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Effect of NPK fertilizers on seedling growth of mangrove species

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ABSTRACT

An experiment was conducted to assess the effect of nitrogen, phosphorus and potassium (NPK) fertilizers on seedling growth and survival of Heritiera fomes (sundri), Xylocarpus mekongensis (passur), Excoecaria agallocha (gewa), Ceriops decandra (goran) and Avicennia officinalis (baen) mangrove species of Bangladesh for nine months. Seedlings were raised in the nursery using plastic pots. NPK fertilizers with three treatments (control, 4 gm and 8 gm doses) were used two times when seedlings age was 3 and 6 months. The result showed that seedlings height growth of Excoecaria agallocha was enhanced significantly with the application of NPK fertilizers but it was shown negatively significant effect on height growth of Xylocarpus mekongensis after second time fertilizer application. Moreover, NPK application enhanced mortality of Avicennia officinalis and Ceriops decandra seedlings in both times of fertilizer application. But no effect of NPK fertilizers on seedlings growth and survival of Heritiera fomes were observed.

***Key words**: NPK, Mangrove, Excoecaria agallocha, Xylocarpus mekongensis and Fertilizer effect*

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I. Introduction

Mangrove forests are distributed in the inter-tidal region between the sea and the land in the tropical and sub-tropical regions of the world (Alongi 2009). The largest single tract natural mangrove forest in the world- the Sundarbans is situated at the south-western part of Bangladesh. The recorded total area of this single tract mangrove forest is about 6017 km^2 determined from SPOT satellite data (IRMP 2010). The floristic composition of this forest is rich compared to many other mangroves of the world. Saiful et al. (2016) found a total of 183 plant species under the 135 genera and 59 families in the Sundarbans. Mangrove forests are among of the most productive and biologically important ecosystems of the world because they provide important and unique ecosystem goods and services to human society and coastal and marine systems (Giri et al. 2010). The mangroves play an important role in the national economy of Bangladesh. Timber, fuel wood, thatching materials, house post and other non-timber produces are harvested from this mangrove forest. Mangroves are important not only in protecting the coast from erosion by storm tides and cyclones but also in maintaining the diversity of coastal ecosystems by

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contributing quantities and providing favorable habitats for other plants and animals (Tomlinson 1986).

The coastline of Bangladesh is 710 kilometers long extending along the Bay of Bengal comprises numerous off-shore islands. It lies between latitude 21^0 to 23^0 N and longitude 89^0 to 93^0 E. Erosion and sedimentation is the common characteristics of the coastal environment. Afforestation with mangrove species was initiated in 1966 along the coastal belt with the primary objective to protect lives and properties of coastal communities from cyclone and tidal surges (Das and Siddiqi, 1985). In the beginning, almost all the commercially important mangrove species were tried but mostly failed due to lack of knowledge on appropriate nursery and plantation techniques. Among the planted species, only *Sonneratia apetala* (keora) is the most successful species in all along the coastal belt and *Avicennia officinalis* (baen) is the successful only in the eastern coastal belt (Siddiqi and Khan, 2004). Some trial plantations with other mangrove species such as *E. agallocha* (gewa), *H. fomes* (sundri), *Xylocarpus mekongensis* (passur), *Aegiceras corniculatum* (khalshi) and *Phoenix paludosa* (hantal) were found suitable inside *S. apetala* forest as under planting (Islam et al. 2013).

Over the last two decades, mangrove forest plantation areas have been increased in Bangladesh (Hasan 2013). Plantations are increasing day by day to cover the barren/vacant forest lands and newly accreted lands. A total of 16% of plantation forests have in Bangladesh (Altrell et al. 2007). In such plantations, fertilization is commonly practiced as a silvicultural tool. Fertilizer enhances the growth of plants. Tree yield can be increased even more by planting on soils with a better texture, breeding or genetic improvement programs and intensive silvicultural treatments such as fertilization and irrigation. It is now well established that the application of commercial fertilizers accelerate the seedlings growth of many tree species (Walker et al. 1993 and Sanginanga et al. 1989). Phosphorus is perhaps the most common limiting nutrient in many tropical areas where it plays as essential role in plant nutrition and energy transparence (Ackerson 1985). The phosphorus availability is a major factor limiting red mangrove growth in intertidal areas (Hussein and AboHasasan, 2010).

NPK fertilizers are three components of fertilizers providing nitrogen, phosphorus and potassium. Nitrogen functions on leaf growth, phosphorus on development of roots, flowers, seeds fruits and potassium on strong stem growth, movement of water in plants, promotion of flowering and fruiting. Although N:P ratios have been widely used to determine plant nitrogen and phosphorus limitation in wetlands (Güseweel and Koerselman, 2002; Güsewell et al. 2003). Effects of NPK and other fertilizers and manures in the agricultural farming has been studied by several authors (Sultana et al. 2019; Sultana et al. 2015; Siddique 2015). Likewise, Boto and Wellington (1983) reported that significant growth response following ammonium fertilization of a mangrove forest in northern Australia and phosphorus limitation among other factors may be a major control on mangrove growth. Fertilization has not been practiced in Bangladesh mangrove forestry service. Many studies throughout the world have demonstrated that fertilization of young trees increase the growth performance. Many previous studies showed that nutrient availability; especially N (Nitrogen) and P (Phosperous) are important factor responsible for mangrove growth (Feller 1995; Mckee et al. 2002; Lin and Stemberg, 2007). The healthy seedlings are essential for raising a successful plantation in the stressed condition. Fertilization of newly planted trees before full canopy closure can be particularly significant in increasing future tree yields. Tropical mangrove forests have been shown highly productive (Bunt 1982). But the growth and yield of planted mangrove species in Bangladesh are lower as compared to other south Asian countries (Hawlader 1999). Therefore, the present study was undertaken to understand the growth characteristics and effect of fertilization on survival and growth performance of some mangrove species at earlier stage.

II. Materials and Methods

Five commercially important mangrove species such as *H. fomes* (sundri), *X. mekongensis* (passur), *E. agallocha* (gewa), *Ceriops decandra* (goran) and *A. officinalis* (baen) were chosen for this study due to their multipurpose values.

***Heritiera fomes* (sundri)**
It has limited distribution and is restricted to the mangroves of Myanmar, Bangladesh and Indian Sundarbans (Kostermans 1959). It is common in less and moderately saline zones of the Sundarbans. It is a small to moderate size evergreen tree with buttressed stem and pneumatophores. It is generally 15-20m tall in the north-eastern part and reducing 5-10m in the south-eastern part of the Sundarbans. Wood is used for bridge and house construction, boat building, electric poles, paneling and furniture.

***Xylocarpus mekongensis* (passur)**
Occurs in Asia, Oceania and East Africa. In Bangladesh it is found in the northern part of the Sundarbans. It is moderate size tree attaining height of about 15 m. It is a highly valuable timber species. Wood is used as posts, poles, beams and for making musical instruments and high grade furniture.

***Excoecaria agallocha* (gewa)**
This species occurs in Asia and Oceania. In Bangladesh, the species is found in the Sundarbans and in the coastal plantations. It is a small to medium size evergreen tree. The tree is normally 10 m in height but occasionally grows up to 15 m in the north-eastern part of the Sundarbans. Wood is used for making papers, packing boxes, matches and fuel wood.

***Ceriops decandra* (goran)**
It is found in Asia and the Pacific. It is the dominant species in the strongly saline zone of the Sundarbans. It is a large shrub to small evergreen tree attaining about 4-15 m in height. Wood is used as fuel wood with high calorific value. It is also used as house posts and fencing materials.

***Avicennia officinalis* (baen)**
The species is found in Asia and the Pacific. In Bangladesh, it is found in the Sundarbans and in the coastal plantations. It is a big tree, attaining heights of 10-15m. Wood of this species is used for construction, rough walling of houses, furniture accessories, rice pounders and tool handles. Logs and branches are used as fuel wood and as anchors.

A nursery trial was conducted in 2012 at the Plantation Trial Unit Division of Bangladesh Forest Research Institute, Barishal to observe the effect of different dosages of NPK fertilizers (nitrogene as a urea, phosohate as a tripple super phosphate and potassium as potash) on growth performance of seedlings of these five mangrove species. The seedlings were raised in plastic containers of size 22.86 cm in length and 12.42 cm in diameter having 8 numbers of pores on sides and bottom. The pots were filled with powdered loamy soil and decomposed cowdung mixture at a ratio of 5:1. Seeds/ propagules of these species were collected from the Rangabali island of Patuakhali district in early June to mid-August. Twenty pots were used for each replication for each species with three treatments. So, totals of 180 pots (20 x 3 replication x 3 treatments) for each species were used and thus a total of (180 x 5 species) 900 pots for raising seedlings for 5 mangrove species. Seeds/ propagules were sown in the pot to ensure raising of one seedling in each pot. NPK Fertilizers namely Urea, TSP and MP were used at a ratio of 1:2:1. Three treatments were control (no fertilizer), 4 gm and 8 gm mixed NPK fertilizers. NPK fertilizers were applied first time when seedlings were 3 months old and it was applied second time when seedlings were 6 months old. Nursery beds were maintained by regular watering, weeding etc. Data on seedlings survival and height growth were recorded two times when seedlings age was 6 and 9 months respectively. Data were computed and analyzed using MINITAB statistical package developed at the Pennsylvania State University, USA during 1972.

III. Results and Discussion

Plant height

The result showed that after first application of NPK on the seedlings of five mangrove species had a significant effect only on *E. agallocha*. After 3 months of first application of fertilizer the height of *E. agallocha* was 25.18 cm, 30.05 cm and 31.06 cm for control, 4 gm and 8 gm treatments respectively. No significant differences were found on seedlings height growth of other four species such as *H. fomes, X. mekongensis, C. decandra and A. officinalis*. The height of *H. fomes* was 32.21 cm, 31.83 cm and 29.42 cm for control, 4 gm and 8 gm treatments respectively. The height of another important species *X.*

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mekongensis was found 56.67 cm, 56.20 cm and 56.37 cm for control, 4 gm and 8 gm respectively (Table 01).

After second application of NPK fertilizers, the height growth showed significantly negative effect on *X. mekongensis*. The heights were 99.30 cm, 83.63 cm and 81.34 cm for control, 4 gm and 8 gm treatments of NPK fertilizers respectively. But, no significant difference was found between 4 gm and 8 gm NPK treatments. The *E. agallocha* species had shown significant effect on plant height after second application of fertilizer like first application. The height of *E. agallocha* was 115.92 cm, 141.48 cm and 150.10 cm for control, 4 gm and 8 gm respectively in second time application and the result showed significant difference between control and NPK treatments. But no difference was found between 4 gm and 8 gm treatments of NPK fertilizers. The height data showed insignificant in both control and NPK treatments for *H. fomes, C. decandra and A. officinalis* (Table 02).

Table 01. Effect of NPK fertilizers on survival and height growth of five mangrove species after first application

Treatment	Name of Species									
	A. .officinalis		*X. mekongensis*		*E. agallocha*		*H. fomes*		*C. decandra*	
	Height (cm)	Survival %	Height (cm)	Survival %	Height (cm)	Survival %	Height (cm)	Survival %	Height (cm)	Survival %
Control	36.39a	72c	56.67a	100a	25.18b	98a	32.21a	100a	12.85a	80c
4 gm	36.44a	65b	56.20a	100a	30.05a	100a	31.83a	100a	12.86a	72b
8 gm	31.17a	50a	56.37a	100a	31.06a	100a	29.42a	100a	13.28a	32a

Figures followed by different letters like a, b and c differ significantly at 5% level.

Plant survival

The result showed that application of NPK fertilizers had negative significant effect on seedlings survival of *C. decandra and A. officinalis* after first application. The survival of *C. decandra* was 80%, 72%, 32% and for *A. officinalis* was 72%, 65%, 50% for control, 4 gm and 8 gm treatments respectively. When the uses of NPK fertilizers were increased then survival was decreased for these two species. The highest survival (100%) was recorded for *E. agallocha, X. mekongensis and H. fomes* in all treatments (Table 01). This means no significant effect of NPK on seedlings survival was found for these three species.

Table 02. Effect of NPK fertilizers on survival and height growth of five mangrove species after second application

Treatment	Name of Species									
	A. .officinalis		*X. mekongensis*		*E. agallocha*		*H. fomes*		*C. decandra*	
	Height (cm)	Survival %	Height (cm)	Survival %	Height (cm)	Survival %	Height (cm)	Survival %	Height (cm)	Survival %
Control	42.73a	64b	99.30b	100a	115.92b	98a	52.87a	88a	16.83a	72c
4 gram	40.83a	16a	83.63a	100a	141.48a	100a	51.63a	87a	15.94a	57b
8 gram	34.00a	15a	81.34a	100a	150.10a	100a	46.98a	87a	17.44a	17a

Figures followed by different letters like a, b and c differ significantly at 5% level.

Similarly, application of NPK had a significant negative effect after second application of fertilizer on survival of *A. officinalis and C. decandra* plants. The lowest survival was only 16% and 15% for 4 gm and 8 gm treatments on *A. officinalis* and 57% and 17% for 4 gm and 8 gm treatments on *C. decandra*

respectively (Table 02). However, no significant effect was found on seedlings survival of *H. fomes, X. mekongensis and E. agallocha*.

It was observed that only height of *E. agallocha* was significantly increased after applying NPK fertilizers in both two treatments but no difference between 4 gm and 8 gm treatments were observed. Significantly negative performance on height growth of *X. mekongensis* was observed after second time fertilizer application. Hussain and Abohossan (2010) reported that application of N fertilizer had a significant negative effect on plant height of *Avicennia marina*. Positive growth response for applying N fertilizer was found in *Avicennia marina* (Boto et al. 1985 and Naidoo 1987). Strewart et al. (1979) stated that nitrogen (N) had been indicated as a major factor limiting the growth of halophytes (Mangrove) in inter-tidal areas. The present study showed that survival of *C. decandra and A. officinalis* were decreased in both applications. So this result indicated mortality of this two species was increased for applying NPK fertilizers. Catherine et al. (2009) found that fertilization with nitrogen (N) enhanced mangrove mortality in many sites of Australia.

IV. Conclusion

The significant height growth response was found for *Excoecaria agallocha* seedlings and negative response for *Xylocarpus mekongensis* seedlings at nursery stage. The present study recommended that *Excoecaria agallocha* considered to 4 gm NPK fertilizer application at nursery stage. The NPK fertilizers enhance mortality of *Avicennia officinalis* and *Ceriops decandra*. Further intensive research on the effect of N, P and K fertilizers separately and NPK mixture in newly established mangrove plantations should be carried out.

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V. References

[1]. Ackerson, R. C. (1985). Osmoregulation in cotton in response to water stress. III. Effects of phosphorous fertility. Plant Physiology, 77, 309–312. https://doi.org/10.1104/pp.77.2.309

[2]. Alongi, D. M. (2009). Introduction of in the energetic of mangrove forests. Springer Science and Business Media BV, New York.

[3]. Altrell, D., Saket, M., Lyckeback, L., Piazza, M., Ahmad, I. U., Banil, H., Hossain, M. M. A. and Chowdhury, R. M. (2007). National forest and tree resources assessment 2005-2007.

[4]. Bangladesh Forest Department, Ministry of Environment and Forest; Bangladesh Space Research and Remote Sensing Organization, Ministry of Defence, Food and Agriculture Organization of the United Nations. p. 192.

[5]. Boto, K. G. and Wellington, J. T. (1983). Phosphorus and nitrogen nutritional status of a northern Australian mangrove forest, Mar. Ecol. Prog. Ser. 11. 63-69. https://doi.org/10.3354/meps011063

[6]. Boto, K. G., Saffigna, P. and Clough, B. (1985) Role of nitrate in nitrogen nutrition of the mangrove Avicennia marina. Mar. Ecol. Prog. Ser. 21, 259-265. https://doi.org/10.3354/meps021259

[7]. Bunt, J. S. (1982). Studies of mangrove litterfall in tropical Australia. In: Clough, B. F. (ed) Structure, Function, Nutritional Status of Mangrove Forest and Management of Mangrove Ecosystem in Australia, A.N.U. Press, Canberra, pp. 239-257.

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[8]. Catherine, E. L., Marilyn, C. B., Katherine, C. M. and Ilka, C. F. (2009). Nutrients enrichment increases mortality of mangroves, PLoS ONE 4 (5):e5600. https://doi.org/10.1371/journal.pone.0005600

[9]. Das, S. and Siddiqi, N. A. (1985). The mangroves and mangrove forests of Bangladesh. Bulletin No. 2, Mangrove Silviculture Division, Bangladesh Forest Research Institute, Chittagong, Bangladesh. p. 142.

[10]. Feller, I. C. (1995). Effects of nutrient enrichment on growth and herbivory of dwarf red mangrove (*Rhizophora mangle*), Ecol. Monogr. 65, 477-505. https://doi.org/10.2307/2963499

[11]. Giri, C., Ochieng,L., Tieszen, L. L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N. (2010). Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography, (Global Ecol.Biogeogr.).

[12]. Güsewell, S. and Koerselman, W. (2002). Variation in nitrogen and phosphorus concentrations of wetland plants, Perspect. Ecol. Evol. Syst. 5, 37-61. https://doi.org/10.1078/1433-8319-0000022

[13]. Güsewell, S., Koerselman, W. and Verhoeven, J. T. A. (2003). Biomass N: P ratios as indicators of nutrient limitation for plant populations in wetland. Ecol. Appl. 13, 372-384. https://doi.org/10.1890/1051-0761(2003)013[0372:BNRAIO]2.0.CO;2

[14]. Hasan, D. Z. (2013). Plants in mangroves and coastal afforestation in Bangladesh. Dewan House, Ukilpara, Naogaon-6500, Bangladesh. p.164.

[15]. Hawlader, N. I. (1999). Forest resources management project. Mid-Term Review, Ministry of Environment and Forest, Dhaka. p. 103.

[16]. Hussein E. O. and AboHassan, A. A. (2010). Effect of NPK fertilization on growth and dry matter accumulation in mangrove [*Avicennia marina* (Forssk) vierh] crown in Western Saudi Arabia. JKAU: Met. Env. and Arid Land Agric. Sci. 21 (2), pp. 57-70.

[17]. IRMP. (2010). Integrated resources management plans for the Sundarbans (2010-2020); Forest Department, Ministry of Environment and Forests: Dhaka, Bangladesh, Volume I, pp. 1–281.

[18]. Islam, S. A., Miah, M. A. Q., Habib, M. A., Moula, M. G. and Rasul, M. G. (2013). Growth performance of under planted mangrove species in *Sonneretia apetala* (Keora) plantations along the western coastal belt of Bangladesh. Bangladesh Journal of Forest Sciences, 32(2):26-35.

[19]. Kostermans, A. J. G. J. (1959). A monograph of the genus Heritiera, Aiton (Steren1.) Reinwardtia, 4(4), 465-583.

[20]. Lin, Y. M. and Sternberg, L. S. L. (2007). Nitrogen and phosphorus dynamics and nutrient resorption of Rhizophora mangle leaves in south Florida, U.S.A. Bull. Mar. Sci., 80, 159-169.

[21]. Mckee, K. L., Feller, I. C. Popp, M. and Wanek, W. (2002). Mangrove isotopic (15N and 13C) fraction across a nitrogen vs phosphorus limitation gradient. Ecology, 83, 1065-1075.

[22]. Naidoo, G. (1987). Effect of salinity and nitrogen on growth and water relations in the mangrove, *Avicennia marina* (Forsk.) Vierh, New Phytol. 107, 317-325. https://doi.org/10.1111/j.1469-8137.1987.tb00183.x

[23]. Sultana, B., Mian, M., Jahiruddin, M., Rahman, M. M., Alam Siddique, M. N. E. and Sultana, J. (2019). Amendment of Acidic Soil with Lime and Manure for Enhancing Fertility, Nutrient Uptake and Yield of Wheat-Mungbean-Monsoon Rice in the Old Himalayan Piedmont Plain. Asian Journal of Soil Science and Plant Nutrition, 4(2), 1-26. https://doi.org/10.9734/ajsspn/2019/v4i230043

[24]. Sultana, J., Siddique, M. N. A. and Abdullah, M. R. (2015). Fertilizer recommendation for agriculture: practice, practicalities and adaptation in Bangladesh and Netherlands. International Journal of Business, Management and Social Research, 1(1), 21-40. https://doi.org/10.18801/ijbmsr.010115.03

[25]. Siddique, M. N. A. (2015). Determination of N mineralization, total N and cation exchange capacity of soil through NIR spectroscopy for decision support in rice farming. International Journal of Business, Management and Social Research, 01(01), 47-50. https://doi.org/10.18801/ijbmsr.010115.05

[26]. Saiful, I., Feroz, S. M., Zahir, A. U., Chowdhary A. H., Khan, I. R. and Mamun. A. A. (2016). Species richness and diversity of the floristic composition of the Sundarbans mangrove reserve forest, Bangladesh in relation to spatial habitats and salinity. The Malaysian Forester, 79(1 and 2), 7-38.

[27]. Sanginga, N., Danso, S. K. A. and Bowen, G. D. (1989). Nodulation and growth response of Allocasuarina and Casuarina species to P fertilization. Plant and Soil, 119, 125–132.
[28]. Siddiqi, N. A. and Khan, M. A. S. (2004). Human-induced succession of vegetation on new accretions in the coastal areas of Bangladesh. Journal of Tropical Forest Science, 16(2), 187-198. https://doi.org/10.1007/BF02232797
[29]. Stewart, G. R., Larher, F., Ahmad, I. and Lee, J. A., (1979). Nitrogen metabolism and salt tolerance in higher plant halophytes. In R.L., Jefferies and A.J. Davey (Eds.). Ecological Process in Coastal Environments. Blackwell Scientific. pp. 33-37.
[30]. Tomlinson, P. B. (1986). The botany of mangroves, Cambridge University Press, Cambridge.
[31]. Walker, R. B., Chowdappa, P. and Gessel, S. P. (1993). Major element deficiencies in Casuarina equisetifolia. Fertilizer Research, 34, 127–133. https://doi.org/10.1007/BF00750107

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