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Full Length Research Paper

The methods of nitrogen application influence on essential oil yield and water use efficiency of summer savory (*Satureja hortensis* L.)

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To evaluate the beneficial impact of methods of nitrogen application on summer savory (*Satureja hortensis* L.), some yield characters were investigated. The objective in this study was, the interactive effects of foliar nitrogen application and solid nitrogen application on: essential oil yield and water use efficiency at Iran in 2006. The experiment was carried out using a factorial design with three replications. Certain factors including solid nitrogen application (non-application, 50, 100 and 150 kg ha^{-1}) and foliar nitrogen application (non-application, 4.5, 6 and 7.5%) that sprayed in three stages (stem elongation stage, the beginning of flowering stage and the beginning of seed formation stage) were studied. The final statistical analysis indicated that in the high solid N application, yield compounds were significantly higher. Flowering shoot yield, essential oil yield, seed yield and root yield of plants were higher in units by higher solid N application in plant. The foliar N application treatment significantly increased yield compounds, biological yield, essential oil percentage and water use efficiency. Foliar N application persist less in damaging of soil N application result, and it enables plant to significantly grow its shoot and root developing along soil depth and consequently increasing essential oil yield and water use efficiency of summer savory. The findings may give applicable advice to commercial farmers and medicinal and aromatic plants researchers for management and concern on fertilizer strategy and carefully estimate solid N supply by foliar N application.

Key words: Foliar nitrogen application, solid nitrogen application, essential oil yield, water use efficiency, *Satureja hortensis* L.

INTRODUCTION

Summer savory (*Satureja hortensis* L., Lamiaceae) is the best known of the savory species. It is an annual, but otherwise is similar in use and flavor to the perennial winter savory. Summer savory is a traditional popular herb in Atlantic Canada, where it is used in the same way sage is elsewhere (Boyraz and Ozcan, 2006). Singh et al. (2008) evaluated the effect of depth (25, 37.5 and 50 mm) and methods (ridge and furrow and broad bed and furrow method) of irrigation and nitrogen levels (0, 200 and 400 kg N ha^{-1}) on herb and oil yields of Java citronella. At the highest level of N application (400 kg N ha^{-1}) ridge was better suited for growth citronella. Their results have shown that highest herb and oil yields of citronella were achieved with the application of 400 kg N ha^{-1}, and content and quality of oil were not affected by nitrogen.

A field experiment was conducted on a center-pivot–irrigated, well-drained Haxtun sandy loam soil (fine-loamy, mixed, superactive, mesic Pachic Argiustolls) by using a randomized complete block split-split plot design, with irrigation rates [0.60, 0.80, and 1.00 of the estimated evapotranspiration (ET)], N fertility rates (30, 140, 250,

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Table 1. Analysis of Soil.

Soil texture	Sand (%)	Silt (%)	Clay (%)	K (mg/kg)	P (mg/kg)	N (mg/kg)	Na (Ds/m)	EC (1: 2.5)	pH	Depth of sampling
Sandy	49	30	21	147.2	6.2	34.7	0.04	0.19	8.1	0 - 15 cm

and 360 kg ha^{-1}, including N from soil, fertilizer, and irrigation water) and corn populations (57000, 69000 and 81000 plants ha^{-1}) as the main-plot, split-plot, and split-split plot treatments, respectively and application of 250 kg N ha^{-1} was provided optimum with water use efficiency (WUE) (Al-Kaisi and Yin, 2003). The objective of a study was to understand the effect of nitrogen (N) on net photosynthesis (P_n), nitrogen use efficiency (NUE), water use efficiency (WUE) of jack pine (*Pinus banksiana* Lamb.) and four boreal forest species. Large-leaved aster (*Aster macrophyllus* L.), Canada blue-joint grass (*Calamagrostis canadensis* (Michx.) Beauv.), trembling aspen (*Populus tremuloides* (Michx.) and red raspberry (*Rubus idaeus* L.) were planted at a range of densities (0 - 8 plants/m^2) with jack pine seedlings. The results showed that Jack pine P_n, NUE and WUE increased by nitrogen application (Robinson et al., 2001). Foliar N applications are often associated with leaf burn when applications are made in the early morning and when dew is still on the plants. A foliar N application applied as a liquid spray resulted in higher balm biological yield levels than when N was broadcast as dry granular fertilizer at later growth stages on balm not grown after fallow (Abbaszadeh et al., 2006).

Zhao et al. (2008) investigated the effect of foliar nitrogen fertilization on the water use efficiency, growth, photosynthetic pigment contents, gas exchange and chlorophyll (Chl) fluorescence parameters in two tall fescue cultivars (*Festuca arundinacea* cv. Barlexas and Crossfire II). Foliar N supply can improved the growth rates, especially for the Barlexas and water use efficiency increased under foliar N supply, especially in Crossfire II. Moreover, cultivar variations in photosynthetic performance were associated with their different responses to foliar nitrogen fertilization, which were evidenced by shoot growth rate and photosynthetic pigment contents. The objectives of Bly and Woodard (2003) in their experiment were evaluating effect of foliar N application on wheat (*Triticum aestivum* L.) water use efficiency. Foliar N was applied at tillering and earing stages on two cultivars of HRWW and HRSW each year from 1995 to 2000. The foliar N rate (33.7 kg N ha^{-1}) was applied as 1:1 solution of urea ammonium nitrate (UAN) and water. The foliar N gave the highest WUE throughout all the years and WUE was significantly reduced 5% by foliar N at earing stage for HRSW. Therefore, the objective of this experiment was to determine the nitrogen application influences on essential oil yield and water use efficiency of summer savory (*Saturejahortensis* L.).

MATERIALS AND METHODS

This study was conducted on experimental field of Research Institute of Forest and Rangelands at Iran (35°48' N, 51°01' W; 1320 m above sea level) from 30 May to 20 Augus, 2006, with sandy soil (Table 1), relative humidity (68%), mean annual temperature (16°C) and rainfall in the study area is distributed with an annual mean of 235 mm.

The experiment was carried out using a factorial design with three replications. Certain factors including solid nitrogen application (non-application, 50, 100 and 150 kg ha^{-1}) and foliar nitrogen application (non-application, 4.5, 6 and 7.5%) that sprayed in three stages (stem elongation stage, the beginning of flowering stage and the beginning of seed formation stage) were studied. Initially, plant nutrient feed of phosphorus and potassium were added by applying 100 kg ha^{-1} ammonium phosphate and 150 kg ha^{-1} K_2O at cultivation time respectively. At the end of flowering stage, we selected 100 g dry matter of flowering shoot from each plot for determination of essential oil percentage by Clevenger. Finally, essential oil yield was determined by the following formula (Aliabadi Farahani et al., 2008b).

Essential oil yield = Essential oil percentage × Flowering shoot yield

To determine biological yield, seed yield and root yield, 10 plants were selected randomly from each plot at maturity and then, harvest index (HI) was determined by the following formula (Rouzbeh et al., 2009):

$$\mathrm{HI} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

The irrigation system was a piping system and water usage was determined by meter for each plot in each irrigation period. Finally, WUE was determined by following formula (Aliabadi Farahani et al., 2008a):

$$\mathrm{WUE} = \frac{\text{Biological yield (kg)}}{\text{Water used by evapotranspiration (m}^{3}\text{)}}$$

The data were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS institute, 1998) computer software at $P < 0.05$.

RESULTS

The final results of plants characteristics showed that foliar N application significantly affected essential oil yield

Table 2. Analysis of variance.

Sources of variation	df	Mean squares							
		Essential oil yield	Biological yield	Essential oil percentage	Seed yield	Water use efficiency	Flowering shoot yield	Root yield	Harvest index
Replication	2	12.425	189143.313	0.005	14173.583 *	0.084 **	42051.521	67.521	3.931
Solid N application	3	28.326 *	1520201.243**	0.071 **	17373.583 **	0.041 **	200191.139 **	14367.854 **	16.105*
Foliar N application	3	57.044 **	1089514.354**	0.058 **	9274.694	0.022 **	132920.25 **	45.688	18.928*
Solid N application, Foliar N application	9	23.092 **	211820.317 *	0.056	3951.898	0.004 *	72736.491 **	78.354	2.688
Error	30	6.547	86199.201	0.003	3344.694	0.002	19382.743	310.654	5.017
CV (%)		9.51	8.22	2.77	7.33	8.08	9.93	7.57	10.01

* and ** : Significant at 5 and 1% levels respectively.

essential oil percentage, WUE, biological yield and flowering shoot yield in $P \leq 0.01$ and harvest index in $P < 0.05$, but the root yield and seed yield were not significantly affected by the foliar N application (Table 2), which indicated the highest essential oil yield (28.27 kg ha^{-1}) and seed yield (811.4 kg ha^{-1}) under application of 7.5% foliar N (Table 3). Highest essential oil percentage (1.988%), WUE (0.54 kg m^{-3}), root yield (234 kg ha^{-1}) and biological yield (3768 kg ha^{-1}) were observed under application of 7.5% foliar N (Table 3). Also, highest flowering shoot yield (1511 kg ha^{-1}) and harvest index (24.21%) were achieved under application of 4.5% foliar N and non-application of foliar N respectively (Table 3). These findings are in agreement with the observations of Abbaszadeh et al. (2006), Bly and Woodard (2003) and Woolfolk et al. (2002). Also, solid N application significantly affected essential oil percentage, WUE, biological yield, flowering shoot yield, seed yield and root yield in $P \leq 0.01$ and harvest index and essential oil yield in $P < 0.05$ (Table 2). Certain yield compounds including essential oil yield (28.85 kg ha^{-1}), seed yield (822.2 kg ha^{-1}), flowering shoot yield (1516 kg ha^{-1}) and root yield (270 kg ha^{-1}) were observed under application of 150 kg N ha^{-1} (Table 3). Highest WUE (0.56 kg m^{-3}) and biological yield (3897 kg ha^{-1}) were achieved under application of 100 kg N ha^{-1} (Table 3). Also, highest essential oil percentage (2.017%) and harvest index (23.89%) were obtained under non-application of solid N (Table 3). These results were similar with the findings of Abbaszadeh et al. (2006) and Al-Kaisi and Yin (2003).

Interaction of the methods of nitrogen application significantly affected flowering shoot yield and essential oil yield in $P \leq 0.01$ and WUE and biological yield in $P \leq 0.05$ (Table 2). Highest biological yield (4424 kg ha^{-1}), flowering shoot yield (1855 kg ha^{-1}), WUE (0.6433 kg m^{-3}) and seed yield (875.3 kg ha^{-1}) were achieved with the application of 100 kg N ha^{-1} and 4.5% foliar N (Table 4). The highest root yield (273.3 kg ha^{-1}) and essential oil yield (33.7 kg ha^{-1}) were obtained with the application of 150 kg N ha^{-1} and 6% foliar N and application of 150 kg N ha^{-1} and 7.5% foliar N respectively (Table 4). Also, the highest essential oil percentage (2.13%) and harvest index (25.98%) were observed under the non-application of solid N and 6% foliar N and non-applications of solid N and foliar N respectively (Table 4). Our results of treatments interaction were similar to the results of Abbaszadeh et al. (2006).

DISCUSSION

However, nitrogen element is not an essential oil components, but our final results indicated that applications of solid N and foliar N increased essential oil content of summer savory, because the nitrogen develops leaf area and lateral stem and because of increase in the essential oil yield. The interaction between the amount of the essential oil percentage and flowering shoot yield is considered important as two components of the essential oil yield. However, the essential oil percen-tage reduced under application of solid N but essential oil yield increased under this condition, because flowering shoot yield increased under application of solid N sorely. Therefore, each increasing factor of essential oil percentage and flowering shoot yield, can increase essential

Table 3. Mean comparison of main treatments.

Treatments		Essential oil yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Essential oil percentage (%)	Water use efficiency (kg m^{-3})	Flowering shoot yield (kg ha^{-1})	Root yield (kg ha^{-1})	Harvest index (%)
Solid N application	Non-application	25.24 b	3119 c	739.8 b	2.017 a	0.45 c	1249 b	196 c	23.89 a
	50 kg ha^{-1}	26.26 b	3465 b	778.9 ab	1.96 b	0.5 b	1340 b	211 b	22.61 ab
	100 kg ha^{-1}	27.22 ab	3897 a	815.9 a	1.839 d	0.56 a	1500 a	252 a	21.23 b
	150 kg ha^{-1}	28.85 a	3809 a	822.2 a	1.897 c	0.55 a	1516 a	270 a	21.77 b
Foliar N application	Non-application	23.64 b	3122 b	748.7 b	1.887 b	0.45 b	1258 b	230 b	24.21 a
	4.5%	27.68 a	3679 a	801 a	1.852 b	0.53 a	1511 a	232 a	21.99 b
	6%	27.98 a	3768 a	795.8 ab	1.988 a	0.54 a	1415 a	234 a	21.36 b
	7.5%	28.27 a	3713 a	811.4 a	1.986 a	0.53 a	1422 a	232 a	21.94 b

Means within the same column and rows and factors, followed by the same letter are not significantly different ($P < 0.05$).

Table 4. Means comparison of interactions.

Survey instance qualifications		Essential oil yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Essential oil percentage (%)	Water use efficiency (kg m^{-3})	Flowering shoot yield (kg ha^{-1})	Root yield (kg ha^{-1})	Harvest index (%)
Non-application	Non-application	19.98 f	2619 g	676.3 c	1.931 de	0.3847 f	1036 f	198.7 c	25.98 a
	4.5%	25.73 bcde	3234 ef	748.3 bc	1.96 cde	0.4728 de	1313 de	197.3 c	23.2 ab
	6%	27.52 bcde	3210 ef	771 abc	2.13 a	0.4694 de	1292 def	198.7 c	24.02 ab
	7.5%	27.72 bcde	3414 cdef	763.7 abc	2.048 abc	0.4986 cde	1354 cde	191 c	22.36 ab
50 kg ha^{-1}	Non-application	26.87 bcde	3304 ef	770.7 abc	1.889 ef	0.4828 de	1423 bcde	203.7 c	23.45 ab
	4.5%	25.65 bcde	3384 def	772 abc	1.993 bcd	0.4943 cde	1288 def	207.3 c	22.87 ab
	6%	28.61 bcd	3731 bcde	797 ab	2.081 ab	0.5444 bcd	1376 cde	217.7 bc	21.38 b
	7.5%	23.91 def	3406 cdef	776 abc	1.875 ef	0.4974 cde	1274 def	218 bc	22.72 ab
100 kg ha^{-1}	Non-application	24.66 cde	3092 fg	739 bc	2 bcd	0.4524 ef	1235 ef	247.7 ab	24.1 ab
	4.5%	30.32 ab	4424 a	875.3 a	1.632 g	0.6433 a	1855 a	256.7 a	19.74 b
	6%	26.14 bcde	3949 abc	776.3 abc	1.723 g	0.5752 abc	1524 bcd	248.7 ab	19.8 b
	7.5%	27.76 bcde	4124 ab	873 a	2.003 bcd	0.6003 ab	1387 cde	255.7 a	21.29 b

Table 4. Contd.

150 kg ha^{-1}	Non-application	23.06 de	3472 cdef	808.7 ab	1.725 g	0.5069 cde	1338 cde	271 a	23.31 ab
	4.5%	29 bc	3674 bcde	808.3 ab	1.825 f	0.5359 bcde	1589 bc	267.7 a	22.16 ab
	6%	29.65 bc	4181 ab	838.7 ab	2.02 bcd	0.6084 ab	1467 bcde	273.3 a	20.23 b
	7.5%	33.7 a	3907 abcd	833 ab	2.016 bcd	0.5692 abc	1672 ab	271.3 a	21.39 b

Means within the same column and rows and factors, followed by the same letter are not significantly different (P < 0.05).

oil yield. The results showed that applications of solid N and foliar N increased biological yield of summer savory, because nitrogen, which is a primary constituent of protein, is extremely susceptible to be lost when considering that average recovery rates fall in the range of 20 to 50% for dry matter production systems in plants, a main element in production. Toxic concentrations of nitrogenous fertilizers cause characteristic symptoms of nitrite or nitrate toxicity in plants, specifically in the leaves. Although pre-plant fertilizer applications decrease the potential for nutrient deficiencies in early stages of growth, presence of residual soil NO_3–N (plant-available mineral N from the previous season) may pose a risk to the soil water and would be salty by inordinate N application and increase its potential. Plant uses much energy for the absorption of saline water at the expense of dry matter production.

The highest biological yield of summer savory resulted from the application of 100 kg N ha^{-1} but decreased with the application of 150 kg N ha^{-1}. Foliar N application is often associated with leaf burn when application is made early in the morning and when dew is still on the crop. Leaf injury and yield depressions tend to be more frequent when fertilizer is applied in midday instead of the hours of early morning or late afternoon. Foliar N at early stages could increase P and K supplies at the time when the root system is not well developed. Reduction in yield could have resulted from leaf damage due to foliar N application. Therefore, dry matter production was reduced under application of high levels of foliar N as a result of injured leaves and was reduced by photosynthesis. Yield increases by foliar N application vary greatly. Solid N applied before planting will normally give a response equal to that of N applied up to stem elongation stage in summer savory at Iran. The highest biological yield was obtained under application of 6% foliar N. Therefore, each increasing factor of biological yield and reducer of evapotranspiration can increase WUE.

Conclusion

The results showed that foliar N application increased essential oil yield of summer savory. Also, application of 6% foliar N increased WUE and decreased application of solid N, but foliar burn was as a result of the application of 7.5% foliar N and reduction of WUE. Therefore, careful estimate of foliar N concentration can increase optimal use from water and nitrogenous fertilizer in sustainable agriculture. Also, our study showed that foliar N application contributed to the protection of water use efficiency against damaging effects of inordinate solid N by increasing biological yield. Practically, findings may suggest farmers and medicinal and aromatic plants researchers to consider carefully on limiting or controlling the huge amount of foliar N application in suffered soils by N fertilizers as it is a current challenge of scientist in global changes.

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