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GROWTH AND HISTO-CHEMICAL RESPONSE OF *GMELINA ARBOREA* SEEDLINGS TO APPLICATIONS OF N AND K FERTILIZERS AND THEIR COMBINATIONS ON OXISOLIC SOIL

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OGBONNAYA, C.I. 1994. Growth and histo-chemical response of *Gmelina arborea* seedlings to applications of N and K fertilizers and their combinations on oxisolic soil. The effects of N and K fertilizers and their combinations on the growth, physical and histo-chemical properties of *Gmelina arborea* seedlings on an oxisolic soil were investigated. The results obtained showed that NK combinations contributed significantly to the height growth, while N alone and NK combinations promoted radial growth and dry matter production. All the treatments improved the wood specific gravity of the seedlings. NK combinations also increased significantly fibre length, but most of the treatments did not affect fibre diameter and lumen size, while all the treatments significantly increased fibre wall thickness. Most of the treatments significantly enhanced slenderness ratio, and produced significantly higher Runkel ratio. Wood pH was lowered by all the tratments except when K was applied alone. Higher levels of K alone or in combination with N brought about significantly higher wood ash content. Soluble substances of the wood were increased by the individual applications of N and K. On the basis of holistic assessment, N3K1, N3K2 and N3K3 were the best nutrient combinations for the growth of *G. arborea* seedling, while most of the treatments did not affect the histo-chemical properties relevant to pulp and paper production.

Key words: *G.arborea* - growth - N and K nutrition - histo-chemical properties - oxisolic soil

OGBONNAYA, C.I. 1994. Respons pertumbuhan dan histo-kimia anak benih *Gmelina arborea* terhadap aplikasi baja N dan K serta kombinasinya pada tanih oksisolik. Kesan baja N dan K dan kombinasinya terhadap ciri-ciri pertumbuhan fizikal dan histo-kimia anak benih *Gmelina arborea* pada satu jenis tanih oksisolik dikaji. Keputusan yang diperolehi menunjukkan bahawa kombinasi NK memberikan sumbangan yang ketara terhadap ketinggian anak benih, sementara N sahaja dan kombinasi NK menggalakkan pertumbuhan jejarian dan pengeluaran jirim kering. Kesemua rawatan memperbaiki graviti spesifik kayu anak benih. Kombinasi NK juga menambahkan panjang gentian dengan nyata sekali. Kebanyakan daripada rawatan tersebut tidak menjejaskan diameter gentian dan saiz lumen manakala kesemua rawatan menambahkan tebal dinding gentian. Kebanyakan daripada rawatan menambahkan nisbah kelangsingan dengan ketara dan menghasilkan dengan nyata sekali nisbah Runkel yang lebih tinggi. Kesemua rawatan menurunkan pH kayu kecuali apabila dirawat dengan K sahaja. Paras K yang tinggi atau kombinasi K dengan N menambahkan kandungan abu kayu dengan ketara. Kandungan

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bahan boleh larut kayu bertambah dengan aplikasi N dan K secara berasingan. Pada dasar penilaian secara holistik, N3K1, N3K2 dan N3K3 merupakan kombinasi nutrien yang terbaik untuk pertumbuhan anak benih *Gmelina arborea*. Kebanyakan daripada rawatan tersebut tidak menjejaskan ciri-ciri histo-kimia yang berkaitan dengan pengeluaran pulpa dan kertas.

Introduction

Gmelina arborea Roxb. (Verbenaceae) is a valuable tree for pulp and paper production in the tropics. It is also very useful for matchwood, and large plantations have also been established in several parts of the tropics in afforestation schemes aimed at stabilizing, restoration and maintenance of soil fertility, prevention of erosion and improvement of environment.

Nitrogen and potassium play key roles in plant metabolism. N affects plant growth through effects on photosynthetic activities in leaves in composition (Hall *et al.* 1972), and leaf protein (Metivier & Kirkby 1977). The major role of K in plant nutrition is believed to be its function as an activator of various metabolically important enzymes. Several workers have reported malformation of chloroplast of K-deficient plants especially in the number of intergrannal lamellae present which are associated with photosynthetic activities (Penny *et al.* 1976).

Although it has been shown that *G. arborea* responds favourably to the application of fertilizers in Malaysia (Zwierink 1983, 1984), in Nigeria (Jackson 1973), and in the Philippines (Mendoza & Glori 1976), no systematic studies have been carried out to determine the effects of fertilization on growth and histo-chemical properties of *G. arborea* relevant to pulp and paper production.

The work described here examines the effects of N and K fertilizers and their combinations on growth and histo-chemical properties of *G. arborea* on an oxisolic soil. The results would make positive contribution in formulating the balanced doses of N and K for raising the said species.

Materials and methods

Potting medium and seedlings

Oxisolic soil was used as the potting medium. The physical and chemical characteristics of the soil are shown in Table 1. The soil was sun-dried for a week and undecomposed plant materials were removed. Twelve kilogramme soil was potted into 12.5l plastic buckets to obtain a bulk density of 1.2 $g\ cm^{-2}$. Two-week old seedlings showing uniform height growth were transplanted into the pots and each pot received only one seedling.

Treatments

Three levels of N (2.22, 4.44 and 6.66 g N/pot) and K (5.70, 11.40 and 17.10g K/pot) were applied in all possible combinations and permutations. Zero fertilizer application was incorporated as the control. The levels were chosen to present the presumed optimum range of the species after a preliminary trial on the soil type. N was applied as calcium ammonium nitrate ($Ca(NH_4)_2NO_3$) and K as muriate of potash (KCl). The complete dose of each nutrient was applied at one instance. The fertilizers were applied in about 5 *cm* deep trenches made round the seedlings and covered with thin mantle of soil. The plants were grown for a period of 20 weeks.

Table 1. Physical and chemical properties of the experimental soil (oxisolic soil)

Properties	Values
Physical properties	
Sand (%)	64.50
Silt (%)	3.30
Clay (%)	32.30
Textural class	sandy clay-loam
Chemical properties	
pH (1:1H_2O)	4.40
pH (1:1KCl)	3.53
Organic matter (%)	1.42
Total N (%)	0.03
Avail. P ($mg\ kg^{-1}$)	2.11
Exch. cations ($cmol\ (+)\ kg^{-1}$)	
K	7.40
Na	3.10
Ca	11.80
Mg	12.20

Measurement of assessment parameters

Physical properties - specific gravity of wood

Specific gravity was used as a measure of the physical strength of the wood. This was measured as the ratio of the oven-dry weight to its original green volume. The green volume was determined after soaking the wood in water, while the dry matter of the sample was obtained by drying the wet wood at 105°*C* to constant weight (Akachukwu 1976).

Growth measurements

Total height growth was measured with the aid of a meter rule from the base of the stem at the soil level to the terminal bud of the main stem. Root collar diameter was measured at the root collar with micrometer screw guage to the nearest 0.01 *mm*. Dry matter production was obtained by carefully uprooting the seedlings from the pot. The roots were thoroughly washed and each plant separated into shoot and roots. The plant parts were oven-dried at 85°*C* until a constant weight was attained. The dry weight of each component was determined to the nearest 0.01*g* with a top-loading meter balance. The leaf area ratio (LAR) was obtained as the ratio of total leaf area to whole plant dry weight. Leaf area was measured with leaf area meter. Root-shoot ratio was obtained as the ratio of the dry weight of root to the dry weight of the shoot.

Histological properties of the wood and the derived values

Stemwood samples for the fibre studies were obtained from the second internode from the base. Small slivers for maceration were obtained from the outside of stem (after the bark), and macerated with 10*ml* of 60% nitric acid in a water bath for 10 *min.* (Okoegwale & Gill 1988). Prepared slides were viewed under a calibrated microscope and fibre length (fl), fibre diameter (fd), fibre lumen diameter (fld), and fibre wall thickness (fwt) were measured. The following derived values were also calculated: coefficient of suppleness (CS) or flexibility coefficient as fld/fd (Petri 1952); slenderness ratio fl/fd (Rydholm 1965), and Runkel ratio (RR) as 2 x fwt/fld (Runkel 1940).

Chemical properties

The pH of wood (passing through 40 mesh) was measured with glass electrode of a pH meter (Pye Unicam, PW418). Ash content of wood was determined by the loss-on-ignition method. TAPPI T6m-59 method was employed in the determination of alcohol-benzene solubles content of wood (Grant 1961). Hot water solubles content was by TAPPI T1m-59 method (Grant 1961). Alkali (1% NaOH) solubles content was determined by digesting 1*g* of sawdust (passing through 40 mesh) in 100 *ml* of 1% NaOH in a hot water bath for 1*h*. The oven-dry weight equivalent of the plant sample minus the weight of the oven-dry residue expressed as a percentage of the total plant sample used for the extraction was the matter soluble in alkali (Casey 1960).

Experimental design and statistical procedure

The experiment incorporated a 4 × 4 factorial design based on randomized block with each treatment replicated five times. The basic factors, N and K, were the main effects, while N × K was the interaction. The pots were laid out (1*m* apart) on a grass field at the University of Port Harcourt Botanical Garden. A total of 80 pots were used for the 16 treatment combinations including the control (N0K0). The results obtained for each parameter were subjected to analysis of variance to determine if there were significant differences due to N, K or their interactions. Next, LSD test was performed to segregate the treatment means.

Holistic assessment of the parameters measured

The results obtained were subjected to holistic analysis in order to obtain a conclusive view. For each parameter measured, the treatment effects including the control were scored according to their relative performance. The scores ranged from 1 for the worst treatment effect to 16 (corresponding to the total number of treatment) for the best treatment effect. The mean score for each treatment was obtained on the basis of which comparisons were made and conclusions drawn.

Results

Plant growth characteristics

N and K, and their combinations brought about significant variations on the total plant height growth. N was the single most important element in promoting height growth of gmelina on the oxisolic soil. K alone at first and second levels (N0K1 and N0K2) of applications did not promote growth in relation to the control. N and K combinations produced significantly taller plants in all the cases, and the highest growth (62.3 ± 5.54 *cm*) was obtained with N3K3. The LSD ($p = 0.05$) between the means was obtained as 5.78*cm* (Table 2).

Analysis of variance indicated significant variation in collar diameter growth due to the different nutrient elements and their combinations. The LSD ($p=0.05$) between the means was recorded as 2.72*mm*. N alone promoted growth while K did not. Though K did not enhance radial growth, its interaction with N was significant and positive (Table 2).

The nutrient elements and their combinations significantly affected dry matter production of gmelina. N remained the most important single nutrient element required by gmelina seedlings for improved growth. K alone significantly reduced dry weight in relation to the control. Combinations of N and K significantly increased dry matter production in all the cases. The highest dry matter was produced by N3K3. The LSD ($p = 0.05$) among the means was obtained as 4.68*g* (Table 2).

The variations due to the application of K and its combinations with N on LAR were significant, while those as a result of N were not. The LSD ($p = 0.05$) between the means was 5.84*g*. While N alone significantly reduced LAR, K significantly enhanced it. Combinations of N and K with the exception of N1K3 significantly reduced LAR in comparison with the control. The highest LAR was obtained with N0K1 (Table 2).

Analysis of variance did not show any significant variations due to the applications of various levels of N, whereas variations due to K and its interaction with N were significant. The LSD ($p=0.05$) among the means was recorded as 0.253. All the levels of fertilization significantly reduced RSR when compared with the control (Table 2).

Table 2. Effects of N and K fertilizers and their combinations on growth and wood specific gravity of *G. arborea* seedlings

Nutrient combination	Plant height (*cm*)	Root collar diameter (*mm*)	Dry matter production (*g*)	Leaf area ratio (LAR)	Root-shoot ratio (RSR)	Specific gravity
N0K0	19.84 ± 2.56	9.21 ± 0.48	8.68 ± 1.71	40.82 ± 4.61	1.36 ± 0.28	0.550 ± 0.039
K1	23.80 ± 2.87	7.17 ± 0.97	3.44 ± 0.83	76.10 ± 5.71	0.66 ± 0.09	0.576 ± 0.034
K2	24.30 ± 3.19	7.82 ± 2.60	3.62 ± 1.53	64.50 ± 3.99	0.80 ± 0.12	0.660 ± 0.042
K3	28.24 ± 4.79	7.41 ± 1.34	4.10 ± 1.19	46.91 ± 6.71	0.72 ± 0.22	0.583 ± 0.033
N1K0	39.30 ± 5.06	15.29 ± 3.18	20.86 ± 1.21	20.86 ± 1.21	0.80 ± 0.18	0.639 ± 0.024
K1	49.44 ± 2.83	13.92 ± 3.25	26.21 ± 5.23	26.21 ± 5.23	0.67 ± 0.11	0.646 ± 0.011
K2	50.88 ± 3.88	14.02 ± 3.36	30.79 ± 3.51	30.79 ± 3.51	0.71 ± 0.13	0.602 ± 0.041
K3	41.44 ± 5.43	12.05 ± 1.94	40.42 ± 5.13	40.42 ± 5.13	0.66 ± 0.11	0.571 ± 0.076
N2K0	52.66 ± 4.13	13.88 ± 2.50	32.76 ± 3.33	32.76 ± 3.33	0.64 ± 0.12	0.619 ± 0.041
K1	56.92 ± 8.50	14.74 ± 3.58	34.03 ± 4.49	34.03 ± 4.49	0.81 ± 0.15	0.636 ± 0.055
K2	44.88 ± 4.10	13.98 ± 0.99	28.11 ± 3.15	28.11 ± 3.15	0.82 ± 0.21	0.625 ± 0.021
K3	60.72 ± 6.24	15.94 ± 4.26	30.09 ± 2.93	30.09 ± 2.93	0.60 ± 0.12	0.587 ± 0.041
N3K0	45.42 ± 3.71	13.50 ± 3.55	36.70 ± 5.98	36.70 ± 4.98	0.76 ± 0.11	0.606 ± 0.066
K1	58.40 ± 4.77	15.94 ± 0.21	30.49 ± 4.63	30.49 ± 4.63	0.62 ± 0.10	0.639 ± 0.052
K2	62.32 ± 5.54	15.37 ± 0.41	30.09 ± 5.92	30.09 ± 5.92	0.60 ± 0.07	0.616 ± 0.045
K3	56.08 ± 7.88	16.62 ± 3.44	29.81 ± 4.97	29.81 ± 4.97	0.61 ± 0.11	0.658 ± 0.011
LSD (p = 0.05)	5.78	2.72	5.84	5.84	0.253	0.064

Physical properties: specific gravity of wood

The variations in wood specific gravity due to the applications of N and K were not significant, whereas their interaction (N × K) was significant. Combinations of N and K significantly enhanced specific gravity of gmelina wood, except for N1K2, N1K3 and N2K3 that were not affected in relation to the control (Table 2).

Holistic assessment of growth parameters and physical properties of wood

Holistic assessment (Table 3) showed that all the fertilization treatments enhanced the performance of *G. arborea* seedlings on oxisolic soil in relation to the control. The best overall performance was obtained with N3K1 and N3K3 with 12.83 mean scores respectively as against 4.0 by the control. The LSD (p=0.05) between the mean scores was obtained as 4.83.

Histological properties

Analysis of variance showed very strong significant variantions on fibre length as a result of various applications of N and K, and their interactions. The LSD (p=0.05) between the means was obtained as 0.04 *mm* (Table 4). All the treatments significantly increased fibre length with the exception of N0K1, N1K0 and N2K0.

Significant variations of fibre diameter were obtained due to N and K fertilizers, while their interaction was found insignificant. The LSD (p = 0.05) between the means was 0.0023 *mm* (Table 4). Most of the values recorded with the treatments were similar with the control, except N1K1, N1K0, N2K2 and N3K0 that were significantly higher than the control.

Fibre lumen diameter was not significantly affected by the different treatments of N and K, and their interactions. Only N0K2 and N0K3 significantly lowered the fld values with reference to the control. The LSD (p=0.05) between the means was obtained as 0.00145*mm* (Table 4).

Subjecting fibre wall thickness values to analysis of variance revealed significant variations due to N, K and their interaction. All the treatments significantly increased fibre wall thickness with respect to the control, except N2K0 which was similar with the control (Table 4).

The derived fibre dimensional values

Analysis of variance on coefficient of suppleness (CS) showed that N, K and their combinations brought about significant variations among the treatments. With the exception of N1K0, N1K2, N2K2 and N3K0, all the treatments significantly reduced CS with reference to the control. The LSD (p=0.05) among the means was 3.741 (Table 5).

Slenderness ratio (SR) showed significant variation due to the treatments of N and K fertilizers. Application of N and K individually did not affect SR with respect

Table 3. Holistic assessment of the effects of N and K fertilizers and their combinations on growth and wood specific gravity of *G. arborea* seedlings

Parameter	Treatment combinations and their performance scores															
	N0K0	N0K1	N0K2	N0K3	N1K0	N1K1	N1K2	N1K3	N2K0	N2K1	N2K2	N2K3	N3K0	N3K1	N3K2	N3K3
Wood specific gravity	2	3	16	4	13	14	6	2	9	11	10	5	7	13	8	15
Height growth	1	2	3	4	5	9	10	6	11	13	7	15	8	14	16	12
Root collar diameter	4	1	3	2	12	8	10	5	7	11	9	15	6	15	13	16
Dry matter production	4	1	2	3	8	10	6	5	12	7	9	11	13	15	14	16
Leaf area ratio	13	16	15	14	1	2	8	12	9	10	3	6	11	7	6	4
Root-shoot ratio	1	11	5	7	5	9	8	11	12	3	2	16	6	13	16	14
Mean score*	4.0	5.67	7.33	5.67	7.33	8.67	8.00	6.83	10.0	9.16	6.67	11.33	8.5	12.8	12.2	12.8

*The LSD (p = 0.05) between the mean scores was obtained as 4.83.

to the control. Combinations of N and K in all cases (except N2K2) significantly enhanced SR. The LSD (p=0.05) between the treatment means was obtained as 2.222 (Table 5).

The result on Runkel ratio (RR) showed significant variation due to the different treatments of N and K fertilizers. All the treatments, except N3K0, produced significantly higher RR than the control. The LSD (p=0.05) between the treatment means was recorded as 0.095 (Table 5).

Table 4. Effects of N and K fertilizers on fibre dimensional properties of *G. arborea* seedlings

Nutrient combination	Fibre dimensions			
	Fibre length (*mm*)	Fibre diameter (*mm*)	Fibre lumen diameter (*mm*)	Fibre wall thickness ($x10^{-3}$ *mm*)
N0K0	0.56 ± 0.03	0.022 ± 0.001	0.016 ± 0.002	2.96 ± 0.36
K1	0.58 ± 0.03	0.023 ± 0.001	0.015 ± 0.001	4.21 ± 0.25
K2	0.63 ± 0.00	0.024 ± 0.000	0.014 ± 0.000	4.24 ± 0.13
K3	0.62 ± 0.02	0.023 ± 0.001	0.014 ± 0.001	4.59 ± 0.10
N1K0	0.58 ± 0.01	0.024 ± 0.001	0.017 ± 0.001	3.93 ± 0.19
K1	0.71 ± 0.03	0.025 ± 0.001	0.016 ± 0.001	4.38 ± 0.23
K2	0.61 ± 0.01	0.025 ± 0.001	0.017 ± 0.001	3.97 ± 0.25
K3	0.76 ± 0.02	0.024 ± 0.001	0.015 ± 0.001	4.73 ± 0.31
N2K0	0.60 ± 0.02	0.025 ± 0.001	0.017 ± 0.001	3.29 ± 0.12
K1	0.68 ± 0.05	0.024 ± 0.001	0.015 ± 0.000	4.85 ± 0.12
K2	0.80 ± 0.02	0.025 ± 0.000	0.017 ± 0.001	4.22 ± 0.07
K3	0.72 ± 0.01	0.024 ± 0.000	0.015 ± 0.001	4.40 ± 0.02
N3K0	0.61 ± 0.01	0.025 ± 0.001	0.017 ± 0.001	3.79 ± 0.10
K1	0.95 ± 0.05	0.026 ± 0.000	0.017 ± 0.002	4.75 ± 0.55
K2	0.72 ± 0.01	0.023 ± 0.001	0.015 ± 0.001	3.98 ± 0.20
K3	0.82 ± 0.02	0.024 ± 0.001	0.015 ± 0.001	4.13 ± 0.18
LSD (p = 0.05)	0.040	0.0023	0.00145	0.450

Chemical properties

The pH of wood showed significant variation as a result of the applications of N, K and their combinations. The pH of the control was not significantly different from the values obtained with N0K1, N0K3 and N1K0. The rest of the treatments significantly lowered the pH of wood in relation to the control. The LSD (p=0.05) among the treatment means was 0.86 (Table 6).

Analysis of variance showed significant variations in the ash content due to the various applications of N and K, while their interaction was not. N when applied alone significantly lowered ash content when compared with the control. High levels of K whether applied alone or in combination with N brought about significantly higher ash content. The LSD among the treatment means was 0.651% (Table 6).

Alcohol-benzene solubles content was significantly influenced by the applications of N, while those of K and its interactions with N were not significant. The least value was recorded with the control, while the highest values were obtained when N was applied alone. The LSD (p=0.05) between the treatment means was recorded as 1.803% (Table 5).

There were significant variations in alkali solubles content due to the application of N. The variations due to K and its interactions with N were not significant. The highest values were obtained when N was applied alone. The combinations of N and K, with the exception of N1K1, N1K3 and N2K1 were significantly higher than the control. The values obtained with K alone and the control were also homogenous. The LSD (p=0.05) between the means was 2.175% (Table 6).

Table 5. Effects of N and K fertilizer on the derived values of fibre dimensional properties of *G. arborea* seedlings

Nutrient combination	Derived fibre dimensional value: Coefficient of suppleness	Slenderness ratio	Runkel ratio
N0K0	71.41 ± 8.30	25.55 ± 2.90	0.38 ± 0.05
K1	61.76 ± 2.27	25.23 ± 0.86	0.05 ± 0.06
K2	63.88 ± 3.54	26.57 ± 0.71	0.06 ± 0.02
K3	60.06 ± 2.36	26.57 ± 1.65	0.68 ± 0.06
N0K0	68.63 ± 2.24	23.72 ± 0.89	0.47 ± 0.05
K1	65.88 ± 1.19	28.88 ± 1.19	0.54 ± 0.02
K2	67.68 ± 3.50	24.70 ± 0.88	0.48 ± 0.06
K3	60.80 ± 3.95	31.51 ± 0.76	0.65 ± 0.09
N2K0	66.94 ± 1.98	24.05 ± 0.99	0.48 ± 0.01
K1	60.67 ± 1.81	28.04 ± 2.00	0.66 ± 0.01
K2	67.45 ± 1.99	31.59 ± 0.40	0.50 ± 0.03
K3	63.33 ± 3.49	29.92 ± 0.62	0.57 ± 0.07
N3K0	69.17 ± 4.07	24.81 ± 1.02	0.45 ± 0.03
K1	63.89 ± 1.65	36.96 ± 3.41	0.57 ± 0.05
K2	65.19 ± 0.07	31.41 ± 0.86	0.53 ± 0.03
K3	63.55 ± 2.34	34.66 ± 0.44	0.55 ± 0.04
LSD (p = 0.05)	3.741	2.222	0.0951

Hot water solubles content showed significant variations due to applications of N and K, but their interactions were not significant. The control recorded the lowest hot water solubles content. With the exceptions of N0K1, N0K3 and N2K3, all the treatments significantly increased the hot water solubles with reference to the control. The LSD (p=0.05) between the treatment means was 2.062% (Table 6).

Holistic assessment of histo-chemical properties

Holistic analysis of the histo-chemical properties (Table 7) showed that N2K2 was the best nutrient combination. N2K1 significantly reduced histo-chemical properties, while the rest of the treatments were not affected with respect to the control. The LSD (p=0.05) between the mean scores was obtained as 3.79.

Table 6. Effects of N and K fertilizers on the chemical properties of *G. arborea* seedlings

Nutrient combination	Wood chemical properties				
	pH of wood	Ash content of wood (%)	Alcohol-benzene solubles (%)	Alkali solubles (%)	Hot water solubles (%)
N0K0	5.53	2.00	2.45	16.80	8.63
K1	5.70	2.40	2.87	16.60	10.28
K2	6.56	2.70	4.20	16.70	11.60
K3	6.06	3.20	3.34	18.18	9.10
N1K0	4.95	1.00	6.19	20.07	11.72
K1	4.30	2.35	3.05	17.77	10.33
K2	4.50	2.55	4.27	20.55	12.67
K3	4.56	2.88	3.15	17.10	11.07
N2K0	4.40	1.10	7.45	21.35	13.47
K1	4.20	2.33	4.93	17.40	12.79
K2	4.46	3.10	4.15	19.70	13.87
K3	4.60	3.05	3.86	20.60	10.24
N3K0	4.10	1.30	6.49	21.80	11.50
K1	4.25	2.00	3.69	19.30	10.90
K2	4.45	2.75	5.10	19.55	11.15
K3	4.25	2.90	4.40	21.90	12.75
LSD (p = 0.05)	0.860	0.651	1.803	2.175	2.062

Discussion

Growth

Plant height, root collar diameter, dry matter production, leaf area ratio and root-shoot ratio were the attributes used in assessing growth of *G. arborea* seedlings on oxisolic soil. The study showed that NK combinations contributed significantly to height growth and the most effective treatment combination was N3K2. N and NK combinations promoted radial growth, and they were also responsible for the best dry matter production, with the best growth made with N3K3 nutrient combination. All the treatments significantly reduced root-shoot ratio with respect to the control.

Table 7. Holistic assessment of the effects of N and K fertilizers and their combinations on the histo-chemical properties of *G. arborea* seedlings

Parameter	Treatment combinations and their performance scores															
	N0K0	N0K1	N0K2	N0K3	N1K0	N1K1	N1K2	N1K3	N2K0	N2K1	N2K2	N2K3	N3K0	N3K1	N3K2	N3K3
Fibre length	1	3	8	7	3	10	6	13	4	9	14	12	6	16	12	15
Fibre diameter	16	15	12	15	12	6	6	12	6	12	6	12	6	1	15	12
Fibre lumen diameter	10	8	2	2	16	10	16	8	16	8	16	8	16	16	8	8
Fibre wall thickness	16	9	7	4	13	6	12	3	15	1	8	5	14	2	11	10
Coeff. of suppleness	16	4	7	1	14	10	13	3	11	2	12	5	15	8	9	6
Slenderness ratio	6	5	8	8	1	10	3	13	2	9	14	11	4	16	12	15
Runkel ratio	16	8	4	1	14	9	13	2	13	3	11	6	15	6	10	8
pH of wood	13	14	16	15	12	5	9	10	6	2	8	11	1	4	7	4
Wood ash content	5	8	10	16	1	7	9	12	2	6	15	14	3	5	11	13
Alcohol-benzene solubles	16	15	8	12	3	14	7	13	1	5	9	10	2	11	4	6
Alkali solubility	14	16	15	10	6	11	5	13	3	12	7	4	2	9	8	1
Hot water solubles	1	4	10	2	11	5	12	7	15	14	16	3	9	6	8	13
Mean score*	10.8	9.08	8.92	7.75	8.83	8.58	9.25	9.08	7.83	6.92	11.3	8.42	7.75	8.33	9.58	9.25

* The LSD (p = 0.05) between the mean scores was obtained as 3.79.

The improved growth when N was applied alone or in combination with K is not unusual because of its role in protein and nucleic acid syntheses which are the core of life processes (Novoa & Loomis 1978). N also affects photosynthetic activity of plants through its effects on chloroplast structure and composition, and leaf protein (Hall *et al.* 1972). The major role of K in plant nutrition is that of an activator of various metabolically important enzymes (Evans & Sorger 1966). K is also essential to catalyze reactions in both carbohydrate and protein metabolism (Black 1968); its application alone, however, was not beneficial to the growth of *G. arborea* seedlings on oxisolic soil.

The low root-shoot ratio recorded with the treatments showed that the seedlings gave more shoot growth than root growth. This is interesting since in forest trees, shoots and not the roots are the harvest index. With more N reaching the shoot and causing the use of carbohydrate there in protein synthesis, less carbohydrates remain for translocation to the roots.

Results of the study showed that all treatments improved wood specific gravity with reference to the control, and the highest specific gravity was obtained with N3K3. There is a direct relationship between specific gravity of a piece of wood and its strength properties, uniformity and yield of pulps (Anonymous 1968). Low specific gravity may be caused by starvation of seedlings leading to an underdevelopment of the pith or it could be a consequence of excessive application of fertilizers which leads to thinning of cell walls. The high specific gravity recorded with most of the treatments could, therefore, be due to adequate fertilization and plant growth.

On the basis of the holistic assessment of the growth and physical properties, N3K1, N3K2 or N3K0 are recommended for the growth of *G. arborea* seedlings on oxisolic soil.

Histological properties

The longest fibres in the study were obtained with NK combinations and the best nutrient combination was N3K1. Shorter fibres were recorded when N or K was applied alone. *G. arborea* seedlings on oxisolic soil, therefore, needs combined applications of N and K for improved fibre length. The overall effect of N is to increase the rate and extent of protein synthesis required for cell division and elongation (Hewitt 1966), while K is essential for actions of enzymes that catalyze certain reactions in both carbohydrate and protein metabolism (Black 1968).

Though fibre lumen diameter was increased by all the treatments, most of the values were not significantly different from the control. In nearly all the cases N and K fertilization increased significantly the fibre wall thickness, though much higher values were obtained with K alone or in combination with N. The increased fibre diameter and fibre lumen diameter, and the relatively thinner fibre wall thickness when N was applied alone were similarly recorded by Letham (1961). He observed that the fruits of apple trees fertilized with N contained larger cells than fruits from unfertilized trees or from trees fertilized with P or K. Black (1968) explained that when N is in adequate supply, carbohydrates are utilized to form more protoplasm and more cell rather than for deposition to thicken the cells. Cells produced under such conditions, therefore, tend to be large and to have thin walls. The increased fibre wall thickness with the application of K is not unusual. Earlier work by Tobler (1929) showed that fibre wall thickness tends to increase with increase in K supply and fibre cell walls from K-deficient plants had thinner walls than those from plants with adequate K. The increased fibre wall thickness could be due to the relatively higher turgidity, and content of cellulose and hemicellulose associated with a high content of K in the stem (Kono & Takahashi 1967).

Derived values from histological properties

Coefficient of suppleness (CS) varied from the highest value (71.41) recorded with the control to the least (60.06) with N0K3. All the values obtained, therefore, were higher than 60. According to the guideline by Petri (1952), CS > 50 but preferably > 60 are required of fibres for papermaking because paper strength tends to improve with increasing CS. Such fibres, according to him, collapse easily and produce good surface contact and fibre-to-fibre bonding.

On the other hand, slenderness ratio (SR) was not affected when N and K were applied singly, while their combinations significantly enhanced SR. Plants treated with NK fertilizers would most probably yield papers with better tearing qualities, since the higher the SR, the stronger the resistance to tearing (Rydholm 1965). Similarly all the treatments, except N3K0, produced significantly higher Runkel ratio (RR), but the values in all the cases were less than unity. In other words, even though fertilization raised RR, good quality papers would still be obtained from the wood. According to Okereke (1962) and Rydholm (1965), better papers are produced the lower the RR.

Chemical properties

The highest pH values in the study which were very weakly acidic were obtained when K was applied alone, while strongly acidic pH was obtained with N3K0. The pH of sap of many plant species is in range of about 5 - 5.5 which is slightly acidic (Mengel & Kirkby 1979). The increased pH with K application can be explained on the basis of the fact that K^+ is an alkaline cation (Black 1968) while K fertilizers tend to be neutral in reaction (Mengel & Kirkby 1979). On the other hand, NO_3^- when assimilated (reduced) by roots yield NO_3^-, which is a very strongly acidic radical. Acidity of wood causes corrosion of metal in contact with wood, it also plays some role in pulp and paper industry in relation to corrosion of equipment and excessive consumption of alkaline cooking liquor in alkaline pulping.

While K and its combinations with N increased ash content with respect to the control, applications of N alone significantly reduced it. This is because wood ash contains 2 - 8% K_2O, some P_2O_5 and a large amount of CaO (Wild 1958). In the chemical industry, a high ash content is undesirable as it reduces the calorific value of charcoal. Wood ash is, however, used in fertilizer and in glass and soap manufacture (Anonymous 1974/75).

The alcohol-benzene, alkali (1% NaOH) and hot water solubles were increased with the applications of N and K and their combinations on oxisolic soil. The highest values were obtained when N was applied alone. The alcohol-benzene solubles are mainly fats and their derivatives, the alkali solubles, and the hot water solubles are mainly carbohydrates. The role of N in the synthesis of fatty compounds, namely, lipoproteins (Goodwin & Mercer 1972) and carbohydrate synthesis through effects on leaf size, chloroplast structure and leaf protein (Hall *et al.* 1972) are well known. The major role of K in plant nutrition is believed to be its action as activator of various metabolically important enzymes (Evans & Sorger 1966). The alcohol-benzene solubles are important because they influence both pulping process and the quality of the resulting pulp (Grant 1961). High percentage of alkali solubles reduces pulp yield and in sulphate pulping process more alkali is consumed (Casey 1960). Although hot water solubility provides no useful information on the pulp value, it is indicative of the nature of substances present, namely, tannins, mucilages, carbohydrates, sugars and salts (Grant 1961).

On the basis of the holistic assessment of the effects of N and K fertilizers and their combinations on histo-chemical properties of *G. arborea* seedling relevant to pulp and paper production, N2K2 with the highest performance score is recommended for the growth of the seedlings for this purpose.

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