Research Reports

Biomass Yield and Dry Matter Partitioning in Greenhouse-grown Stinging Nettle under Different Fertilization Regimes

Laban K. Rutto^{1,3}, Myong-Sook Ansari², and Michael Brandt¹

ADDITIONAL INDEX WORDS. season, summer, fall, nitrogen, potassium, mineral nutrition, *Urtica dioica*

SUMMARY. Stinging nettle (*Urtica dioica*) is a specialty crop with economic potential. Apart from being harvested and consumed as a leafy vegetable, stinging nettle has well-documented applications in alternative medicine and industry. However, research on stinging nettle mineral nutrition is insufficient and the current study is part of efforts to establish agronomic guidelines for managed cultivation. Greenhouse experiments were conducted over two seasons (summer and fall) to evaluate stinging nettle growth and dry matter partitioning in response to variations in the supply of nitrogen (N), and N in combination with potassium (K). In the first experiment, seedlings were transplanted into potted media amended with N applied at rates equivalent to 0, 15, 30, 45, 60, and 75 g·m⁻², while Expt. 2 consisted of N (15, 45, and 75 g·m⁻² equivalent) and K (4, 8, and 12 g·m⁻² equivalent) applied in factorial combinations. In Expt. 1, stinging nettle growth was positively correlated with N supply up to 60 g·m⁻² during the reproductive phase (summer) and 75 g·m⁻² during the vegetative phase (fall), while there was a slight decline in growth and dry matter yield at the highest level of K (12 g·m⁻²) at all N levels in Expt. 2. In both experiments, growth and dry matter accumulation was higher in the fall than in summer, and high N accounted for significantly more vegetative growth with a concomitant increase in aboveground biomass. Our results suggest that K should be applied at a rate below the growth-limiting threshold of 12 g·m⁻². In this study, N strongly stimulated aboveground growth suggesting it is the most important element in stinging nettle nutrition.

Stinging nettle is a herbaceous perennial plant native to Europe, Asia, northern Africa, and North

America. Despite being rated highly for both edibility and medicinal value, stinging nettle has received little research attention and is one among

species classified as “underutilized” (Plants for a Future, 2012).

The many documented functions of stinging nettle make it a prime candidate for introduction into the marketplace. According to Gibbons (1966), fresh young leaves and shoots, eaten as a pot herb or added to soups, are a highly nutritious and easily digestible alternative to spinach (*Spinacia oleracea*). Dried shoots can be preserved for off-season use (Alibas, 2007), made into tea, tisane, or tincture (Dreyer, 1995), or included in animal diets as a high protein supplement (Grela et al., 1998). Roots, rhizomes, and leaves are an important source of medicine (Hayden, 2006), and stinging nettle leaf extract is used in the manufacture of shampoos and other personal care products. Stinging nettle leaf chlorophyll is also processed into a coloring agent (natural green) used in food processing (Bown, 1995).

In clinical studies carried out to examine the medicinal value of stinging nettle products, Lopatkin et al. (2005), Koch (2001), and Sokeland (2000) report positive results for combined stinging nettle root and sabal (*Serenoa repens*) fruit extracts in the treatment of benign prostatic hyperplasia. Stinging nettle leaf preparations have also been shown to alleviate symptoms associated with allergic rhinitis (Mittman, 1990) and arthritic rheumatism (Randall et al., 2000).

Stinging nettle prefers rich organic soils and is commonly found growing in disturbed sites, e.g., abandoned homesteads, along river banks, or in open spaces within forests. The few reports on nutrition and agronomy (e.g., Bruneton, 1999; Weiss, 1993) show that stinging nettle is highly responsive to N, and Gosling (2005) found that yellow bush lupine (*Lupinus arboreus*) facilitates stinging nettle colonization of nutrient-poor soils through improved N availability. Pigott and Taylor (1964) observed

This is a contribution of Virginia State University Agriculture Research Station Journal Article No. 298.

The authors are grateful to Drs. Asmare Atalay, Christopher Catanzaro, and Harbans Bhardwaj for technical contributions to the experimental design. We would also like to thank Mr. Brodie Whitehead, technical specialist at the VSU Soil and Water Quality lab, for help with sample processing and analysis.

¹Agriculture Research Station, Virginia State University, P.O. Box 9061, Petersburg, VA 23806

²Department of Agriculture and Human Ecology, Virginia State University, P.O. Box 9416, Petersburg, VA 23806

³Corresponding author. E-mail: lrutto@vsu.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
305.1517	oz/ft ²	g·m ⁻²	0.0033
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

that stinging nettle growth was diminished in phosphorus (P) limited woodland soils because of inhibited N uptake, and Pigott (1971) demonstrated that stinging nettle benefits from high P availability. In the United States, Hayden (2006) developed a system for aeroponic and hydroponic production of stinging nettle herb and root, and Kleitz et al. (2008) report a significant increase in stand establishment and yield of transplanted medicinal herbs including stinging nettle, relative to direct seeding.

However, there has been limited study on the effect of K supply on growth and interaction with other nutrients. Šrútek (1995) applied compound fertilizer (12.5N–8.5P–16K) at 75, 225, and 375 kg·ha⁻¹ and found a positive correlation between high nutrient supply and biomass allocation to vegetative and reproductive organs. In another study, Pagliarulo et al. (2004) observed no significant response to high and low P/K combinations in aeroponic stinging nettle. Both studies, alongside the one by Weiss (1993) that failed to identify a rate for optimum N fertilization justify further work on nutrient management in stinging nettle.

In particular, examination of dry matter allocation in stinging nettle as affected by mineral nutrition is important because the species holds promise as a source of multiple products. It can be grown as a vegetable or medicinal herb with agronomic focus on leaf/shoot yield, or for root biomass as raw material for alternative medicine. Plant biochemistry, biomass yield, and dry matter allocation can be manipulated by adjusting the quantity and timing of nutrient supply. For example, Marschner (1995) demonstrated that a higher shoot:root dry weight ratio is a common response to P deficient conditions, and Boivin et al. (2002) found that initial rapid growth in black spruce (*Picea mariana*) in response to high N fertilization may lead to internal nutrient dilution if later stages of growth are characterized by mineral deficiency. Specific to stinging nettle, Dambroth and Seehuber (1988) report that high N fertilization could have a negative effect on the quality of stinging nettle biomass. In preliminary work preceding the current study, we also observed that root, stem, and leaf weight ratios varied with N availability

even when there were no significant differences in total biomass.

In this work, greenhouse studies were conducted to 1) determine the optimum N level for potted stinging nettle and 2) study the effects of N and K interaction at different levels on stinging nettle growth.

Materials and methods

SITE AND GROWTH CONDITIONS. Experiments were performed in a climate controlled greenhouse at Randolph Farm, Virginia State University, Petersburg, VA. Plants were exposed to natural light during both seasons and greenhouse temperature was moderated by cooling to match seasonal mean ambient temperatures (≈ 20 – 25 °C in season 1 and 10 – 20 °C in season 2).

PLANT MATERIALS. During summer (season 1) and fall (season 2) of 2009, stinging nettle seeds (lot no. 16560; Richters®, Goodwood, ON, Canada) were germinated in trays filled with vermiculite and grown to 2–3 cm before transplanting into 250-mL pots. Seedlings were used to set up nutrition experiments after they attained a height of 15 ± 2.0 cm (Fig. 1).

EXPERIMENTAL SETUP. Two experiments were conducted to analyze the effects of N (Expt. 1) and factorial combinations of N and K (Expt. 2) on stinging nettle growth and dry matter allocation. Both experiments were repeated over the course of two seasons in 2009. Nitrogen levels were based on recommendations by Weiss (1993) for cultivated stinging nettle, and the minimum and maximum K levels were calculated around the optimum concentration for hemp (*Cannabis sativa*) recommended by Iványi and Izsáki (2009). Phosphorus was applied uniformly across treatments based on results from a preliminary experiment that found 0.04 g/pot P (0.6 g·m⁻² P equivalent) to be sufficient for optimum stinging nettle growth across different N levels. Lawn fertilizer (26N–0P–2.5K, 2.3% soluble, 13.7% ammonium and slow-release N; Scotts

Miracle Gro Co., Marysville, OH) was used as the N source, and Hi-Yield bone meal (0N–4.4P–0K) and muriate of potash (0N–0P–50K) registered to Hi Yield Products (Alden, MN) were used as sources of P and K, respectively.

EXPT. 1. Uniform seedlings were transplanted into 1.5-gal pots filled with field soil (mixed, semiactive, thermic Typic Fragiudults) and vermiculite in the ratio of 1:1 (v/v) and initially fertilized with six levels of N (0, 0.5, 1.0, 1.5, 2.0, and 2.5 g/pot) equivalent to (0, 15, 30, 45, 60, and 75 g·m⁻² N). Each pot received 0.5 g N at transplanting and the remainder was applied in splits at 20 and 40 d after transplanting. Phosphorus and K were applied uniformly in all treatments at 0.04 g/pot P and 0.33 g/pot K. Pots were laid out on greenhouse benches in a completely randomized design with three pots per treatment.

EXPT. 2. A 3 × 3 factorial experiment with three replications per treatment was established with N and K applied at three levels (0.5, 1.5, and 2.5 g/pot N and 0.17, 0.33, and 0.50 g/pot K) equivalent to 15, 45, and 75 g·m⁻² N and 4, 8, and 12 g·m⁻² K. Pots were arranged randomly on greenhouse benches and all treatments received uniform P (0.04 g/pot) and 0.5 g N at transplanting. Additional N for treatments two (1.5 g/pot) and three (2.5 g/pot) was applied in 1.0-g splits at 20-d intervals. Pot media was maintained at near field capacity by subsurface irrigation in both experiments.

CHLOROPHYLL MEASUREMENT. Chlorophyll content (intensity of green color) of four middle leaves per plant was measured weekly for 7 weeks after transplanting using a chlorophyll meter (SPAD 502; Spectrum Technologies, Plainfield, IL).

HARVESTING AND PROCESSING OF SAMPLES. Destructive harvesting was done two months after transplanting and plants were divided into leaf, stem, and root portions. The total number of stems per plant was recorded and main stem length measured. Main stem leaves were counted,

Fig. 1. Stinging nettle plants after transplanting into experimental pots at the start of the experiment.

and total leaf area per main stem and individual leaf width determined using a leaf area meter (LI-3100; LI-COR Biosciences, Lincoln, NE). Roots were washed, and all tissue samples rinsed with de-ionized water before oven drying for 72 h at 70 °C to determine dry matter yield. All samples were ground to pass a 2-mm sieve in preparation for mineral analysis.

MINERAL ANALYSIS. Samples were digested by dry-ashing, and K, calcium (Ca), and magnesium (Mg) were measured using an inductively coupled plasma emission spectrometer (Prodigy High Dispersion ICP Spectrometer; Leeman Laboratories, Hudson, NH). Phosphorus content in samples was measured using a microflow analyzer (Seal QuAAtro SFA Analyzer; SEAL Analytical, Mequon, WI), and carbon (C) and N by the dry combustion method using a CN analyzer (Vario MAX CN analyzer; Elementar, Mt. Laurel, NJ).

STATISTICAL ANALYSIS. Stinging nettle response to different levels of N and K fertilizer was analyzed by

comparing growth and biomass yield as affected by season. Analysis of variance (ANOVA) was performed to determine the significance of treatments, and polynomial contrasts were used to determine the best model to fit the data. Both ANOVA and regression analysis were done using the Analyst function in SAS (version 9.2 for Windows; SAS Institute, Cary, NC). Fisher's least significant difference ($P \leq 0.05$) was used to compare treatment means in Expt. 1.

Results

Expt. 1.

PLANT GROWTH AND BIOMASS YIELD. Increasing N availability did not significantly affect main stem leaf area in season 1. Stem number (total), and leaf and root dry matter were responsive to N with more growth and dry matter yield correlated with increasing N supply (Table 1). Growth and biomass yield were generally higher in season 2 than in season 1. Nitrogen had a significant ($P \leq 0.05$) impact on all parameters

measured in season 2 with higher stem and leaf growth, and dry matter production recorded with increasing N availability. The opposite was observed for root dry matter that declined at higher N levels. A positive linear relationship between N supply and plant performance was observed in season 2 with a higher proportion of dry matter allocated to above-ground growth (Table 1). Based on length of main stem, plant height was marginally higher in season 2 than in season 1, but there was no significant difference in plant height across treatments and within season (data not included).

MINERAL NUTRITION. Leaf C content was higher in season 1 than in season 2, but there was not much treatment related variation within season. During both seasons, C content was lower in plants receiving no N (Table 2). Leaf N increased with N level and was highest at 2.5 g/pot N during both seasons. A similar trend was observed for leaf K, Mg, and Ca. Generally, leaf mineral content was

Table 1. Dry matter yield and partitioning in stinging nettle grown under greenhouse conditions in media amended with different levels of nitrogen (N) fertilizer. Data are means for three plants.

N treatment (g/pot) ^z	Season 1					Season 2				
	Leaf area (cm ²) ^y	Stem no.	Leaf dry wt (g)	Stem dry wt (g)	Root dry wt (g)	Leaf area (cm ²)	Stem no.	Leaf dry wt (g)	Stem dry wt (g)	Root dry wt (g)
0	9.2	21	10.8	2.8	4.4	27.0	22	15.1	10.7	25.5
0.5	12.4	26	16.6	4.5	6.6	31.0	30	23.5	18.3	29.2
1.0	12.7	27	15.6	3.5	4.9	41.3	36	29.2	28.1	25.7
1.5	11.9	39	22.8	6.3	7.8	33.5	39	35.1	34.4	20.4
2.0	15.0	55	29.7	8.0	7.5	41.4	38	42.9	34.8	20.7
2.5	12.2	55	24.0	5.4	6.1	46.0	40	44.0	35.8	19.6
Rate effect ^x	NS	**	**	*	NS	**	**	***	***	*
LSD ^w	5.2	15.9	9.4	3.1	4.4	7.8	8.2	6.7	6.5	6.7
Linear ^x	NS	***	***	**	NS	***	***	***	***	**
Quadratic ^x	NS	***	**	NS	NS	**	***	***	***	*

^zEquivalent to 0, 15, 30, 45, 60, and 75 g·m⁻²; 1 g·m⁻² = 0.0033 oz/ft², 1 g = 0.0353 oz.

^yLeaf data for main stem only; 1 cm² = 0.1550 inch².

^xNS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on ANOVA.

^wFisher's least significant difference.

Table 2. Leaf mineral content in stinging nettle plants grown under greenhouse conditions in media amended with different levels of nitrogen (N) fertilizer. Data are means for three plants.

N treatment (g/pot) ^z	Season 1				Season 2			
	Carbon	Nitrogen	Potassium	Calcium	Carbon	Nitrogen	Potassium	Magnesium
	[means ± SE (%)]							
0	37.0 ± 1.2	3.27 ± 0.28	1.46 ± 0.12	0.98 ± 0.16	34.92 ± 2.2	1.49 ± 0.13	1.08 ± 0.19	0.81 ± 0.11
0.5	37.9 ± 0.9	3.53 ± 0.30	1.64 ± 0.10	1.21 ± 0.12	36.14 ± 1.9	1.65 ± 0.11	1.39 ± 0.11	0.99 ± 0.13
1.0	38.0 ± 0.8	4.21 ± 0.57	1.83 ± 0.26	1.44 ± 0.18	36.31 ± 2.0	1.70 ± 0.14	1.90 ± 0.16	1.11 ± 0.16
1.5	38.4 ± 2.1	4.07 ± 0.61	1.97 ± 0.31	1.47 ± 0.18	35.16 ± 1.8	1.65 ± 0.20	1.80 ± 0.20	1.16 ± 0.12
2.0	37.3 ± 1.8	3.90 ± 0.35	2.18 ± 0.72	1.61 ± 0.11	35.52 ± 1.6	2.00 ± 0.18	1.89 ± 0.16	1.18 ± 0.16
2.5	37.5 ± 1.1	4.58 ± 0.42	2.14 ± 0.63	1.71 ± 0.20	36.87 ± 1.3	2.35 ± 0.21	2.06 ± 0.19	1.18 ± 0.18

^zEquivalent to 0, 15, 30, 45, 60, and 75 g·m⁻²; 1 g = 0.0353 oz, 1 g·m⁻² = 0.0033 oz/ft².

Table 3. Three-way analysis of variance for main effects and interactions of nitrogen (N), potassium (K), and season (summer and fall) on growth and biomass yield in stinging nettle grown under greenhouse conditions. N and K were applied at rates equivalent to 15, 45, and 75 g·m⁻² and 4, 8, and 12 g·m⁻², respectively.^z

Main effects and interactions	df	Leaf no. ^y	Leaf area ^y	Leaf width ^y	Stem length ^x	Stem no.	Dry wt
P value							
Source							
K	2	0.2882	0.0459	0.0142	0.6217	0.7661	0.1093
N	2	0.0261	0.4200	0.1852	0.1401	0.0213	<0.0001
Season (S)	1	<0.0001	<0.0001	<0.0001	0.0006	0.0328	<0.0001
K × N	4	0.1385	0.5694	0.7563	0.4741	0.3224	0.3090
K × S	2	0.8373	0.0521	0.0762	0.4990	0.1882	0.9378
N × S	2	0.5346	0.2714	0.3779	0.7557	0.6838	0.1802
K × N × S	4	0.6905	0.1204	0.0297	0.3339	0.7462	0.4302

^z1 g·m⁻² = 0.0033 oz/ft².

^yData collected for leaves on main stem only.

^xLength of main stem.

higher in season 1 than in season 2 with significantly higher N per unit of leaf biomass observed across treatments in season 1 (Table 2). There were no big differences in stem and root mineral content in season 1. Similar results were observed in season 2 except for stem N, and root Mg and Ca that were significantly different at N application levels of 1.5 g/pot N and higher (data not included).

Expt. 2.

PLANT GROWTH AND BIOMASS YIELD. Nitrogen applied in factorial combinations with K had a significant effect on leaf and stem number and on total dry weight with improved performance observed at higher levels of N. Leaf size (area and width) was marginally affected by K treatment though no K related trends were observed for other parameters (Table 3). Owing to big differences in growth between season 1 and 2, season had a significant impact on overall plant performance. There were no interactions between K and N, and between fertilizer treatment and season (Table 3). Composite graphs for N and K effects on leaf, stem, and root dry matter show that aboveground growth and biomass allocation increased with N irrespective of K level, while the opposite was true for K where a slight decline in dry matter yield was observed at the highest K level in season 1, and for leaf and root dry matter yield in season 2. Overall, there was better plant performance in season 2 than in season 1 (Fig. 2).

MINERAL NUTRITION. Data are presented for elements where trends were observed in response to N and K treatments. Leaf N was higher at N application rates above 1.5 g/pot N

Fig. 2. Dry matter partitioning as affected by nitrogen (N) and potassium (K) applied at rates equivalent to 15, 45, and 75 g·m⁻² and 4, 8, and 12 g·m⁻², respectively, in stinging nettle grown under greenhouse conditions in summer (S1) and fall (S2). Data points are means of three plants; 1 g = 0.0353 oz, 1 g·m⁻² = 0.0033 oz/ft².

in both seasons irrespective of K availability. A similar trend was observed for Ca leaf content in season 1, but not in season 2, where leaf Ca content was higher at K levels above 0.33 g/pot. In season 1, leaf Mg

content was highest in low N treatments at all K levels but was higher at the highest level of K (0.50 g/pot K) in season 2 (Table 4). There was higher leaf Ca, root N, and stem K in season 2 than in season 1, while

Table 4. Leaf mineral content in stinging nettle plants grown in media amended with different levels of nitrogen (N) and potassium (K) fertilizer. Data are means for three plants.

N and K treatments (g/pot)*		Season 1			Season 2			
K	N	Carbon	Calcium	Magnesium	Nitrogen	Potassium	Calcium	Magnesium
[means $\pm$ SE (%)]								
0.17	0.5	36.9 $\pm$ 0.3	1.23 $\pm$ 0.26	1.36 $\pm$ 0.15	1.67 $\pm$ 0.35	0.72 $\pm$ 0.21	1.58 $\pm$ 0.14	0.47 $\pm$ 0.19
0.17	1.5	37.5 $\pm$ 0.7	1.72 $\pm$ 0.30	1.40 $\pm$ 0.18	2.21 $\pm$ 0.34	1.25 $\pm$ 0.18	1.74 $\pm$ 0.10	0.65 $\pm$ 0.17
0.17	2.5	37.1 $\pm$ 0.5	1.88 $\pm$ 0.20	1.21 $\pm$ 0.20	2.27 $\pm$ 0.22	1.61 $\pm$ 0.20	1.86 $\pm$ 0.37	0.81 $\pm$ 0.21
0.33	0.5	36.3 $\pm$ 0.8	1.30 $\pm$ 0.38	1.36 $\pm$ 0.23	1.47 $\pm$ 0.29	1.30 $\pm$ 0.30	2.24 $\pm$ 0.35	1.00 $\pm$ 0.17
0.33	1.5	36.9 $\pm$ 0.5	1.47 $\pm$ 0.27	1.32 $\pm$ 0.16	2.23 $\pm$ 0.34	1.75 $\pm$ 0.28	2.22 $\pm$ 0.26	1.05 $\pm$ 0.20
0.33	2.5	37.1 $\pm$ 1.0	1.70 $\pm$ 0.30	1.16 $\pm$ 0.32	2.83 $\pm$ 0.27	1.87 $\pm$ 0.31	2.21 $\pm$ 0.27	1.11 $\pm$ 0.16
0.50	0.5	35.5 $\pm$ 0.8	1.25 $\pm$ 0.27	1.52 $\pm$ 0.20	1.58 $\pm$ 0.31	1.57 $\pm$ 0.29	2.41 $\pm$ 0.31	1.25 $\pm$ 0.10
0.50	1.5	37.4 $\pm$ 0.8	1.50 $\pm$ 0.35	1.32 $\pm$ 0.18	2.31 $\pm$ 0.16	2.11 $\pm$ 0.32	2.28 $\pm$ 0.19	1.23 $\pm$ 0.24
0.50	2.5	36.2 $\pm$ 0.7	1.84 $\pm$ 0.16	1.28 $\pm$ 0.16	3.09 $\pm$ 0.56	2.19 $\pm$ 0.35	2.24 $\pm$ 0.38	1.26 $\pm$ 0.23

*Equivalent to 15, 45, and 75 g·m⁻² N and 4, 8, and 12 g·m⁻² K, respectively; 1 g = 0.0353 oz, 1 g·m⁻² = 0.0033 oz/ft².

Fig. 3. Change in stinging nettle leaf chlorophyll content (SPAD units) in response to nitrogen (N) fertilization under greenhouse conditions. Potted plants were supplied with N at rates of 0.5, 1.5, and 2.5 g/pot (equivalent to 15, 45, and 75 g·m⁻²) in split applications. Regression equations for 0.5 N, 1.5 N, and 2.5 N are $y = -0.4484x^2 + 3.6976x + 23.538$, $y = -0.2988x^2 + 3.2036x + 26.278$, and $y = -0.0183x^2 + 1.4087x + 27.819$, respectively. Data points are means of three plants; 1 g = 0.0353 oz, 1 g·m⁻² = 0.0033 oz/ft².

the opposite was true for leaf Mg (root and stem data not shown).

LEAF CHLOROPHYLL CONTENT. In both Expt. 1 and 2, leaf chlorophyll varied with both level and timing of N application across seasons. Chlorophyll data from Expt. 2 (season 2) as shown in Fig. 3 represent typical stinging nettle response to N treatment. After transplanting, color intensity increased with time at all N levels reaching a maximum in week 3, but continued increasing only in treatments that received a split application of N at day 20. The regression curve for the 2.5 g/pot N treatment shows a linear relationship between N application and leaf chlorophyll with a decline in leaf chlorophyll observed after the last

dose of N in both the 0.5 g/pot N and 1.5 g/pot N treatments (Fig. 3).

Discussion

In this study, we found that dry matter accumulation is correlated with mineral nutrition in stinging nettle. There was a positive correlation between biomass yield and N availability, and an inverse relationship between N availability and root dry matter during both seasons. These findings and preliminary data that showed differences in whole-plant response vs. dry matter allocation to stem and leaf growth in response to mineral availability have implications for stinging nettle as a potential specialty crop.

Differences in biomass allocation, growth, and mineral acquisition observed in response to mineral availability and season show that overall, there was higher biomass and nutrient uptake with increasing levels of N and K, and irrespective of treatment, more dry matter yield in the fall (season 2) than in summer (season 1). The higher below and aboveground biomass accumulation reported for both experiments in season 2 is likely to be linked not only to mineral nutrition but also to seasonal growth cycles. Observations from an ongoing field study show that stinging nettle growth in south-central Virginia is characterized by two phenological stages: rapid (vegetative and reproductive) growth up to late spring, limited development during the summer, and rapid (mostly vegetative) growth during the fall. This pattern approximates that reported by Srútek (1995), with fall growth consisting of significant investment in spreading, scaly rhizomes with rudimentary lamina. These rhizomes bear roots at each four-node stipule and are responsible for the many new shoots the following spring that facilitate stinging nettle encroachment into open spaces within disturbed sites.

Data on chlorophyll illustrate the importance of N in stinging nettle growth. As expected, chlorophyll content was significantly affected by N level, but the marked variation in leaf color over relatively short periods following N application indicates a rapid spike in N uptake leading to depletion of available N before the next split application. In a scenario where stinging nettle is grown for extraction of chlorophyll, it is clear from our results that timing and management of N supply can be a useful tool for maximizing chlorophyll yield

per unit of leaf biomass. Similarly, stem production for fiber or attempts to maximize root yield for medicinal purposes can be influenced by nutrient (particularly N) management. However, the decline in overall stinging nettle performance at 2.5 g/pot N (75 g·m⁻² N equivalent) in Expt. 1 suggests that this may represent the upper limit for N fertilization in stinging nettle.

Varying the level of K in Expt. 2 affected leaf size, and a slight decline in plant dry matter was observed at the highest level of K fertilization. However, the K effect was masked by N treatment, with dry matter accumulation varying more in response to N than K. Leaf, stem, and root mineral content show significant differences in relation to season in addition to variations in response to treatment, e.g., increased uptake of Ca and Mg at higher levels of N and K. Although there are reports of high soil K inhibiting the uptake of Ca and Mg (Peacock, 1999; Woods et al., 2005), there were no clear interactions between K, Ca, and Mg in the case of stinging nettle. However, the general decline in biomass yield at 0.50 g/pot means the optimum range for K fertilization in stinging nettle is below this threshold.

Our work and that by Šrútek (1995) were carried out under greenhouse conditions with natural lighting, and in our case, temperatures that were controlled to approximate external conditions. This means the seasonal differences observed in mineral uptake, dry matter allocation, and organ yield may have been driven by photoperiod and ambient temperature. It is possible that the high mid-summer temperatures common to south-central Virginia may have contributed to depressed growth in Expt. 1 as is being observed under field conditions. Furthermore, seasonal variation in N nutrition and biomass yield may point to reproduction as a strong sink channeling metabolites away from vegetative growth into floral organs and seed that were harvested as part of leaf samples in Expt. 1.

Conclusion

Results obtained in this study show that growth and dry matter partitioning in stinging nettle are affected by mineral nutrition and season. This suggests growers could manipulate stinging nettle yield and quality through judicious supply of fertilizer,

timed planting, and selective harvesting of different organs.

Literature cited

- Alibas, I. 2007. Energy consumption and color characteristics of nettle leaves during microwave, vacuum and convective drying. *Biosystems Eng.* 96:495–502.
- Boivin, J.R., B.D. Miller, and V.R. Timmer. 2002. Late-season fertilization of *Picea mariana* seedlings under greenhouse culture: Biomass and nutrient dynamics. *Ann. For. Sci.* 59:255–264.
- Bown, D. 1995. *Encyclopaedia of herbs and their uses*. Dorling Kindersley, London, UK.
- Bruneton, J. 1999. *Pharmacognosy, phytochemistry, medicinal plants*. Lavoisier Publ., Paris, France.
- Dambroth, M. and R. Seehuber. 1988. Flachs-Züchtung, Anbau und Verarbeitung. Ulmer, Stuttgart, Germany.
- Dreyer, J. 1995. Nessel, p. 145–162. In: F. Waskow (ed.). *Hanf & Co-die Renaissance der heimischen Faserpflanzen*. Verlag Die Werkstatt, Göttingen, Germany.
- Gibbons, E. 1966. *Stalking the healthful herbs*. Alan C. Hood and Co., Chambersburg, PA.
- Gosling, P. 2005. Facilitation of *Urtica dioica* colonization by *Lupinus arboreus* on a nutrient-poor mining spoil. *Plant Ecol.* 178:141–148.
- Grela, E.R., R. Krusinski, and J. Matras. 1998. Efficacy of diets with antibiotics and herb mixture additives in feeding growing-finishing pigs. *J. Anim. Feed Sci.* 7:171–175.
- Hayden, A.L. 2006. Aeroponic and hydroponic systems for medicinal herb rhizome and root crops. *HortScience* 41:536–538.
- Iványi, I. and Z. Izsáki. 2009. Effect of nitrogen, phosphorus, and potassium fertilization on nutritional status of fiber hemp. *Commun. Plant Sci. Soil Anal.* 40:974–986.
- Kleitz, K.M., M.M. Wall, C.L. Falk, C.A. Martin, M.D. Remmenga, and S.J. Guldán. 2008. Stand establishment and yield potential of organically grown seeded and transplanted medicinal herbs. *HortTechnology* 18:116–121.
- Koch, E. 2001. Extracts from fruits of saw palmetto (*Sabal serrulata*) and roots of stinging nettle (*Urtica dioica*): Viable alternatives in the medical treatment of benign prostatic hyperplasia and associated lower tract urinary symptoms. *Planta Med.* 67:489–500.
- Lopatkin, N., A. Sivkov, C. Walther, S. Schläfke, A. Medvedev, J. Avdeichuk, G. Golubev, K. Melnik, N. Elenberger, and U. Engelmann. 2005. Long-term efficacy and safety of a combination of sabal and urtica extract for lower urinary tract symptoms—a placebo controlled, double-blind, multicenter trial. *World J. Urol.* 23: 139–146.
- Marschner, H. 1995. *Mineral nutrition of higher plants*. Academic Press, London, UK.
- Mittman, R. 1990. Randomized, double-blind study of freeze-dried *Urtica dioica* in the treatment of allergic rhinitis. *Planta Med.* 56:44–47.
- Pagliarulo, C.L., A.L. Hayden, and G.A. Giacomelli. 2004. Potential for greenhouse aeroponic cultivation of *Urtica dioica*. *Acta Hort.* 629:61–66.
- Peacock, B. 1999. Potassium in soils and grapevine nutrition. Univ. California Coop. Ext. Tulare County, Publ. No. NG9-99.
- Pigott, C.D. 1971. Analysis of the response of *Urtica dioica* to phosphate. *New Phytol.* 90:389–404.
- Pigott, C.D. and K. Taylor. 1964. The distribution of some woodland herbs in relation to the supply of nitrogen and phosphorus in the soil. *J. Ecol.* 52:175–185.
- Plant for a Future. 2012. A resource and information centre for edible and otherwise useful plants. 12 July 2012. <<http://www.pfaf.org/user/Plant.aspx?LatinName=Urtica+dioica>>.
- Randall, C., H. Randall, F. Dobbs, C. Hutton, and H. Sanders. 2000. Randomized controlled trial of nettle sting for treatment of base-of-thumb pain. *J. R. Soc. Med.* 93:305–309.
- Sokeland, J. 2000. Combined sabal and urtica extract compared with finasteride in men with benign prostatic hyperplasia: Analysis of prostate volume and therapeutic outcome. *Brit. J. Urol. Intl.* 86:439–442.
- Šrútek, M. 1995. Growth responses of *Urtica dioica* to nutrient supply. *Can. J. Bot.* 73:843–851.
- Weiss, F. 1993. Effects of varied nitrogen fertilization and cutting treatments on the development and yield components of cultivated stinging nettles. *Acta Hort.* 331:137–144.
- Woods, M.S., Q.M. Ketterings, and F.S. Rossi. 2005. Measuring the effects of potassium application on calcium and magnesium availability in a calcareous sand. *Intl. Turfgrass Soc. Res. J.* 10:1015–1020.