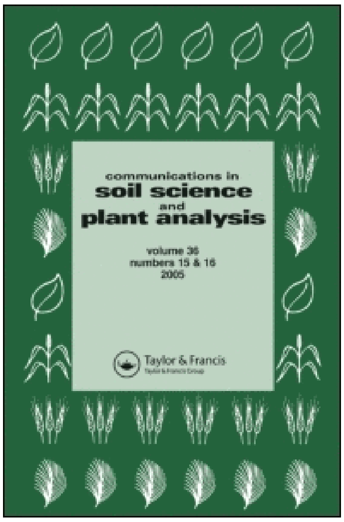

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Influence of Nitrogen and Potassium Fertilization on Yield and Quality of Rosemary in Relation to Harvest Number

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Rosemary is an important aromatic and spice plant. Its cultivation for production of its essential oil has gained importance in recent years. An experiment was conducted in a red sandy loam (Kandiustalf) soil to study the impact of cultivation of this multiharvest crop at different nitrogen (N) and potassium (K) application regimes on soil fertility and crop yield at the farm of the Central Institute of Medicinal and Aromatic Plants, Resource Center, Bangalore, during 2003–2005. The treatments consisted of all combinations of N levels (0, 150, and 300 kg per hectare per year) and K levels (0, 50, and 100 kg per hectare per year). Five harvests were taken at about 5-month intervals. The results showed that initially the soil alone was able to meet the crop requirements for K, but with the progress of time, addition of K to the soil in the form of fertilizer became necessary for obtaining optimum yields. At the end of five harvests, exchangeable K in soil was significantly lower as application of K decreased from 100 to 50 and 0 kg per hectare per year. Soil fertility could be maintained and oil yields of rosemary from four harvests could be increased from 146.6 L to 344.7 L per hectare by application of 150 kg N and 100 kg K.

Keywords Rosemary, potassium application, herb and oil yields, oil quality, soil fertility

Introduction

Rosemary is an important aromatic and spice plant. It grows wild in the Mediterranean region and is cultivated in Yugoslavia, Spain, Portugal, and other parts of Europe and the USA. Rosemary was introduced as a crop in south India in early 1990s in cool regions (Rao 2000). It has antibacterial, antifungal, and antioxidant properties (Hammer, Carson, and Riley 1999; Pintore et al. 2002). Carnosol, a phenolic compound extracted from the rosemary herb, has been reported to have anticancer activity (Dorrie, Sapala, and Zunino 2001). The essential oil of rosemary is suitable for use in perfume, soap, and fragrances. Therapeutic properties and uses of its essential oil have been reviewed (Farooqi and Srikant Sharma 2002).

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Rosemary has been recently introduced as a commercial crop in the South Indian Plains, near Bangalore. It is a perennial crop giving multiple harvests. However, nutritional studies of this crop are rare (Prakasa Rao et al. 1999; Singh, Ganesha Rao, and Ramesh 2007). The impact of this plant on some soil properties has been studied (Garcia, Andreu, and Rubio 2001; Garcia, Roldan, and Hernandez 2005). However, these studies have not included soil potassium (K). The present article describes a study on influence of nitrogen (N) and K fertilization on yield and quality of rosemary in relation to harvest number and impact of rosemary cultivation on soil K.

Materials and Methods

A field experiment was conducted to study the N and K nutrition of rosemary under drip irrigation at the farm of the Central Institute of Medicinal and Aromatic Plants, Resource Center, Bangalore, India, in August 2003. Bangalore is located at latitude 12° 58′ N, longitude 77° 35′ E, and an altitude of 930 m above mean sea level. The soil of the experimental field was a sandy loam (Kandiustalf) and had a pH of 5.68, electrical conductivity of $0.12\,dS\,m^{-1}$, 0.33% organic carbon (C), $190.4\,kg\,ha^{-1}$ available N, $22.5\,kg\,ha^{-1}$ available phosphorus (P), and $84.1\,kg\,ha^{-1}$ available K. Rosemary rooted cuttings were planted on 5 August 2003 on raised beds in plots 3.6 × 3.6 m. In each plot, there were three 70-cm-wide and 30-cm-high raised beds with 50-cm furrows separating them. In each raised bed, two rows of rosemary plants were planted, maintaining plant spacing of 60 × 45 cm. Drip irrigation lines, with drip holes 50 cm apart, were arranged to pass along the middle of each raised bed. The treatments, consisting of all combinations of N levels (0, 150, and $300\,kg\,ha^{-1}\,yr^{-1}$) and K levels (0, 50, and $100\,kg\,ha^{-1}$), were randomized in each of the three replications of a randomized complete block design (RCBD). Nitrogen, in the form of urea, was applied in six equal splits at 2-month intervals, whereas a common dose of P ($35\,kg\,ha^{-1}\,yr^{-1}$), as single superphosphate, and K, in the form of muriate of potash, were applied basally. The crop was maintained, and five harvests were taken on 11 February 2004, 10 June 2004, 16 November 2004, 12 May 2005, and 19 October 2005. At each harvest, herb and dry-matter yields were recorded. The dry-matter samples were preserved for N, P, and K analysis. Essential oil content in the herb was determined by laboratory distillation in a Clevenger's apparatus (Langenau 1948). Moisture was determined by drying a weighed sample of herb in an oven at 80 °C for 16 h and weighing the dry matter. The dried samples were preserved for nutrient analysis. Oil yields were calculated from dry-matter yields and oil content on a dry basis. The oil samples were analyzed for major constituents using a Varian CP 3800 gas chromatograph. The chromatograph was fitted with a CP-5 SIL 30-m × 25-mm column and programmed for 100 °C (2 °C), 8 °C, 220 °C (3 min). The carrier gas (N) had a flow rate of 0.4 mL/min and the injector and the flame ionization detector were maintained at 250 °C and 300 °C, respectively. The 0.2-μL samples were injected with a split ratio of 1:100. Peaks were identified by coinjection with authentic pure component samples wherever available and by calculation of Kovat's index. In this way, the main components of rosemary oil, namely, α-pinene, camphene, β-pinene, 1:8 cineole, camphor, isoborneol, borneol, α-terpenol, verbenone, and bornyl acetate, were determined using the respective peak areas.

Plant samples were analyzed for N, P, and K by standard methods, and uptake values were calculated from dry-matter yields. Soil samples were collected at the end of the experiment and analyzed for total N, available P, and exchangeable K. The results were analyzed by analysis of variance (Cochran and Cox 1957).

Results and Discussion

Herb and Dry-Matter Yields

The herb and dry-matter yield data are presented in Tables 1 and 2. Herb and dry-matter yields of rosemary were increased significantly by the application of 150 kg N per hectare per year over those of control in the first four harvests (but at 10% level of significance in the fourth harvest) as well as in the total of five harvests (Table 1). Response of rosemary to up to 300 kg N ha^{-1} $year^{-1}$ has been reported for flood-irrigated crop (Singh, Ganesha Rao, and Ramesh 2007). The data presented here showed that under drip irrigation the response of rosemary to N was limited to 150 kg ha^{-1} $year^{-1}$. In the fifth harvest, there was no significant response to N.

Herb and dry-matter yields of rosemary did not show a response to K in the first two harvests (Tables 1 and 2). In the third and fourth harvests, there was a response to application of 100 kg K (at 10% significance in case of the third harvest's herb yield). The soil was able to supply the plant's requirements for K in the early stages, but as the plants removed K from the soil, deficiency of K developed and the plant began to respond to K. In the fifth harvest, response to K was not significant because of increase in error resulting from wilt disease. In the total herb and dry-matter yields, the main effect of K was significant. Response of rosemary to 50 kg K was not significant, but application of 100 kg K significantly increased herb and dry-matter yields of rosemary. Singh, Ganesha Rao, and Ramesh (2007) reported that rosemary produced more herb and oil yields when 83 kg K was applied than when 41.5 kg was

Table 1. Effect of nitrogen and potassium applications on fresh herb yields (Mg ha^{-1}) of rosemary

Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Total
N_0K_0	3.02	6.59	1.72	2.18	1.21	14.72
N_0K_{50}	2.86	7.15	3.17	2.69	1.54	17.41
N_0K_{100}	3.09	6.78	3.89	2.47	0.96	17.19
$N_{150}K_0$	4.97	10.08	7.24	4.31	2.19	28.78
$N_{150}K_{50}$	4.34	9.73	5.22	3.19	1.87	24.36
$N_{150}K_{100}$	4.49	11.07	8.87	10.82	3.09	38.35
$N_{300}K_0$	4.91	9.62	3.57	2.06	1.30	21.46
$N_{300}K_{50}$	5.21	10.18	4.20	4.63	1.45	25.66
$N_{300}K_{100}$	4.47	11.87	6.29	6.21	2.48	31.31
$SEd_{N,K}$	0.30	0.56	0.98	1.43	0.50	2.74
$SEd_{N\times K}$	0.53	0.97	1.70	2.48	0.87	4.74
$LSD_{5\%\ N}$	0.65	1.19	2.08	NS	NS	5.80
$LSD_{5\%\ K}$	NS[a]	NS	NS (2.61)*	3.04	NS (0.88)*	5.80
$LSD_{5\%\ N\times K}$	NS	NS	NS (3.95)*	NS (5.79)*	NS (2.02)*	11.04

[a]NS, nonsignificant.
*LSD10% significant, and value is given in parentheses.

Table 2. Effect of nitrogen and potassium applications on dry-matter yields of rosemary ($Mg\,ha^{-1}$)

Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Total
N_0K_0	0.99	2.30	0.64	0.83	0.43	5.20
N_0K_{50}	0.90	2.33	1.07	1.03	0.59	5.93
N_0K_{100}	0.99	2.14	1.44	0.94	0.37	5.88
$N_{150}K_0$	1.67	3.08	2.72	1.53	0.80	9.80
$N_{150}K_{50}$	1.44	3.06	1.94	1.15	0.68	8.25
$N_{150}K_{100}$	1.57	3.25	3.29	3.50	1.10	12.71
$N_{300}K_0$	1.68	3.09	1.44	0.81	0.47	7.50
$N_{300}K_{50}$	1.74	3.23	1.50	1.68	0.56	8.70
$N_{300}K_{100}$	1.44	3.60	2.33	2.30	0.81	10.48
$SEd_{N,K}$	0.10	0.19	0.35	0.47	0.17	0.88
$SEd_{N\times K}$	0.17	0.34	0.61	0.82	0.29	1.52
$LSD_{5\%\ N}$	0.21	0.41	0.74	NS	NS	1.86
$LSD_{5\%\ K}$	NS[a]	NS	0.74	1.00	NS	1.86
$LSD_{5\%\ N\times K}$	NS	NS	NS	NS	NS	NS (3.54)*

[a]NS, nonsignificant.
*LSD10% significant, and value is given in parentheses.

applied. Leaching of N could have caused rosemary to respond to greater doses of N in the experiments of Singh, Ganesha Rao, and Ramesh (2007), but this factor is not likely to be important in the present studies.

Oil Content

The oil content in rosemary was not affected by treatments in first, third, and fourth harvests (data not presented), but second and fifth harvests were exceptions. In the second harvest, the oil content in rosemary increased on application of N up to 300 kg, whereas in the fifth harvest, application of 150 kg but not 300 kg N per

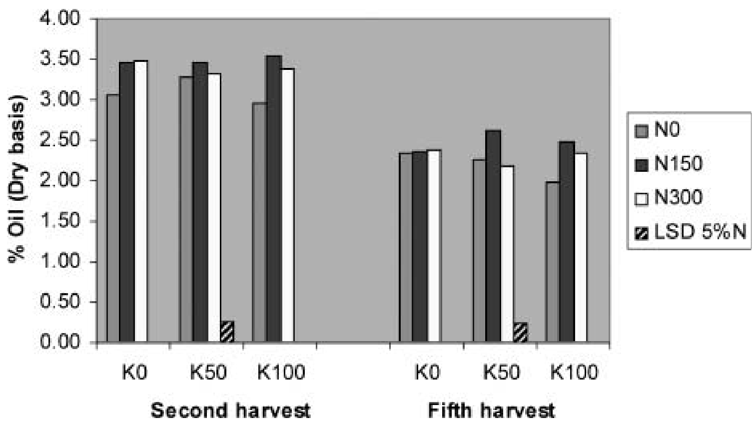

Figure 1. Effect of levels of nitrogen and potassium applications on oil content in rosemary.

hectare per year increased the oil content in rosemary (Figure 1). Singh, Ganesha Rao, and Ramesh (2007) reported that oil content in rosemary did not change with N and K applications. There are many reports saying that the oil content of aromatic plants did not change on application of fertilizers (Puttanna, Nanje Gowda, and Prakasa Rao 2001; Prakasa Rao et al. 1985; Prakasa Rao and Puttanna 1994). The mean oil contents on dry-weight basis in first, second, third, fourth, and fifth harvests were 5.40, 3.33, 2.59, 2.71, and 2.33%, respectively. The oil content in the first harvest was high because the harvested material had less proportion of woody parts and greater proportion of leaves. The latter contains most of the oil. The increase in oil content occasionally found on application of N could be due to increase in the proportion of leafy parts in the herb.

Oil Yield

Rosemary oil yield data are presented in Figure 2. Rosemary oil yields showed significant interaction effect with respect to N and K applications. Maximum oil yields could be obtained by the application of 150 kg N and 100 kg K per hectare per year. Singh, Ganesha Rao, and Ramesh (2007) reported increases in rosemary oil yields due to application of N and K.

Composition of the Essential Oil

In general, the composition of the oil was not affected by experimental treatments. Singh, Ganesha Rao, and Ramesh (2007) also reported that rosemary oil composition did not change as a result of application of N and K fertilizers. This in agreement with the findings reported in literature for another aromatic crop, citronella (Puttanna, Nanje Gowda, and Prakasa Rao 2001; Prakasa Rao et al. 1985; Prakasa Rao and Puttanna 1994). The mean percentages of the main components

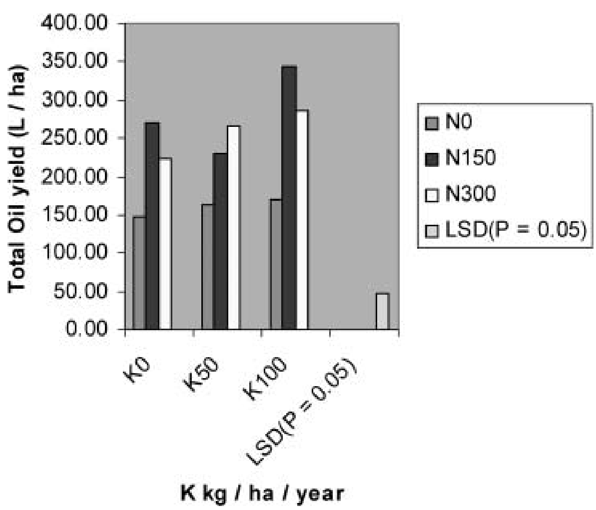

Figure 2. Effect of nitrogen and potassium application levels on oil yield in rosemary.

Table 3. Mean content of major constituents in rosemary essential oil

Name of the constituent	Concentration in oil (%)
β-Pinene	3.88
α-Pinene	10.65
Camphene	5.80
1:8 Cineole	27.75
Camphor	25.67
Iso-borneol	2.21
Borneol	1.44
α-Terpeneol	2.21
Verbenone	7.91
Iso-bornyl acetate	1.48

are presented in Table 3. There were no marked changes in oil composition between harvests.

Nutrient Content

The mean N, P, and K contents in rosemary plant dry matter were 1.30, 0.15, and 1.46%, respectively. Application of a nutrient occasionally increased the concentration of the same nutrient in the rosemary plant (data not presented). In the third harvest, application of 100 kg K decreased the P content in rosemary from 0.17 to 0.15%. Also, in the third harvest, in the absence of N application, application of 50 kg K decreased P content in rosemary dry matter from 0.21 to 0.18%, and application of 100 kg K further decreased it to 0.15%. These are probably due to increases in growth.

Nutrient Uptake

Uptake data are presented in Tables 4 to 6. Nitrogen uptake by rosemary was increased by the application of 150 kg N per ha per year in the first four harvests (Table 4). Application of a higher dose (300 kg N) did not further increase the N uptake except in the fourth harvest. In the third harvest, application of 100 kg K also increased N uptake, probably because of an increase in herb and dry-matter yields.

Phosphorus uptake was increased by the application of 150 kg N in the first four harvests (Table 5).

Application of 150 kg N increased the uptake of K by rosemary in the first three harvests and also in the total of five harvests (Table 6). In the first harvest, uptake of K was not significantly influenced by application of K fertilizer, indicating that the soil was able to meet the crops' requirement for K. This is also reflected in herb yields because there was no response to K in the first harvest (Table 1). Application of 50 or 100 kg K per hectare per year in the second harvest and application of 100 kg K in the third harvest increased the uptake of K. In the fourth and fifth harvests, as well as in the total of five harvests, application of 100 kg but not 50 kg K ha^{-1} year^{-1} increased the uptake of K by rosemary.

Table 4. Effect of nitrogen and potassium application levels on uptake of nitrogen (kg ha^{-1}) by rosemary

Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Total
N_0K_0	13.30	25.10	8.04	1.37	4.97	74.47
N_0K_{50}	11.24	29.21	12.94	1.32	6.62	81.66
N_0K_{100}	14.14	26.45	17.99	1.30	4.22	94.86
$N_{150}K_0$	23.18	44.36	31.78	1.35	8.47	148.39
$N_{150}K_{50}$	19.87	33.33	25.06	1.54	7.68	107.31
$N_{150}K_{100}$	21.63	39.20	42.15	1.45	9.38	130.20
$N_{300}K_0$	23.91	37.40	19.67	1.53	4.58	111.82
$N_{300}K_{50}$	23.68	40.91	20.58	1.55	6.54	127.54
$N_{300}K_{100}$	22.51	49.64	34.71	1.59	7.57	143.21
$SEd_{N,K}$	1.64	3.03	4.70	0.06	1.64	12.57
$SEd_{N \times K}$	2.85	5.25	8.13	0.10	2.83	22.29
$LSD_{5\%\ N}$	3.37	6.23	9.64	0.11	NS	27.28
$LSD_{5\%\ K}$	NS[a]	NS	9.64	NS	NS	NS
$LSD_{5\%\ N \times K}$	NS	NS	NS	NS	NS	NS

[a]NS, nonsignificant.

Soil Potassium

Exchangeable K in soil after five harvests of rosemary is shown in Figure 3. Exchangeable K values were significantly diminished after five harvests of rosemary when no K was applied to rosemary, but K status was maintained when 50 kg K ha^{-1} year^{-1} was applied (Figure 3). This shows that even if there is no response

Table 5. Effect of nitrogen and potassium application levels on uptake of phosphorus (kg ha^{-1}) by rosemary

Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Total
N_0K_0	1.58	3.74	1.34	1.56	0.72	8.94
N_0K_{50}	1.41	3.99	1.76	1.50	0.78	9.45
N_0K_{100}	1.63	3.39	2.01	1.25	0.58	8.86
$N_{150}K_0$	2.48	4.81	4.00	2.40	1.06	14.75
$N_{150}K_{50}$	2.14	4.66	3.79	1.99	0.76	13.34
$N_{150}K_{100}$	2.03	4.76	4.46	4.90	1.36	17.57
$N_{300}K_0$	2.32	4.43	2.32	1.26	0.67	10.99
$N_{300}K_{50}$	2.60	4.76	2.24	2.64	0.80	13.04
$N_{300}K_{100}$	2.28	5.64	3.84	3.08	1.18	16.02
$SEd_{N,K}$	0.21	0.36	0.55	0.64	0.21	1.17
$SEd_{N \times K}$	0.36	0.62	0.95	1.11	0.36	2.03
$LSD_{5\%\ N}$	0.42	0.74	1.13	1.31	NS	2.41
$LSD_{5\%\ K}$	NS[a]	NS	NS	NS	NS	NS
$LSD_{5\%\ N \times K}$	NS	NS	NS	NS	NS	NS

[a]NS, nonsignificant.

Table 6. Effect of nitrogen and potassium application levels on uptake of potassium ($kg\,ha^{-1}$) by rosemary

Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Total
N_0K_0	16.61	25.47	8.98	11.81	7.22	70.10
N_0K_{50}	15.57	33.35	17.34	16.35	9.70	94.31
N_0K_{100}	18.05	33.41	22.35	14.01	6.74	94.57
$N_{150}K_0$	22.69	40.99	32.83	18.85	8.66	124.02
$N_{150}K_{50}$	22.80	42.04	33.81	17.77	9.38	125.79
$N_{150}K_{100}$	25.06	47.20	50.11	56.87	16.47	195.70
$N_{300}K_0$	19.83	34.41	15.93	8.80	6.17	85.13
$N_{300}K_{50}$	25.49	45.20	21.92	24.48	8.70	125.78
$N_{300}K_{100}$	23.50	55.71	35.14	33.22	11.37	158.94
$SEd_{N,K}$	2.02	3.13	5.55	7.54	2.07	12.38
$SEd_{N\times K}$	3.50	5.42	9.61	13.06	3.59	21.45
$LSD_{5\%\ N}$	4.15	6.43	11.38	NS	NS	25.41
$LSD_{5\%\ K}$	NS[a]	6.43	11.38	15.47	NS	25.41
$LSD_{5\%\ N\times K}$	NS	NS	NS	NS	NS	NS

[a]NS, nonsignificant.

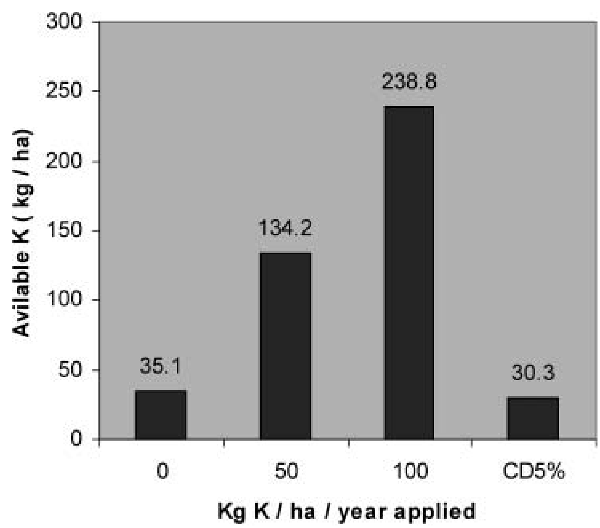

Figure 3. Exchangeable potassium in soil after five harvests of rosemary.

initially to K, it is necessary to apply sufficient quantities of K to maintain soil fertility.

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