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Effects of nitrogen, phosphorus and irrigation regimes on growth and leaf productivity of sage (*Salvia officinalis* L.) in Kenya

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ABSTRACT

Sage (Salvia officinalis L.) is among the herbs and spices grown for culinary uses is increasingly becoming important in Kenya. Its leaf productivity is however often limited by nitrogen and phosphorus, which are deficient in many Kenyan soils. The problem is even exacerbated by irregular rainfall in most parts of the country where it is grown, thus necessitating irrigation. The objective of this study was therefore to determine the effects of nitrogen, phosphorus and watering regimes on vegetative and leaf yield of sage. The experiment conducted at the Horticultural research and teaching Farm of Egerton University, was laid out in a three factor Strip Plot arrangement in a Randomised Complete Block Design (RCBD, with three replications. The treatments consisted of nitrogen (N) supplied as urea (46% N) at four rates; 0, 40, 80 and 120kg N/ha while phosphorus (P) was supplied as Triple Superphosphate (46% P_2O_5) at four rates; 0, 30, 60 and 90kg P/ha. Watering regimes included W1= Watering to field capacity once after every week, W2= Watering to field capacity once after every two weeks, and W3= watering to field capacity once after every four weeks. Nitrogen was assigned to the main plots; watering to the strip plots, and P to the sub-sub plots. The experiment was conducted in three trials; trial 1 (June 2011 – October 2011), trial 2 (October 2011 – February 2012) and trial 3 (March 2012 – May 2012). Data were collected on plant height, Leaf Area Index (LAI), leaf fresh and dry weights. All data were subjected to the analysis of variance (ANOVA) and where F test was significant; treatment means were separated using the Tukey's Studentized Range Test at $P \leq 0.05$. Results indicated that nitrogen applied at 80 kg N/ha, P at 60 kg P/ha and watering once after every two weeks gave the highest plant height (50.67 cm, 60.58 cm and 46.50 cm in trials 1, 2 and 3, respectively), and leaf fresh yield (27.10 ton/ha, 16.03 ton/ha 14.67 ton/ha in trials 1, 2 and 3, respectively). There is need however for economic evaluation of these practices before they can be recommended for use in Kenya.
Keywords: Sage, leaf yield, nitrogen, phosphorus, watering regimes

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INTRODUCTION

Sage (*Salvia officinalis* L.) is a member of the Lamiacea family which is rich in volatile constituents [1]. It is indigenous to the Mediterranean region. Sage has been grown mainly for its leaves, which serve as a raw material for pharmaceutical as well as food industries, due to its richness in essential oils [2], flavonoids and phenolic acids [3]. It is one of the most promising herbs for the growth and development of the herbs and spices/ Medicinal and Aromatic Plants (MAPs) sub-sector of Kenya's horticultural sector. The crop is well known for its medicinal properties for which it has been adopted as a medicinal and culinary herb. In Kenya, the crop is grown for both export and domestic markets. Moreover, it has a versatile application in health, agriculture and nutrition. It is extensively cultivated in the world, mainly to obtain dried leaves to be used as a raw material in medicine, perfumery and food industry [4]. It is reported to have a wide range of biological activities, such as anti-bacterial, fungistatic, virustatic, astringent, eupeptic and anti-hydrotic effects [5, 6, and 7].

Sage production in Kenya is limited by nitrogen and phosphorus as well as irregular rainfall. Although chemical fertilizers are available, excessive application of fertilizers results in both economic and environmental costs while rates below optimum reduces yield potential of most crops including sage. The recommended rates for sage in South Africa for the basic application range from 40 to 100 kg N; 30 to 80 kg P_2O_5 and 30 to 100 kg K_2O per hectare [8] Nitrogen (N) is the most needed essential element for plant growth and development, contributing 1-5% of the dry matter [9]. It has the largest effect on physiology of plants but it is the most limiting nutrient for all crop production [10]. Phosphorus (P) is becoming important in agricultural production because of lack of available P in the soils [11] yet it is required for the biosynthesis of primary and secondary metabolites [12]. In addition to N and P, drought stress, caused by soil and atmospheric water deficiency is one of the most significant environmental factors affecting plant growth and crop productivity in the majority of agricultural fields of the world [13]. Studies have shown that stress caused by lack of water lead to numerous morphological, physiological and biochemical plant changes [14] that may cause low crop production through decreased growth trend of roots, leaf area, photosynthesis, transpiration, plant height, dry weight as well as stomatal closure, enzymatic interruption, destruction of proteins, structural changes in synthesized proteins and amino acids and also decreased chlorophyll accumulation (14). It has been demonstrated that application of suitable fertilizers mitigates the detrimental effects of drought on biomass yield mint (*Mentha arvensis* L.) [15]. Moreover, enhancing crop water and nutrient use efficiency is essential for increasing crop productivity and sustaining the environment.

This study was informed by the fact that there is limited information on the agronomic practices and their influence on leaf productivity of sage which has a great potential as a culinary herb. The current study aimed at investigating the effects of nitrogen, phosphorus and watering regimes on the plant growth and leaf productivity of sage under Kenyan conditions.

MATERIALS AND METHODS

Site description

Sage was planted in a plastic tunnel at the Horticultural research and teaching Field of Egerton University, Njoro, in three trials between June 2011 and May 2012. The experimental site was characterized by mean temperatures of 19.0 ^{0}C, 20.1 ^{0}C and 20.7 ^{0}C for trial 1 (June 2011 – October 2011), trial 2 (October 2011 – February 2012) and trial 3 (March 2012 – May 2012), respectively. The soils at the site are ventric mollic andosols. Selected soil chemical properties at the site were as listed in table 1.

Table 1: Selected chemical properties of the experimental site soil.

Depth of collection of sample	pH	N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)
0-30 cm	6.1	1.14	3	334	655	405	0.68	25	49
0-45cm	6.1	0.77	5	362	824	432	0.66	18	49

Experimental design and crop management

The experiment was conducted in a three factor Strip Plot arrangement in a Randomised Complete Block Design (RCBD), with three replications. The factors studied were nitrogen assigned to main plots, watering regimes to strip plots, and phosphorus to sub-sub plots. Four rates of nitrogen 0 kg N/ha (N1), 40 kg N/ha (N2), 80 kg N/ha (N3) and 120 kg N/ha (N4) were applied using urea (46% N) as the source, each in two equal splits, the first one two weeks after planting and the second one four weeks later (trial 1). During the second and third trial, the first split was applied one week after the first and second cuts respectively, and the second split, six weeks after the first and second cuts respectively.

Four rates of Phosphorus 0 kg P/ha (P1), 30 kg P/ha (P2), 60 kg P/ha (P3) and 90 kg P/ha (P4) were applied at planting for the first cut and a week after the first and second cuts for the regenerated crop as Triple Superphosphate (TSP). Watering regimes were watering once every week (W1), watering once after every two weeks (W2) and watering once after every four weeks (W3).

The duration of irrigation water application was determined by using a Waterscout (Model SM 100 Sensor) connected to 2475 Plant Station (Watch Dog Model, Spectrum Technologies, Plainfirld, IL 60585, USA) based on the time taken to achieve field capacity.

The sub-sub-plots measured 2 m x 0.5 m and planting was done at a spacing of 0.5 m x 0.25 m giving a plant population of 15 plants/plot. Three inner row plants/plot were used for data collection. Plant height was measured using a ruler on the terminal/ main branch. The leaf area was determined for a randomly selected sample of one hundred leaves per plot. This involved boring discs from each of the leaves using a cork borer. Discs were counted and recorded. The area of each disc was determined using the radius of the cork borer (which was 0.6 cm). The area of each disc was 0.6 x 0.6 x 22/7=1.13 cm^2. The discs were then put in khaki bags and oven dried at 65 ^oC to a constant weight. The number of discs obtained from the sampled leaves was used to calculate the leaf area of all sampled leaves. The dried discs were then weighed and the relationship between area and dry weight of the discs was used to estimate leaf area as follows: Area of discs x leaf dry weight/ dry mass of discs. Leaf area index (LAI) was determined by the formular: LAI=Leaf Area/Land area.

Harvesting was achieved through cutting the plants at the base (15 cm above the ground) using secateurs. Leaf fresh and dry weights were determined by stripping off all the leaves and weighed to determine the leaf fresh weight. The fresh leaves were put in paper bags and placed in an oven at 65^{o}C to dry to a constant weight. They were then weighed using an electric balance and readings recorded to give the leaf dry weight.

Growth and yield data obtained were subjected to Analysis of Variance (ANOVA) using SAS statistical program (SAS Institute, 2002-2003) and treatment means separated using the Tukey's Studentized Range Test at $p \leq 0.05$.

RESULTS

Table 2. Effects of nitrogen, watering and phosphorus on sage plant height

		Trial 1				Trial 2				Trial 3			
N rate (kg N/ha)	Watering frequency	Phosphorus rate (kg P/ha)											
		0	30	60	90	0	30	60	90	0	30	60	90
0	W1	45.33**	45.00	43.67	44.67	47.33rx***	43.00wy	43.67uy	46.00ty	37.33	39.67	39.67	42.67
	W2	40.33	49.33	41.33	44.67	47.00sx	46.33ty	48.00qw	46.67ty	40.00	40.33	44.67	41.33
	W3	44.00	50.00	43.67	50.00	52.33nr	56.00kn	53.67mp	54.00mp	42.67	46.00	45.00	47.00
40	W1	48.67	49.67	46.67	45.00	58.33jm	59.33jl	58.33jm	62.67ij	46.00	48.00	40.33	47.67
	W2	48.67	49.33	47.00	46.67	44.33uy	46.33ty	45.67ty	44.33uy	39.00	42.33	39.00	37.67
	W3	50.67	49.67	49.00	48.67	45.67uy	47.67qx	48.67qu	48.33qv	43.00	41.00	41.67	43.00
80	W1	48.67	50.67	49.33	49.67	48.00qw	55.33lo	56.00kn	54.00mp	38.33	40.67	41.00	41.00
	W2	51.67	47.67	50.67	53.00	58.33jm	60.67ik	58.67jm	64.67i	44.67	46.33	45.33	49.67
	W3	41.33	41.67	36.33	41.00	42.67xy	44.00uy	41.67y	43.33vy	38.67	41.67	35.67	40.33
120	W1	43.67	41.33	39.00	41.00	48.00qw	50.67ot	47.00s-x	48.33q-v	37.67	38.00	36.00	37.67
	W2	44.00	38.33	39.67	45.33	49.67pt	52.33nr	52.00n-s	50.67o-t	36.67	36.00	38.00	38.00
	W3	41.00	38.33	41.67	41.67	52.67nq	56.00kn	57.00k-n	57.00k-n	39.67	40.00	41.67	41.33
LSD N rate		2.39*				NS				NS			
LSD Water		NS				NS				NS			
LSD Phosphorus		NS				1.212*				1.389*			
LSD N X Water		5.621*				5.347*				4.708*			
LSD N X P		3.477*				NS				NS			
LSD Water X P		NS				NS				NS			
LSD N X Water X P		NS				4.198*				NS			

* *Significantly different at $p \leq 0.05$; NS= Not significantly different at $p \leq 0.05$.; ** Values not followed by a letter are not significantly different according to the F-Test at $p \leq 0.05$; *** Values followed by the same letter within a letter series are not significantly different according to the Tukey's Studentized Range Test at $p \leq 0.05$.*

Nitrogen significantly influenced plant height only in trial 1 with the tallest plants being recorded on the plots that received 80 kg N/ha and the lowest on plants that received the highest level of N fertilization (120 kg N/ha) (Table 2). Phosphorus had significant effects on plant height, but only in trials 2 and 3. The plants were taller (51.71 cm and 41.97 cm) on plots where 60 kg P/ha was applied and shortest (49.21 cm and 40.34 cm) on those that received no P application. This gives a 2.5 cm and 1.63 cm increase in height in the respective trials as compared to no P application (Table 2).

The N X W interactions significantly affected plant height across the trials (Table 2). The tallest plants were attained on 80 kg N/ha and watering once after every two weeks for all the trials. The plants were 50.67 cm, 60.58 cm and 46.50 cm in plots receiving 80 kg N and watering once every two weeks in trials 1, 2 and 3, respectively compared to 40.67 cm, 40.92 cm and 36.58 cm on those fertilized with 120 kg N/ha and were watered once after every four weeks. The increase in height amounts to 10 cm, 19.66 cm and 9.92 cm for trials 1, 2 and 3, respectively. Nitrogen x phosphorus x watering regimes only had significant ($p \leq 0.05$) effects on plant height in trial 2 (Table 2). Watering once every two weeks increased plant height when combined with 80 kg N/ha and 60 kg P/ha to 53 cm, 64.67 cm and 49.67 cm in trials 1, 2 and 3 respectively, as compared to 36.33 cm, 41.67 cm and 35.67 cm during trials 1, 2 and 3 respectively, on plots that received no nitrogen with 120 kg P/ha and were watered once after every four weeks (Table 2). This translated to an increase in height of 16.67 cm, 23 cm and 14 cm.

Watering had significant ($p \leq 0.05$) effects on LAI and only in trial 1. Application of nitrogen and phosphorus at all watering regimes resulted in higher LAI compared to no fertilizer application. The best LAI was recorded on watering once after every two weeks across the trials 1 (5.64), 2 (4.34) and 3 (4.56) while the lowest was 3.99, 3.74 and 4.33 in trials 1, 2 and 3, respectively. The increase as quantified was 1.65, 0.6 and 0.23 for trials 1, 2 and 3. The noted interaction effects ($p \leq 0.05$) were however not significantly different across all the trials (Table 3). It is clear that the LAI was greater in trial 1 and least in trial 3. The best LAI values were reported on 80 kg N/ha combined with 60 kg P/ha and watering once after every two weeks in all the trials. The highest values were 6.90, 5.98 and 6.70 in trials 1, 2 and 3 compared to the lowest values of 2.90, 1.99 and 2.30 for the respective trials which were recorded on plots that received no nitrogen combined with 90 kg P/ha and watering once after four weeks. The increase translated into 4, 3.99 and 4.4 for trials 1, 2 and 3. The N x P x W interaction effects reported were however, not statistically different.

Table 3. Effects of nitrogen, watering and phosphorus on sage Leaf Area Index (LAI)

		Trial 1				Trial 2				Trial 3			
N rate (kg N/ha)	Watering frequency	Phosphorus rate (kg P/ha)											
		0	30	60	90	0	30	60	90	0	30	60	90
0	W1	3.85	5.70	3.87	4.87	4.87*	3.79	4.70	3.03	4.27*	3.20	2.40	2.77
	W2	6.83	6.27	5.23	4.60	3.53	4.91	4.94	4.96	4.00	2.83	3.53	3.67
	W3	3.70	3.50	3.63	2.97	3.05	3.57	3.64	1.99	4.03	4.60	4.53	2.30
40	W1	5.07	5.33	4.47	4.90	2.99	2.54	2.28	3.36	3.70	6.57	3.60	5.33
	W2	5.83	5.63	4.97	4.77	2.60	3.53	2.79	2.61	4.93	5.47	3.13	3.37
	W3	3.73	3.23	4.53	4.37	2.90	3.64	3.31	3.45	4.83	4.90	3.97	5.30
80	W1	3.53	4.52	4.34	5.33	4.09	3.18	2.46	3.65	3.20	4.03	4.23	4.13
	W2	6.43	5.63	6.90	5.43	2.20	3.87	5.98	3.08	4.33	4.80	6.70	4.47
	W3	4.90	3.40	4.13	4.57	4.57	3.74	3.35	3.59	4.63	5.37	4.67	3.90
120	W1	4.10	5.30	5.20	3.67	3.07	4.88	3.38	5.63	4.07	6.03	4.47	5.20
	W2	5.47	6.20	5.67	5.53	4.64	5.22	4.96	4.93	5.90	5.50	5.13	5.07
	W3	3.40	4.43	4.53	4.76	4.45	4.38	4.23	5.62	4.63	5.80	5.33	5.23
LSD N rate		NS				NS				NS			
LSD Water		0.913*				NS				NS			
LSD Phosphorus		NS				NS				NS			
LSD N X Water		NS				NS				NS			
LSD N X P		NS				NS				NS			
LSD Water X P		NS				NS				NS			
LSD N X Water X P		NS				NS				NS			

* *Significantly different at p ≤ 0.05; NS= Not significantly different at p ≤ 0.05.*
*** Values not followed by a letter are not significantly different according to the F-Test at p ≤ 0.05.*

Table 4. Effects of nitrogen, watering and phosphorus on sage leaf fresh weight

		Trial 1				Trial 2				Trial 3			
N rate (kg N/ha)	Watering frequency	Phosphorus rate (kg P/ha)											
		0	30	60	90	0	30	60	90	0	30	60	90
0	W1	15.20**	20.60	9.93	10.70	10.80	15.13	13.35	8.00	11.57	7.10	9.33	12.90
	W2	8.80	16.43	13.80	17.70	14.23	11.90	9.77	13.23	8.00	8.43	14.23	7.10
	W3	11.37	14.30	10.87	13.53	7.87	9.90	13.43	8.87	9.80	11.10	11.57	6.20
40	W1	13.43	19.40	14.67	10.37	10.10	7.00	10.67	10.77	12.43	12.00	14.23	11.13
	W2	16.90	20.63	23.40	15.57	8.10	9.87	9.23	7.10	8.03	8.90	11.57	9.77
	W3	16.90	19.90	12.40	28.10	10.77	12.33	12.57	10.77	10.23	8.90	10.67	8.00
80	W1	21.13	23.40	23.20	16.43	10.33	11.73	13.28	9.23	8.90	12.43	9.33	9.77
	W2	20.00	23.47	27.10	17.93	7.67	11.67	16.03	9.43	11.13	9.33	14.67	10.53
	W3	13.73	12.87	14.37	8.63	10.77	10.77	9.47	6.10	13.33	11.80	12.27	5.77
120	W1	17.23	12.97	11.90	15.60	6.90	10.43	10.37	9.80	11.90	14.20	8.90	11.53
	W2	16.33	16.27	12.70	14.93	9.90	8.23	12.10	9.87	10.93	10.23	12.43	12.87
	W3	13.67	14.60	12.43	15.80	9.43	9.90	6.33	8.10	10.93	11.57	13.53	13.30
LSD N rate		3.117*				NS				NS			
LSD Water		1.816*				NS				NS			
LSD Phosphorus		NS				NS				NS			
LSD N X Water		NS				NS				NS			
LSD N X P		NS				NS				NS			
LSD Water X P		NS				NS				NS			
LSD N X Water X P		NS				NS				NS			

**Significantly different at P ≤ 0.05.NS=Not significantly different at p ≤ 0.05.*
*** Values not followed by a letter are not significantly different according to the F-Test at p ≤ 0.05.*

The results in table 5 indicate that greater leaf dry weight 5.26 tons/ha, 5.26 tons/ha and 3.70 tons/ha was observed on 80 N/ha X 60 kg P/ha X watering once after every two weeks for trials 1, 2 and 3 respectively compared to 2.51 tons/ha on no nitrogen combined with 90 kg P/ha X watering once after every one weeks in trials 1, 1.77 tons/ha on plots that received no nitrogen combined with 90 kg P/ha X watering once after every four weeks in trial 2 and 1.50 tons/ha on no nitrogen combined with 90 kg P/ha X watering once after every one week in trial 3. The noted increase for the respective trials was 2.75 tons/ha, 3.49 tons/ha and 2.2 tons/ha (Table 5). However, these differences were not statistically different at (p≤0.05).

Table 5. Effects of nitrogen, watering and phosphorus on sage leaf dry weight

		Trial 1				Trial 2				Trial 3			
N rate (kg N/ha)	Watering frequency	Phosphorus rate (kg P/ha)											
		0	30	60	90	0	30	60	90	0	30	60	90
0	W1	3.25*	4.10	2.64	2.51	3.73	3.10	2.47	4.08	2.50	1.70	1.50	1.63
	W2	2.69	4.23	3.08	3.67	2.40	3.87	3.60	2.30	2.37	1.6	2.67	2.17
	W3	2.92	3.10	3.34	3.66	2.37	2.97	2.90	1.77	1.87	2.87	2.70	1.67
40	W1	2.89	3.69	3.86	4.07	3.80	3.48	4.20	3.82	1.93	3.40	2.03	2.27
	W2	3.84	4.26	3.83	3.14	2.33	2.80	2.97	2.30	3.10	3.00	2.93	2.30
	W3	4.21	4.37	4.37	3.56	2.93	2.43	3.27	2.23	2.97	3.00	2.47	3.17
80	W1	4.14	4.16	4.47	4.02	2.37	3.37	3.10	3.87	1.97	2.87	2.70	2.63
	W2	4.13	4.50	5.26	4.31	2.77	2.53	5.03	3.00	2.33	2.67	3.70	2.77
	W3	3.51	3.35	3.63	2.60	4.00	2.77	3.57	3.13	2.87	3.23	3.00	2.47
120	W1	3.67	3.10	3.48	3.74	2.10	3.80	3.05	3.13	2.67	3.57	2.60	3.33
	W2	3.71	3.18	3.66	4.30	3.90	2.67	3.83	2.77	3.43	2.47	3.23	3.30
	W3	3.06	4.10	3.38	3.62	3.97	4.97	4.07	2.93	2.80	3.40	2.97	3.07
LSD N rate		NS				NS				NS			
LSD Water		NS				NS				NS			
LSD Phosphorus		NS				NS				NS			
LSD N X Water		NS				NS				NS			
LSD N X P		NS				NS				NS			
LSD Water X P		NS				NS				NS			
LSD N X Water X P		NS				NS				NS			

*NS= Not significantly different at $p \leq 0.05$; *Values not followed by a letter are not significantly different according to the F-Test at $p \leq 0.05$.*

Both nitrogen and watering significantly ($P \leq 0.05$) influenced the leaf fresh weight in trial 1 and not in 2 and 3. The best N treatment for highest leaf fresh weight (18.53 tons/ha) was 80 kg/ha in trial 1 and the poorest leaf fresh weight (13.60 tons/ha) was recorded on plots that received no nitrogen. Watering regime that favoured leaf fresh weight in trial 1 was watering once after every two weeks, yielding 17.82 tons/ha in comparison to the lowest yield recorded on watering once after every four weeks 15.05 tons/ha giving an increase of 2.77 tons/ha. There were no significant effects between nitrogen, watering and phosphorus for leaf fresh weight.

DISCUSSION

The growth and development, and consequently yield of crops are highly influenced by available soil moisture as well as mineral nutrition. In the current study, 80 kg N/ha in combination with 60 kg P/ha and watering once after every two weeks resulted into the best growth and yield of sage plants with respect to plant height, LAI, fresh and dry weights. This indicates that the 80 kg of N/ha and 60 kg P/ha application was adequate enough to support leaf yield through enhanced leaf area development leading to adequate photosynthesis hence an increase in growth with respect to plant height. The above supports the current finding that the 80 kg of N/ha application was adequate enough to support leaf yield through enhance leaf area development leading to adequate photosynthesis hence an increase in growth with respect to plant height. Sifola and Barbieri and Sinclair and Rufty [16 and 17] further supports our findings by indicating that application of N increases yield through increasing photosynthesis, chlorophyll content, and Rubisco activity, biomass yield, plant growth and leaf surface area. Leaf Area Index was lowest in unfertilised plots probably due to early leaf shedding due to N deficiency which decreases plant photosynthesis potential resulting into decrease in vegetative growth under low N levels. Rajeswara Rao [18] reported that addition of 80 kg N/ha/year enhanced the total biomass yield of *Cymbopogon martinii* (Roxb.) Wats. Var Motia Burk by 57.6% relative to untreated plots. Azizi et al. [19] also reported that high nitrogen levels (1.0-1.5g N/pot) increased the dry matter herbage of oregano as compared to low N levels (0.5 g N/pot). Elsewhere, Ozguven et al.; Ram et al. and Singh and Sharma [20, 15 and 21], had similar observations for wormwood, mint and palmarosa, respectively.

In plants, phosphorus (P) is required in relatively large amounts for the biosynthesis of primary and secondary metabolites [12] since P has essential functions as a constituent of nucleic acids and phospholipids (biomembranes) and plays a key role in the energy metabolism of cells. Nell et al. [22] reported that P application (either 136 mg KH_2PO_4/L or 68 mg KH_2PO_4/L) to garden sage increases the leaf biomass, the total phenolic compounds and rosemarinic acid concentration and the rosemarinic acid yield in leaves. Similar findings were reported for *M. piperita* by Santos de Souza et al. [23] who reported that the production of biomass was not significantly influenced by phosphorus fertilization. They reported a higher main branch length with the highest level of phosphorus. They also noted that phosphorus concentrations did not influence the accumulation of dry matter, shoot and root of plants of *M. piperita* during its development.

Karamanos [8] reported that there is an impressive positive response of herbage growth to water supply. This is in agreement with the current study, because watering once after every two weeks yielded the best results for all the treatments under study while watering once after every four weeks resulted in the poorest response. Tanjia et al. [24] indicated that water stress significantly decreased plant height, leaf area index, dry matter accumulation and oil content of *Mentha arvensis*, findings which are similar to this study although in our case the differences were only significant in season 1 for plant height LAI and leaf fresh weight.

Finally, it is possible that sage plants supplied with low irrigation water, N and P rates experienced both water and nutrient deficiency stresses due to imbalance in optimum growth conditions which resulted into shorter plants, low LAI as well as leaf fresh and dry weights. Increased LAI due to the N X P X W interaction effects might have allowed plants to trap more radiant energy required for enhanced photosynthetic activity, which in turn increased the amount of photoassimilates produced and available for leaf production.

CONCLUSION

The indiscriminate use of fertilizers in intensive agriculture has increased crop performance under irrigated conditions but has also harmed the ecosystems and increased costs of production and hence reducing profitability. Integrated nutrient management approaches advocate the controlled use of nitrogen fertilizer [25]. This therefore embraces our findings that N and P application at 80 kg N/ha and 60 kg P/ha as opposed to 120 kg N/ha and 90 kg P/ha is sufficient enough to support sage growth and fresh yield (which was attained as 27.10 ton/ha, 16.03 ton/ha 14.67 ton/ha in trials 1, 2 and 3, respectively) under watering once after every two weeks regime. Lower and higher rates of N and P as well too close and far irrigation intervals resulted into reduced growth as well as leaf yields at different combinations. There is need however for economic evaluation of these practices before they can be recommended for use in Kenya.

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