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Effect of NPK Fertilization on Growth and Dry Matter Accumulation in Mangrove [*Avicennia marina* (Forssk) vierh] Grown in Western Saudi Arabia

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Abstract. Despite a growing knowledge of nutrient limitation for mangrove species and how mangroves adapt to low nutrients, there is scant information about the relative importance of NPK fertilizer application on the performance of mangroves in terrestrial environments. In this study, a 2-yesr-eight-NK- combinations (2^3) was conducted to evaluate the possible role of nutrients (NPK) on growth, dry matter accumulation, total leaf area and specific leaf area on mangrove species (*Avicennia marina*) in a barrel experiment directly irrigated from the sea. Plant height, number of leaves and number of branches significantly increased with time. The increase in plant height within a period of 21 months was 2.53 folds of values attained at the end of the first growing season. Estimates recorded for number of leaves/plant and branches/plant, within the same period, were respectively 51.5 and 48.7 folds. Application of phosphorus alone had significantly increased plant height, number of leaves and number of branches/plant, especially at later stages of plant growth. Application of K significantly increased number of branches/plant in the later stages, whereas that of N had negatively reduced plant height in the early stages of growth, but increased number of branches in the late stages of growth. Application of phosphorus alone had significantly increased culms, leaves and total dry weights/plant, whereas that of N significantly increased leaves weight.

Keywords: Avicennia marina, dry matter,fertilizer, culms.

Introduction

Mangroves are important not only in protecting the coasts from erosion by storm tides, but also in maintaining the diversity of coastal ecosystems by contributing quantities of food/nutrients and providing favorable habitats for other plants and animals (Tomlinson, 1986). Many previous studies showed that nutrient availability, especially N and P, is an important factor responsible for mangrove growth (Feller, 1995; McKee *et al*., 2002 and Lin & Sternberg, 2007). Although, N: P ratios have been widely used to determine plant nitrogen and phosphorus limitation in wetlands (Güsewell & Koerselman, 2002; and Güsewell *et al*., 2003), they have not been used as an indicator in mangrove ecosystems (Lin & Sternberg, 2007). According to Güsewell (2004), plant N: P ratio reflects the gradual and dynamic character of nutrient limitation rather than the fixed characters such as N-limited *vs.* P-limited.

In Saudi Arabia, the coastal areas of the Red Sea and the Arabian Gulf are considered to be optimum areas for supporting mangrove forests. In the Gulf coast, the mangroves grew south of Al-Gateef and Tawort, but extensive tree cutting and irregular grazing led to the destruction and removal of the dense mangrove cover that was once observed by the Roman sailors in the third century (Kogo, 1984). Similar factors or other unidentified environmental factors also led to the deterioration of the mangrove cover along the Red Sea coast, but to a lesser extent (Zahran, 1983). The prevalence of optimum temperatures and fertile soils brought into the sea coast by 'Wadis' from 'Tehama' high lands had somewhat contributed to the maintenance of the mangrove forests along the Red Sea Coast.

Ground surveys have shown that mangroves grow as scattered clusters along the sea coast, north of Jeddah. Thereafter, the belt widens in areas extending between Lat. 25° and 26°N opposite to Hanak and the small islands in its vicinity. It then extends further north up to Daba' at Lat. 28°N. South of Jeddah, the mangrove belt is more extensive, as the plant occupies larger areas, reaching its climax at Lat. 16°N in Jazan region and Farasan Islands. The shrub also grows extensively in land intrusions and areas protected from tidal waves especially in runoff areas where silt and organic matter were brought in by 'wadis' coming from the high lands (Abo Hassan & Osman, 1998).

Avicennia marina, the dominant species in the Red Sea Coast, was observed to grow up to 10 m in Jazan area; flower in March, ripen during June, July and August and seeds disappear totally in October (Mandura, 1988). In the central region of the Red Sea Coast, however, the plants were observed to flower during both fall and winter (March, October) while their seeds ripen late in the winter or early spring (Mandura, 1988).

Tropical mangrove forests have been shown to be generally highly productive and capable of sustaining high rates of litter production (Bunt *et al*., 1979; Duke, 1981 and Bunt, 1982). However, examination of litter fall data reveals that these forests, in many cases, are producing at well below the expected levels upper limit of 20 Mg ha^{-1} y^{-1} of litter were reported for a mangrove forests in Taiwan (Boto & Wellington, 1983). This was reported to be very similar to the very high litter production for rain forests in Thailand (Kira *et al*., 1967).

Recent research work conducted along the Red Sea Coast in Saudi Arabia (Mandura 1988; Khafaji *et al.,* 1988; Saifullah *et al.,* 1989; Khafaji *et al.,* 1991 and Khafaji *et al.,* 1993) indicated that litter production in A. marina was in the range of 2.16 to 3.37kg dry wt. m^{-2} d^{-1} reaching its maximum estimates in March and April when the fruits contribute the most. Flowering is usually initiated in early September and continues through April. The research workers also indicated that leaves and fruits of mangroves are rich in protein, carbohydrates and lipids and the amount of these constituents were observed to vary with plant age and season of the year.

In Saudi Arabia, research was directed towards the estimation of total litter production in mangrove stands along the southern and central Red Sea Coast (Mandura, 1988; Saifullah *et al*., 1989 and Khafaji *et al*., 1991), and the assessment of nutritive value of various parts of the mangrove plant (Khafaji *et al*., 1988 and Khafaji *et al*., 1993).

Nutrient retranslocation from senescing leaves is the process by which plants withdraw nutrients from these leaves, making them available for later investment in new structure (Millard and Neilsen, 1989 and Aerts, 1996). This increases the use of absorbed nutrients and reduces plant dependence on soil supply (Pugnaire & Chapin, 1993). The process of retranslocation is closely associated with leaf senescence and conservation of nutrients, and thus is an important mechanism enabling plants to maintain growth at nutrient-poor sites (Fife & Nambiar, 1997; Lin & Wang, 2001; Lodhiyal & Lodhiyal, 2003 and Lin & Sternberg, 2007). Nutrients may be used more efficiently at nutrient-poor sites, and this efficient nutrient use could be important to the survival of individuals under such conditions (Birk & Vitousek, 1986 and Aerts, 1995).

Escudero *et al.,* (1992) showed that leaf longevity was far more important as a nutrient conservation mechanism than high retranslocation efficiency (RE). Plants growing on infertile soils do not retranslocate a greater fraction of nutrients from senescing leaves, *i.e.* RE is independent of status of individuals (Birk & Vitousek, 1986; Walbridge, 1991; and Helmisaari, 1992). RE was, however, found to be high under higher nutrient status (Nambiar & Fife, 1987).

Despite a growing knowledge of nutrient limitation for mangrove species and how mangroves adapt to low nutrients (McKee *et al*., 2002 and Lin & Sternberg, 2007), there is scant information about the relative importance of N:P ratio in determining nutrient conservation. Mangrove forests are generally considered oligotrophic ecosystems and the species that grow are considered adapted to low-nutrient conditions (Hutchings & Saenger 1987; and Lugo, 1989).

However, the study presented here is the first controlled terrestrial experimental test of this hypothesis. This work is thought to be an essential step for establishing mangroves plantations in the desert areas under saline irrigation in the Arabian Desert in order to provide green fodder for the increasing livestock in Western Saudi Arabia.

Materials and Methods

The present work was conducted in Al-Shoieba at a distance of 120 Km south of Jeddah. In conducting this trial, 120 barrels of 44 gallons capacity each, were used. The base of each barrel (about one third) was filled with course gravel and the remaining portion, except for the top 10 cm, was filled with a mixture of clay and sand in 1:1 ratio and planted with mangroves seedlings on 20/10/1996. A drip irrigation system was installed to allow for direct irrigation with sea water. In executing the trial eight NPK fertilizer treatment combinations (2^3), *i.e.* two levels (N_0 = 0, N1= 100 kg N ha^{-1}), (P_0 = 0, P_1= 75 kg P ha^{-1}) and ((K_0 = 0, K_1= 50 kg K ha^{-1}kg P ha^{-1}) for the indicated elements were evaluated in a factorial experiment in a randomized complete block design with three replications. In conducting the trial, urea as source of N, superphosphate as source of P_2O_5 and potassium sulphate as source of K_2O were thoroughly mixed and applied in small amounts every 91 days throughout the experimental period. Irrigation water was given as need arose.

Starting on 21/3/1997, *i.e.* after 5 months from the planting and for eight consecutive seasons (*i.e.* until 21/12/1998), data was recorded from the middle three plants (none destructive sampling) for plant height, number of leaves and number of branches per plant. However, and in order to show the overall trend of plant growth with time, only data recorded on 21/ 12/1996 (the first sampling date), 21/ 12/1997 (the fifth sampling date) and on 21/ 9/1998 (the last sampling date) were presented in this manuscript. Destructive sampling was carried out on the last sampling date (21/ 9/1998) to assess total dry weight and each of its components (*i.e.* culms and leaves dry weights), as well as, total leaf area and specific leaf area.

Results and Discussion

Plant Height

Data in Table 1 indicate that application of N alone had a significant negative effect on plant height in the second sampling date. In this respect, estimates of 53.9 cm at N_0 and 50.0 cm at N_1 were recorded for the trait at the specified date. Estimates recorded under P application were 70.3 cm at P_0 and 75.1 cm at P_1, indicating a significant positive effect of P on plant height in the third sampling date. The LSD test (Table 2) revealed that the joint application of P and K (P x K) had significantly ($P \leq 0.05$) affected plant height in the second sampling date. The joint effect and its magnitude varied, however, with the levels of the fertilizer elements in the indicated combinations (Table 2). Literature indicated that nutrient enrichment resulted in significant differences in most plant growth variables measured in *Rhizophora mangle* (Feller, 1995). In this respect, P and NPK fertilizers caused similar and significant increases in plant growth, whereas N fertilizer had no effect. According to Feller (1995), an increase of 60 and 70%, in a period of two years, in tree height was attained in P and NPK fertilized trees, respectively, but it did not change significantly for the N-fertilized and control trees. In this study, the percentage increase in plant height recorded at the end of the two years period was highest (208%) at N_0 P_0 K_0 level and lowest (133%) at the N_1 P_0 K_0 level, confirming the negative effect of N application on plant height.

Table 1. Main effects of NPK treatments on plant height, number of leaves and on number of branches of mangroves at three sampling dates.

	Sampling date								
source of variation	21/12/96	21/12/97	21/9/98	21/12/96	21/12/97	21/9/98	21/12/96	21/12/97	21/9/98
	Plant height (cm)			Number of leaves			Number of Branches		
N0	27.6	53.9*	72.3	9.3	56.1	337	0.51	5.7	26.2
N1	29.8	50.0	73.2	8.5	58.8	408**	0.58	5.7	30.4**
P0	27.6	52.2	70.3	8.9	56.6	294	0.50	5.5	24.3
P1	29.8	51.6	75.1*	8.9	58.4	451**	0.60	5.9	32.3**
K0	28.9	52.0	73.0	8.5	55.2	363	0.42	5.2	26.3
K1	28.5	52.0	72.5	9.3	59.7	382	0.68	6.2	30.3**
Mean	28.7	51.9	72.7	8.9	57.5	373	0.55	5.7	28.3
LSD(5%)	2.61	3.25	4.22	1.21	6.43	33.07	0.30	1.03	2.73

*and ** indicate significance at 5 and 1% levels, respectively

Number of Leaves per Plant

Data in Table 1 reveal that application of P alone (second sampling date), as well as, of each N and P alone (third sampling date) had significant positive effects on number of leaves per plant. In this respect, estimates of 337 leaves at N_0 and 408 leaves at N_1 and of 294 and 451 leaves at P_0 and P_1 , respectively, were recorded at the third sampling date (Table 1). The LSD test (Table 2) revealed that the joint application of P and K (P x K), in the second sampling date, as well as, of N with P (N x P), in the third sampling date, had significantly affected the number of leaves attained. The magnitude of this effect varied, however, with the levels of the fertilizer elements in the indicated combinations.

Previous studies revealed that as for plant height and number of leaves per shoot increased dramatically for trees fertilized with P and NPK, but showed no change for N-fertilized and control trees (Feller, 1995).

Number of Branches per Plant

Data in Table 1 reveal that application of each of N, P and K alone had significantly affected number of branches per plant. In this respect, estimates of 26.4 branches at N_0 and 30.4 branches at N_1 and 24.3 and 32.3 branches at P_0 and P_1, respectively, and 28.3(K_0) and 32.3 branches (K_1) were recorded at the third sampling date, indicating a significant positive effect of each of N and P and K alone in number of branches per plant (Table 1). Data in Table 2 reveal that the joint application of P with K (P x K) and of N with P (N x P), in the first sampling date, had significantly ($P \leq 0.05$) affected number of branches plant (Table 2).The direction of this effect and its magnitude, however, varied with the levels of the fertilizer elements in the indicated combinations.

Table 2. Significant (first order) interactions of NPK elements on plant height, number of leaves and on number of branches of mangroves at three sampling dates.

	Plant height (cm)		Number of branches				Number of leaves								
source of variation	21/12/97		21/9/98		21/9/98		21/12/98		21/12/98		MEAN P		21/12/97		MEAN K
	K_0	K_1	K_0	K_1	N_0	N_1	N_0	N_1	K_0	K_1			N_0	N_1	
LSD(5%)a	3.70		3.85		3.85		4.67		4.67				9.10		
P_0	26.0	29.2	20.7	27.9	20.3	28.3	238	349	267	321	132.74	K_0	49.7	60.8	55.3
P_1	31.8	27.8	31.8	32.8	32.1	32.5	436	466	460	442	199.28	K_1	62.5	56.9	59.7
LSD(5%)b	2.61		2.73		2.73		33.07		33.07				6.37		
Mean	28.9	28.5	26.3	30.3	26.2	30.4	143.2	160.1	363	381			80.7	91.4	

A &b: refer to LSD estimates for the interactions and main effects, respectively.

Previous studies (Feller, 1995) revealed, as for plant height and number of leaves per shoot, branching, measured as the number of sub shoots per shoot, also increased significantly on trees fertilized with P and NPK, but few if any sub shoots were produced on N-fertilized and control trees.

Culm Dry Weight

Application of P alone had a significant positive effect ($P \leq 0.01$) in culms dry weight (Table 3). In this respect, estimates of 52.9 g at P_0 and of 75.2g at P_1 were recorded for the trait at the last sampling date (Table 3).

Leaves Dry Weight

Data in Table 3 reveal that application of each of P and N alone had a significant effect ($P \leq 0.01$) in total dry weight of leaves. In this respect, estimates of 60.80 (N_0), 72.7 g (N_1) and 52.5g at P_0 and 830.3g at P_1 were recorded for total leaves dry weight at the last sampling date (Table 3).

In a previous study, Laclau *et al*. (2008) observed that the peak of leaf production in *Eucalyptus* plantations occurred in the second year after planting (about 800 g m^{-2} $year^{-1}$) and was not significantly modified ($P \leq 0.05$) by N and K fertilizations. In contrast, K addition significantly increased the maximum leaf standing biomass from 292 to 528 g m^{-2}, mainly as a consequence of the increase in leaf lifespan.

Table 3. Main effects of NPK treatments on total, culms and leaves dry weights and on total leaf area and specific leaf area of mangroves at the last sampling date (21/12/98).

source of variation	Culm dry weight(g)	Leaf dry weight(g)	Total dry weight(g)	Total leaf area (cm^2)	SLA (cm^2/g)
N_0	60.8	60.1	120.9	2985	46.9
N_1	67.3	72.7*	140.0	3059	42.0
P_0	52.9	52.5	105.3	2192	41.0
P_1	75.2**	80.3**	155.5**	3853**	47.9
K_0	62.7	67.4	130.1	2972	44.1
K_1	65.4	65.3	130.7	3072	44.8
Mean	64.0	66.9	130.4	3023	44.4
LSD(5%)	13.35	10.31	22.45	745.63	7.89

*and ** indicate significance at 5 and 1% levels ,respectively
a and b:refer to LSD estimates for the interactions and main effects respectively.

Total Dry Weight

Application of P alone had significantly (P≤0.01) affected total dry weight in the last sampling date (Table 3). In this respect, estimates of 105.3g at P_0 and 155.5g at P_1 were recorded for the trait at the specified date (Table 3). Litter production, in the range of 2.16 to 3.37 dry wt. m^{-2}.day^{-1}, reaching its maximal estimates in March and April, when the fruits contribute the most, was recorded in Saudi Arabia (Mandura, 1988). Reports in literature (Laclau *et al.,* 2008) indicated that the effects of N fertilization on tree growth only occurred in the first 24 months after planting, whereas in case of K fertilization, increased the above-ground net primary production from 4478 to 8737 g m^{-2} over the first 36 months after planting.

Total Leaf Area

Data in Table 3 indicate that application of P alone had a significant effect (P≤0.01) in Total Leaf Area (TLA). In this respect, estimates of 3853 cm^2/plant (P_1) and 2192 cm^2/plant (P_0) were attained for the trait in last sampling date (Table 3). The LSD test (Table 4) revealed that joint application of N and P (N x P) had significantly affected the TLA attained at last sampling date.

Estimates for total leaf area per plant recorded at the last sampling date were 1609, 4361, 2775 and 3344 cm^2/plant at N_0P_0, N_0P_1, N_0P_1 and

N_1P_1 respectively (Table 4). Similarly, (Feller, 1995) indicated the leaf area (cm^2) per shoot and LA1 were significantly higher for trees fertilized with P and NPK, but showed no change for N-fertilized and control trees. Laclau *et al*. (2008) indicated that potassium fertilization increased the stand biomass in *Eucalyptus* mainly through the enhancement in Leaf Area Index (LAI) since growth efficiency (defined as the ratio between woody biomass production and LAI) was not significantly modified.

Specific Leaf Area

Main effects of N, P and K on specific leaf area (Table 3), unlike their interactions, had no significant effects. Application of N and P, as well as, that of N with both P and K had a significant effect ($P \leq 0.05$) in SLA (Table 4). In this respect, estimates of SLA were 39.2, 54.6, 242.8 and 41.2 cm^2/g for the combinations N_0P_0, N_0P1, N_0P_1 and N_1P_1, respectively, at the specified sampling date (Table 4). Meziane and Shipley (2001) assessed the direct and indirect relationships between specific leaf area, leaf nitrogen and nutrient supply in 22 herbaceous species. Their tested model indicated that specific leaf area is the forcing variable that directly affects both leaf nitrogen levels and net photosynthetic rates. Leaf nitrogen then directly affects net photosynthetic rates.

Table 4. Significant (first order) interactions of NPK treatments total leaf area, specific leaf area of mangroves at the last sampling date (21/12/98).

	Total leaf area (cm^2)			SLA (cm^2/g)		
source of variation	**P_0**	**P_1**	**Mean**	**P_0**	**P_1**	**Mean**
LSD(5%)**a**	1054.44			11.22		
N_0	1609	4361	2985	39.2	54.6	46.9
N_1	2775	3344	3059.5	42.8	41.2	42.0
LSD(5%)b	745.63			7.89		
Mean	2192	3853		41.0	47.9	

A and b:refer to LSD estimates for the interactions and main effects, respectively.

Further examination of the data on dry matter and its components indicated that application of P and N had positive effects on number of leaves and number of branches. These differences were, however, highly manifested in the older plants (last sampling date), indicating that adequate amounts of N and P to sustain the life of plant in the early stages of growth are available in the mangrove soil. Application of P, unlike that of N, resulted in significant increases in total leaf and culm dry weights and TLA, indicating that P, and not N, may be limiting dry matter accumulation in older (large) plants. Application of K to induce more branching appeared to be important at the late stages of plant growth. Reports in literature (Feller, 1995) indicated that P and fertilizers significantly increased leaf number, leaf area, branching and shoot length over 2-year period. N-fertilized trees grew very slowly and their responses were not different from control trees over the 2-year period. Such findings indicated, as in the present study, that phosphorus availability is a major factor limiting red mangrove growth in intertidal areas. Studies conducted in the dwarf red mangrove (*R. mangle*) indicated that, phosphorus rather than nitrogen, was the important macro-nutrient limiting leaf area, root and leaf biomass development. Under P enrichment in the field, seedling stem elongation rates increased from 0.03 mm. d^{-1} to 0.20 mm. d^{-1} and leaf area increased from 25 cm^2. d^{-1} to 75 cm^2 d^{-1}, relative to unfertilized controls. Similarly, nitrogen (N) has been indicated as a major factor limiting the growth of halophytes (mangroves) in intertidal areas (Stewart *et al*., 1979). Higher productivity of various kinds of halophytes seems to be induced by an additional supply of N (Tyler, 1967). Evidence suggests that mangrove forests are generally nutrient limited with N (Onuf *et al*., 1977; Boto & Wellington, 1983; and Boto & Wellington, 1984). Positive growth responses to added N were found in mangrove *Avicennia marina* (Boto *et al*., 1985 and Naidoo, 1987). N was also considered a limiting factor for microbial activity in the mangrove swamp of the Indus Delta (Kristensen *et al*., 1992).

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أثر التسميد بعناصر النيتروجين، والفسفور، والبوتاسيوم على نمو وتجميع المادة الجافة بالشورى [*Avicennia marina* (Forssk) vierh] بالمنطقة الغربية بالمملكة العربية السعودية

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المستخلص. بالرغم من تنامي المعلومات عـن محدودية أثـر العناصر الغذائية على نمو الشورى، وعن كيفيـة تأقلمهـا لتلـك المحدودية، فمازالت المعلومات المتوفرة عن الأهمية النسبية لأثـر التسميد بالعناصر الكبرى على سلوك المنجروف محدودة. وعليـه استهدف البحث الحالي دراسة سلوك الشورى (*Avicennia marina*) تحت ثمانية معاملات سمادية بالعناصـر الكبـرى(النيتـروجين، والفسفور، والبوتاسيوم)، ولمدة عـامين درس خلالهـا دور تلـك العناصر فى تجميع وتجزئة المـادة الجافـة، والمـساحة الكليـة للأوراق، ومحتوى الأوراق والسوق من بعض العناصـر. نفـذت التجربة فى براميل(سعة ٤٤ جالون) ورويت مباشرة من البحـر. أظهرت النتائج ازدياد طول النبات، وعدد الأوراق، وعدد الأفـرع إحصائيًا مع الوقت ووصل إلـى ٢,٥٣، و٥١,٥ ، و٤٨,٧ ضـعفًا خلال ٢١ شهرًا مما كان عليه عند الموسم الأول للصفات المـشار إليها على التوالي. أدت إضافة الفسفور منفردًا إلى زيـادة طـول النبات، وعدد الأوراق، وعدد الأفرع، خاصة فى الأطوار المتأخرة

للنمو. كذلك أدت إضافة البوتاسيوم، خاصة فى الأطوار المتأخرة، إلى زيادة عدد الأفرع. بينما أثّرت إضافة النتروجين، فى الأطوار المبكرة، سلبًا على طول النبات، وأثرت إيجابا على عدد الأفرع فى الأطوار متأخرة النمو. كذلك أدت إضافة الفسفور منفردًا إلى زيادة الوزن الجاف للسوق، والأوراق، والوزن الكلي الجاف للنبات. بينما أدت إضافة الأزوت إلى زيادة وزن الأوراق.

الكلمات الدالة: الشورى، المادة الجافة، السماد، السوق.