fortunei</i> 'Green and Gold'	237	32	202	370	52	280
<i>Gazania</i> 'Majestic Yellow'	400	91	797	662	107	1146
<i>Hemerocallis</i> 'Stella de Oro'	740	148	975	1253	210	1334
<i>Hypericum calycinum</i>	539	105	637	693	131	750
<i>Ilex aquifolium</i> 'San Gabriel'	279	53	374	362	57	458
<i>Imperata cylindrica</i> 'Red Baron'	246	73	491	254	73	462
<i>Lagerstroemia indica</i> 'Petite Orchid'	462	126	456	729	165	669
<i>Ligustrum japonicum</i> 'Texanum'	339	46	376	381	51	354
<i>Miscanthus sinensis</i> 'Purpurescens'	213	53	349	296	51	312
<i>Pachysandra terminalis</i>	286	46	392	480	83	586
<i>Parthenocissus quinquefolia</i>	408	113	404	518	200	476
<i>Phalaris arundinacea</i> 'Strawberries and Cream'	637	179	943	981	214	1285
<i>Prunus laurocerasus</i> 'Zabeliana'	352	72	344	594	120	417
<i>Pyracantha coccinea</i> 'Low Boy'	317	10	239	479	37	337
<i>Pyracantha koidzumii</i> 'Walden Prostrata'	487	49	419	676	67	502
<i>Rhaphiolepis indica</i> 'Pink Lady'	410	51	509	408	49	466
<i>Rosa</i> 'The Fairy'	437	32	364	496	43	381
<i>Rosmarinus officinalis</i> 'Prostratus'	643	128	927	779	165	1105
<i>Spiraea japonica</i> 'Neon Flash'	326	77	327	348	70	311
<i>Thuja</i> 'Green Giant'	123	32	200	260	61	303

Table 15. Cumulative water uptake (in liters) and calculated minimum liquid feed NPK concentrations (in mg/l, based on ratio of total NPK uptake and total water uptake) in Year 3 experiment.

Scientific name/cultivar	Low fertilizer rate				High fertilizer rate			
	Water use	[N]	[P]	[K]	Water use	[N]	[P]	[K]
<i>Aptenia cordifolia</i>	10.4	42	22	118	11.3	68	23	160
<i>Armeria maritima</i>	9.4	27	7	43	8.6	29	6	55
<i>Berberis thunbergii</i> 'Crimson Pygmy'	7.9	28	2	27	7.8	38	5	36
<i>Buxus microphylla</i> 'Winter Gem'	11.6	25	3	16	12.1	32	3	23
<i>Euonymus fortunei</i> 'Green and Gold'	11.4	21	3	18	12.6	29	4	22
<i>Gazania</i> 'Majestic Yellow'	8.9	45	10	90	10.1	66	11	114
<i>Hemerocallis</i> 'Stella de Oro'	9.3	80	16	105	8.9	140	24	149
<i>Hypericum calycinum</i>	16.3	33	6	39	16.6	42	8	45
<i>Ilex aquifolium</i> 'San Gabriel'	13.8	20	4	27	14.1	26	4	33
<i>Imperata cylindrica</i> 'Red Baron'	9.4	26	8	52	9.0	28	8	52
<i>Lagerstroemia indica</i> 'Petite Orchid'	10.6	44	12	43	11.3	65	15	59
<i>Ligustrum japonicum</i> 'Texanum'	7.4	46	6	51	7.4	51	7	48
<i>Miscanthus sinensis</i> 'Purpurescens'	10.3	21	5	34	9.9	30	5	31
<i>Pachysandra terminalis</i>	6.9	41	7	57	7.7	62	11	76
<i>Parthenocissus quinquefolia</i>	7.6	54	15	53	8.0	65	25	59
<i>Phalaris</i> 'Strawberries and Cream'	15.5	41	12	61	15.9	62	13	81
<i>Prunus laurocerasus</i> 'Zabeliana'	13.4	26	5	26	15.0	40	8	28
<i>Pyracantha coccinea</i> 'Low Boy'	7.7	41	1	31	8.0	60	5	42
<i>Pyracantha koidzumii</i> 'Walden Prostrata'	14.6	33	3	29	15.2	45	4	33
<i>Rhaphiolepis indica</i> 'Pink Lady'	14.4	28	4	35	13.0	31	4	36
<i>Rosa</i> 'The Fairy'	10.0	44	3	36	8.6	58	5	44
<i>Rosmarinus officinalis</i> 'Prostratus'	16.1	40	8	58	15.9	49	10	69
<i>Spiraea japonica</i> 'Neon Flash'	7.2	45	11	45	6.3	55	11	49
<i>Thuja</i> 'Green Giant'	8.0	15	4	25	8.1	32	7	37

Year 4

Liners of the plant species used in this experiment were obtained from several nurseries in California and Florida and transplanted into 1-gallon (15-cm) pots with a volume of 2.4 l, using UC Mix as the potting medium. The plants were grown in a glasshouse under natural day length with day/night temperatures of 75°/65°F (24°/18°C) for 6 to 15 weeks from August 24, 2006 – December 14, 2006. The plants were irrigated as needed with one of two fertilizer solutions, half-strength Hoagland's or quarter-strength Hoagland's, delivered to the pots from stock containers using submersible pumps and irrigation tubing. The irrigation system used Netafim emitters delivering 0.5 gallon per hour. The plants were pruned as needed to develop structure during the experiment.

Yields differed significantly among species, but fertilizer rate affected the yield of only two crops, *Coreopsis grandiflora* and *Osteospermum* (Table 16). Shoot N, P, and K concentrations were significantly different among species and across fertilizer rates (Table 17). About half the crops tested had higher tissue N concentrations when grown at the higher fertilizer rate, but only two crops had higher P concentrations and four had higher K concentrations. The highest quantity of N uptake was 1.16 g, by *Heuchera* plants (Table 18). Average N uptake was 273 mg at the low fertilizer rate and 506 mg at the high rate. P uptake averaged 69 and 99 mg at the low and high fertilizer rates, respectively, and average K uptake was 411 and 644 mg, respectively.

Table 16. Dry weights (g) of liners and commercially mature plants in the Year 4 experiment. Asterisks indicate significantly greater yields at the higher fertilizer rate ($P = 0.05$).

Scientific name/cultivar	Common Name	Liner	Harvest DW	
			Lowrate	High rate
<i>Acer palmatum</i>	Japanese Maple	0.83	7.74	5.93
<i>Argyranthemum frutescens</i> 'Bright Carmine'	Marguerite Daisy	0.53	15.15	21.35
<i>Coreopsis auriculata nana</i>	Coreopsis	4.03	18.19	19.68
<i>Coreopsis grandiflora</i> 'Early Sunrise'	Coreopsis	0.85	30.14	47.41*
<i>Dianthus deltoides</i>	Maiden Pink	2.45	16.20	20.63
<i>Dianthus</i> 'Wink'	Hybrid Pink	1.42	4.27	5.30
<i>Diascia integerrima</i>	Twinspur	0.99	11.58	17.50
<i>Euonymus fortunei</i> 'Gracilis'	Wintercreeper	2.35	12.22	12.65
<i>Euryops pectinatus</i> 'Viridis'	Green Bush Daisy	1.61	19.64	25.47
<i>Heuchera sanguinea</i>	Coral Bells	3.14	39.68	46.40
<i>Hypoestes phyllostachya</i> 'Red Splash Select'	Polka-dot Plant	1.57	16.10	19.96
<i>Ophiopogon japonicus</i>	Tall Mondo Grass	0.76	4.27	4.20
<i>Osteospermum</i> 'Sunny Mary'	African Daisy	0.48	17.78	32.30*
<i>Rhododendron</i> 'Remembrance'	Azalea	1.78	12.09	11.93
<i>Salvia greggii</i> 'Wild Thing'	Autumn Sage	1.35	16.12	23.49
<i>Salvia leucantha</i> 'Santa Barbara'	Mexican Bush Sage	0.92	8.90	14.65
<i>Trachelospermum asiaticum</i>	Star Jasmine	2.99	13.44	14.80
<i>Verbena peruviana</i> 'Red Devil'	Verbena	0.83	10.90	16.56
<i>Viburnum suspensum</i>	Sandankwa Viburnum	2.64	21.32	20.56
<i>Vinca minor</i> 'Bowles'	Dwarf Periwinkle	3.82	13.72	13.60

Table 17. Whole shoot nutrient concentrations (% dry weight) of finished plants in Year 4 experiment. Single asterisks indicate greater values at the higher fertilizer rate and double asterisks indicate significantly smaller values at the higher fertilizer rate ($P = 0.05$).

Scientific name/cultivar	Low fertilizer rate			High fertilizer rate		
	N	P	K	N	P	K
<i>Acer palmatum</i>	1.84	0.93	2.20	2.50*	0.67**	2.66
<i>Argyranthemum frutescens</i> 'Bright Carmine'	2.51	1.16	5.77	3.20*	0.91**	5.90
<i>Coreopsis auriculata nana</i>	2.19	0.34	4.14	2.98*	0.47	4.84*
<i>Coreopsis grandiflora</i> 'Early Sunrise'	2.19	0.27	5.02	2.91*	0.37	4.99
<i>Dianthus deltoides</i>	2.62	1.14	3.35	2.98	0.98	3.41
<i>Dianthus</i> 'Wink'	2.04	0.68	2.32	2.19	0.62	2.15
<i>Diascia integerrima</i>	3.00	0.45	3.12	3.46	0.55	4.00*
<i>Euonymus fortunei</i> 'Gracilis'	2.07	0.38	1.57	2.80*	0.61*	2.15
<i>Euryops pectinatus</i> 'Viridis'	2.80	0.50	4.09	3.62*	0.56	4.98*
<i>Heuchera sanguinea</i>	1.97	0.32	1.68	2.78*	0.40	2.19
<i>Hypoestes phyllostachya</i> 'Red Splash Select'	2.92	0.54	3.72	3.75*	0.54	4.22
<i>Ophiopogon japonicus</i>	2.10	0.36	1.89	2.55	0.47	2.01
<i>Osteospermum</i> 'Sunny Mary'	3.41	0.56	4.88	4.13*	0.56	5.10
<i>Rhododendron</i> 'Remembrance'	1.60	0.28	1.56	2.03	0.27	2.09
<i>Salvia greggii</i> 'Wild Thing'	2.81	0.43	3.83	3.07	0.39	3.71
<i>Salvia leucantha</i> 'Santa Barbara'	2.54	0.50	3.90	3.43*	0.60	4.52*
<i>Trachelospermum asiaticum</i>	1.91	0.22	2.08	2.21	0.28	2.24
<i>Verbena peruviana</i> 'Red Devil'	3.23	0.49	2.78	3.83	0.57	3.39
<i>Viburnum suspensum</i>	1.50	0.26	2.56	2.39*	0.53*	2.92
<i>Vinca minor</i> 'Bowles'	2.32	0.33	2.63	2.87	0.41	2.87

Table 18. Whole plant nutrient uptake (in mg) of finished plants in Year 4 experiment. Asterisks indicate greater values at the higher fertilizer rate ($P = 0.05$).

Scientific name/cultivar	Low fertilizer rate			High fertilizer rate		
	N	P	K	N	P	K
<i>Acer palmatum</i>	99	52	120	117	35	108
<i>Argyranthemum frutescens</i> 'Bright Carmine'	315	150	747	604*	176	1122*
<i>Coreopsis auriculata nana</i>	259	53	417	487*	83	693*
<i>Coreopsis grandiflora</i> 'Early Sunrise'	454	133	1018	1001*	242*	1690*
<i>Dianthus deltoides</i>	293	146	408	498*	187	619
<i>Dianthus</i> 'Wink'	46	20	60	74	22	68
<i>Diascia integerrima</i>	301	48	325	556*	91	650*
<i>Euonymus fortunei</i> 'Gracilis'	162	38	160	270	66	238
<i>Euryops pectinatus</i> 'Viridis'	414	84	731	778*	124	1152*
<i>Heuchera sanguinea</i>	678	114	589	1160*	169	949*
<i>Hypoestes phyllostachya</i> 'Red Splash Select'	367	83	572	632*	102	797
<i>Ophiopogon japonicus</i>	44	8	70	80	15	60
<i>Osteospermum</i> 'Sunny Mary'	484	114	811	1097*	211*	1490*
<i>Rhododendron</i> 'Remembrance'	117	27	97	176	30	168
<i>Salvia greggii</i> 'Wild Thing'	369	64	538	635*	87	800*
<i>Salvia leucantha</i> 'Santa Barbara'	190	40	316	444*	80	603*
<i>Trachelospermum asiaticum</i>	171	24	222	251	34	286
<i>Verbena peruviana</i> 'Red Devil'	290	49	279	556*	89	528*
<i>Viburnum suspensum</i>	234	67	460	409	98	543
<i>Vinca minor</i> 'Bowles'	179	40	278	288	48	314

Table 19. Cumulative water uptake (in liters) and calculated minimum liquid feed NPK concentrations (in mg/l, based on ratio of total nutrient uptake and total water uptake) in Year 4 experiment.

Scientific name/cultivar	Low fertilizer rate				High fertilizer rate			
	Water use	[N]	[P]	[K]	Water use	[N]	[P]	[K]
<i>Acer palmatum</i>	5.0	20	10	24	4.7	25	8	23
<i>Argyranthemum frutescens</i>	5.7	55	26	130	5.6	107	31	199
<i>Coreopsis auriculata nana</i>	4.8	53	11	86	5.6	88	15	125
<i>Coreopsis grandiflora</i> 'Early Sunrise'	9.3	49	14	110	11.2	89	22	150
<i>Dianthus deltoides</i>	6.3	46	23	65	7.8	64	24	80
<i>Dianthus</i> 'Wink'	2.9	16	7	21	3.0	25	7	23
<i>Diascia integerrima</i>	7.5	40	6	44	8.2	68	11	79
<i>Euonymus fortunei</i> 'Gracilis'	6.3	26	6	25	5.9	45	11	40
<i>Euryops pectinatus</i> 'Viridis'	8.2	50	10	89	9.3	83	13	123
<i>Heuchera sanguinea</i>	9.2	74	12	64	10.8	108	16	88
<i>Hypocistes phyllostachya</i>	6.2	59	13	93	6.7	94	15	119
<i>Ophiopogon japonicus</i>	3.9	11	2	18	3.6	22	4	17
<i>Osteospermum</i> 'Sunny Mary'	7.7	63	15	105	9.8	112	22	152
<i>Rhododendron</i> 'Remembrance'	5.8	20	5	17	5.5	32	5	31
<i>Salvia greggii</i> 'Wild Thing'	6.6	56	10	82	7.6	83	11	105
<i>Salvia leucantha</i> 'Santa Barbara'	4.3	44	9	73	6.1	73	13	99
<i>Trachelospermum asiaticum</i>	5.3	32	4	42	5.7	44	6	51
<i>Verbena peruviana</i> 'Red Devil'	4.3	67	11	65	5.4	102	16	97
<i>Viburnum suspensum</i>	6.9	34	10	67	6.6	62	15	82
<i>Vinca minor</i> 'Bowles'	4.4	41	9	63	4.6	63	11	69

The calculated ratio of nutrient uptake:water uptake over the course of the experiment indicates that, except for *Coreopsis grandiflora*, *Heuchera*, and *Osteospermum*, all of these crops achieve acceptable yields at ratios of about 50 mg N/l, 10 to 15 mg P/l, and 60 mg K/l (Table 19). *Coreopsis grandiflora*, *Heuchera*, and *Osteospermum* required approximately 100 mg N/l, 15 mg P/l, and 150 mg K/l. A few other crops, notably *Argyranthemum*, *Coreopsis auriculata nana*, and *Euryops*, also had relatively high K uptake, but tissue levels were high and the critical levels of nutrients for these species are not known.

Salvia greggii had the highest average rate of water use at 160 ml/day, and the highest water use on any single day was 335 ml, by *Euryops*. Daily water use by other crops never exceeded 250 ml. The overall average for daily evapotranspiration was 82 ml, and values ranged from 30 to 160 ml. Cumulative water use ranged from 2.9 l for *Dianthus* 'Wink' to 11.2 l for *Coreopsis grandiflora* (Table 19).

CONCLUSIONS

Nursery crops vary widely in both nutrient and water consumption, hence it is difficult to establish a fertilizer recommendation that satisfies all common nursery crops. Average daily uptake of N, P, and K for all of the crops tested during this project are presented in Table 20. Average daily N uptake values ranged from negligible uptake to 24.5 mg/day for *Phalaris*, and average N uptake across all crops was 7.3 mg/day. The highest average daily P uptake was 6.4 mg/day by *Aptenia*, and the overall average P uptake was 1.3 mg/day. *Aptenia* also had the highest average K uptake, 45 mg/day. The average K uptake across all crops was 8.7 mg/day.

Although these nursery crops vary in both nutrient and water uptake, there is less variation in the ratio of nutrient and water uptake, which gives a reasonable estimate of the required concentration for a liquid feed. In most cases, woody species should receive adequate nutrition from a liquid feed containing 50 mg N/l, 20 mg P/l, and 50 mg K/l. Most herbaceous species require about 100-150 mg N/l, 20 mg P/l, and 120-150 mg K/l. Water use in one-gallon or smaller containers rarely exceeds 250 ml/day (about one-half pint), but it is not well-correlated with ET. It is unlikely that reliable crop coefficients can be established for most of these crops.

Table 20. Cropping time and average daily uptake of N, P, and K (in mg/day) for all crops tested during 2003-2007.

Species	Days	N	P	K
<i>Acer palmatum</i>	109	1.1	0.3	1.0
<i>Acorus gramineus</i> 'Ogon'	182	2.9	0.3	3.9
<i>Angelonia angustifolia</i>	45	4.1	1.3	6.9
<i>Aptenia cordifolia</i>	40	19.3	6.4	45.1
<i>Argyranthemum frutescens</i> 'Bright Carmine'	47	12.9	3.7	23.9
<i>Armeria maritima</i>	81	3.1	0.7	5.8
<i>Aucuba japonica</i> 'Variegata'	182	0.4	0.0	0.1
<i>Berberis thunbergii</i> 'Crimson Pygmy'	88	3.3	0.4	3.1
<i>Buxus microphylla</i> 'Winter Gem'	150	2.6	0.3	1.8
<i>Calibrachoa</i> 'Super Bells Red'	45	5.9	0.8	5.6
<i>Canellia</i> x 'Winter's Star'	182	0.2	0.0	0.0
<i>Capsicum annuum</i> 'Sweet California Wonder'	42	15.6	2.0	16.2
<i>Caryopteris</i> 'Longwood Blue'	45	12.9	1.6	8.7
<i>Coleus</i> 'Tilt A Whirl'	42	9.0	1.5	9.4
<i>Coreopsis auriculata nana</i>	60	8.1	1.4	11.6
<i>Coreopsis grandiflora</i> 'Early Sunrise'	96	10.4	2.5	17.6
<i>Cosmos bipinnatus</i> 'Sonata Pink'	42	21.0	3.1	24.5
<i>Cuphea hyssopifolia</i> 'Lavender Lace'	57	2.3	0.4	1.3
<i>Dianthus</i> 'Wink'	98	0.8	0.2	0.7
<i>Dianthus deltoides</i>	84	5.9	2.2	7.4
<i>Diascia integerrima</i>	60	9.3	1.5	10.8
<i>Dietes vegeta</i>	183	0.7	0.1	0.8
<i>Echinacea purpurea</i> 'Magnus'	57	8.5	1.2	9.4
<i>Euonymus fortunei</i> 'Gracilis'	109	2.5	0.6	2.2
<i>Euonymus fortunei</i> 'Green and Gold'	148	2.5	0.4	1.9
<i>Euryops pectinatus</i> 'Viridis'	69	11.3	1.8	16.7

Table 20 (continued).

Species	Days	N	P	K
<i>Gazania</i> 'Majestic Yellow'	40	16.6	2.7	28.7
<i>Hedera helix</i>	57	1.9	0.3	2.2
<i>Hemerocallis</i> 'Stella de Oro'	68	18.4	3.1	19.6
<i>Heuchera sanguinea</i>	92	12.6	1.8	10.3
<i>Hydrangea macrophylla</i> 'Nikko Blue'	182	2.5	0.2	2.5
<i>Hypericum calycinum</i>	76	9.1	1.7	9.9
<i>Hypoestes phyllostachya</i> 'Red Splash Select'	92	6.9	1.1	8.7
<i>Iberis sempervirens</i> 'Snowflake'	57	4.1	0.4	3.8
<i>Ilex aquifolium</i> 'San Gabriel'	150	2.4	0.4	3.1
<i>Impatiens hawkeri</i> 'Bonfire Orange'	42	3.5	0.6	3.0
<i>Impatiens walleriana</i> 'Double ole Rose'	42	13.1	0.8	6.6
<i>Imperata cylindrica</i> 'Red Baron'	76	3.3	1.0	6.1
<i>Juniperus scopulorum</i> 'Moonglow'	183	0.8	0.0	0.6
<i>Kniphofia</i> 'Border Ballet'	57	6.9	0.5	8.2
<i>Lagerstroemia indica</i> 'Petite Orchid'	54	13.5	3.1	12.4
<i>Lantana camara</i> 'Pink Caprice'	183	3.1	0.2	2.9
<i>Lavandula angustifolia</i> 'Munstead'	45	4.1	0.5	5.1
<i>Lavandula dentata</i>	183	3.3	0.3	3.0
<i>Ligustrum japonicum</i> 'Texanum'	68	5.6	0.8	5.2
<i>Miscanthus sinensis</i> 'Purpurescens'	81	3.7	0.6	3.9
<i>Nandina domestica</i>	182	2.3	0.2	1.3
<i>Nepeta X faassenii</i> 'Dropmore'	45	17.8	2.0	16.6
<i>Ophiopogon japonicus</i>	110	0.7	0.1	0.5
<i>Osteospermum</i> 'Sunny Mary'	71	15.5	3.0	21.0
<i>Pachysandra terminalis</i>	82	5.9	1.0	7.1
<i>Parthenocissus quinquefolia</i>	47	11.0	4.3	10.1
<i>Pelargonium X hortorum</i> 'Flamingo'	42	6.3	3.0	15.5
<i>Penstemon X mexicali</i> 'Red Rocks'	45	5.7	1.1	5.8
<i>Perovskia atriplicifolia</i>	45	9.9	1.6	11.5
<i>Phalaris arundinacea</i> 'Strawberries and Cream'	40	24.5	5.4	32.1
<i>Prunus laurocerasus</i> 'Zabeliana'	150	4.0	0.8	2.8
<i>Pyracantha coccinea</i> 'Low Boy'	54	8.9	0.7	6.2
<i>Pyracantha koidzumii</i> 'Walderi Prostrata'	122	5.5	0.5	4.1
<i>Rhaphiolepis indica</i> 'Pink Lady'	122	3.3	0.4	3.8
<i>Rhododendron</i> 'Remembrance'	110	1.6	0.3	1.5
<i>Rosa</i> 'The Fairy'	54	9.2	0.8	7.1
<i>Rosmarinus officinalis</i> 'Prostratus'	76	10.3	2.2	14.5
<i>Rudbeckia fulgida</i> 'Goldsturm'	57	12.5	1.9	17.9
<i>Salvia greggii</i> 'Wild Thing'	47	13.5	1.9	17.0
<i>Salvia leucantha</i> 'Santa Barbara'	54	8.2	1.5	11.2
<i>Sedum spurium</i> 'Fuldaglut'	57	5.0	0.4	3.6
<i>Spiraea japonica</i> 'Neon Flash'	47	7.4	1.5	6.6
<i>Stachys byzantina</i> 'Silver Carpet'	57	22.5	3.3	25.7
<i>Thuja</i> 'Green Giant'	88	3.0	0.7	3.4
<i>Trachelospermum asiaticum</i>	110	2.3	0.3	2.6
<i>Verbena peruviana</i> 'Red Devil'	54	10.3	1.6	9.8
<i>Viburnum suspensum</i>	91	4.5	1.1	6.0
<i>Vinca minor</i> 'Bowles'	79	3.6	0.6	4.0
<i>Weigela florida</i> 'Variegata Nana'	182	1.7	0.2	1.1