PERFORMANCE OF SELECTED WOODY AGROFORESTRY SPECIES GROWN ON AN ALFISOL AND AN ULTISOL IN THE HUMID LOWLAND OF WEST AFRICA, AND THEIR EFFECTS ON SOIL PROPERTIES

B.T. Kang, F.K. Akinnifesi

International Institute of Tropical Agriculture (IITA), PMB 5320, Ibadan, Nigeria

&

D.O. Ladipo

International Centre for Research in Agroforestry (ICRAF), c/o IITA, PMB 5320, Ibadan, Nigeria

Received June 1993

KANG, B.T., AKINNIFESI, F.K. & LADIPO, D.O. 1994. Performance of selected woody agroforestry species grown on an Alfisol and an Ultisol in the humid lowland of West Africa, and their effects on soil properties. Performance of commonly grown agroforestry woody species was assessed at two locations in southern Nigeria, on an Alfisol (Oxic Paleustalf) at Ibadan in the forest-savanna transition zone and on an Ultisol (Typic Paleudult) at Onne in the forest zone, with annual rainfall of 1280 and 2400 mm respectively. The improvement effect of the wood species on soil properties appeared to be more pronounced on the Alfisol than on the acidic and nutrient poor Ultisol. *Cordia alliodora* and *Gmelina arborea* performed equally well on both sites, but *Cordia alliodora* seemed to be more suitable for use in an agroforestry system. *Leucaena leucocephala* and *Pterocarpus soyauxii*, which performed better on the Alfisol, were more suitable for use in agroforestry systems in this ecozone. *Dialium guineense, Irvingia gabonensis*, and *Treculia africana* had more potential for use in agroforestry systems on the Ultisol in the humid forest zone. Fruit productivity in these wild fruit species was found to differ between sites; substantial between-tree variations were observed. Indicative productivity values for future economic evaluations of *Irvingia gabonensis* plantations are presented.

Keywords : Multipurpose woody species - ecozone - performance - soil properties

KANG, B.T., AKINNIFESI, F.K. & LADIPO, D.O. 1994. Prestasi spesies hutan tani berkayu yang ditanam pada tanih Alfisol dan tanih Ultisol di tanah pamah lembap di Afrika Barat serta kesan-kesannya pada ciri-ciri tanih. Prestasi spesies hutan tani berkayu ditaksir pada dua lokasi di selatan Nigeria iaitu pada Alfisol (Oxic Paleustalf) di Ibadan dalam zon peralihan hutan savana dan pada Ultisol (Typic Paleudult) di Onne dalam zon hutan, masing-masing dengan hujan tahunan sebanyak 1280 mm dan 2400 mm. Kesan perbaikan oleh spesies kayu pada ciri-ciri tanih kelihatan lebih ketara pada Alfisol daripada Ultisol yang berasid dan kurang nutrien. *Cordio alliodora*

Corresponding Address: Dr. B.T. Kang (IITA), c/o Ms. Maureen Larkin, 26 Dingwal Road, Croydon CR9 3EE, England, United Kingdom, United Kingdom.

dan *Gmelina arborea* memberi prestasi yang sama baik pada kedua-dua jenis tanih, tetapi *Cordio alliodora* lebih sesuai digunakan dalam sistem hutan tani. Kedua-dua *Leucaena leucocephala* dan *Pterocarpus soyauxii* yang memberi prestasi yang lebih baik pada Alfisol, adalah lebih sesuai untuk digunakan dalam sistem hutan tani pada ekozon ini. *Dialium guineense, Irvingia gabonensis* dan *Treculia africana* lebih berpontesi untuk digunakan dalam sistem hutan tani pada Ultisol dalam zon hutan lembap. Daya pengeluaran buah spesies tumbuhan liar didapati berbeza antara kedua-dua tapak; perbezaan antara pokok yang cukup besar dapat diperhatikan. Petunjuk nilai-nilai produktiviti untuk penaksiran ekonomi masa depan ladang-ladang *Irvingia gabonensis* dikemukakan.

Introduction

Land degradation, resulting from deforestation due to shifting cultivation and agricultural intensification without external chemical input, is becoming a major problem in humid tropical Africa. Agroforestry interventions have been shown to lessen the problem (King 1968, Kang & Wilson 1987). Inclusion of multipurpose woody species (MWS) in food production system with low external chemical inputs could play an important role in sustaining and increasing crop yield, and it could provide other auxillary products such as timber, firewood, staking material, browse, etc. (Kang *et al.* 1990). However, as research on MWS is rather recent compared to that on conventional forestry species, there is a paucity of information on MWS with a potential for use in agroforestry systems. Huxley (1983) described MWS as woody perennials purposely grown to provide more than one significant contribution to the production and service functions.

Peformance of tree species/provenances, progenies, or clones could vary with sites, depending on edaphic and climatic conditions (Jackson & Ojo 1973, Ladipo & Leakey 1986). MacDicken and Brewbaker (1988) also reported significant location and species interactions in their work on five tropical leguminous fuelwood species, which reflected different site requirements for each of the test species. Site soil properties have also been reported to have a direct effect on the performance of woody species and also on the ability of MWS in soil-nutrient restoration (Hamilton 1965, Challinor 1968, Lundgren 1977, Chijioke 1980). This paper reports the performance of seven woody species grown on an Alfisol and an Ultisol in southern Nigeria, and their effects on soil properties.

Materials and methods

Description of study area

The study was conducted at the arboreta located at the International Institute of Tropical Agriculture (IITA) main research station at Ibadan (7°30'N, 3°54'E) and at the Institute's high rainfall station at Onne (4°43'N, 7°01'E) (near Port

Harcourt), both in southern Nigeria. Vegetation at Ibadan is typical of a forest-savanna transition zone. The mean annual rainfall is 1280 mm, bimodally distributed over eight months from March till October, with peaks between June-July and September- October. A short dry spell during August is typical of this zone. The soil at the site is classified as an Alfisol (Oxic Paleustalf), characterized by high base saturation (Moorman *et al.* 1975).

The Onne site is located in the forest zone. The mean annual rainfall is 2400 mm, monomodal and distributed over a 10-month period (February - November). The soil is classified as an Ultisol (Typic Paleudult), characterized by low base saturation, strongly acidic, with high aluminium saturation (Van der Heide *et al.* 1985).

The arboreta were established in June 1979, consisting of plots of 10 × 20 m at Ibadan and 12 × 22 m at Onne per species. Plots were cleared from secondary forest at both locations and grown with food crops for a year before tree establishment. Bagged seedlings were used for establishing the trees. The trees were planted at Ibadan with maize and at Onne with cassava during establishment, at interhedge row spacing of 2 m and interhedge row spacing of 4 m. Budded materials were used for *Irvingia* and *Treculia.*

Selection of test species

Seven species planted at both sites were studied: *Cordia alliodora, Dialium guineense, Gmelina arborea, Irvingia gabonensis* var. *gabonensis, Leucaena leucocephala* var. K28, *Pterocarpus soyauxii,* and *Treculia africana. Cordia alliodora* and *Gmelina arborea* are commonly grown exotic forestry or agroforestry species in the area. *Leucaena leucocephala* is a commonly grown exotic MWS (Brewbaker *et al.* 1985). The other MWS are indigenous species commonly grown in traditional agroforestry systems in the humid zone of West Africa (Okafor 1982, 1990). *Dalium guineense* (velvet tamarind), in addition to its value in natural fallow improvement, provides fruit used in drinks, fodder, and wood for staking material and charcoal production. *Irvingia gabonensis* var. *gabonensis* (wild mango) provides fruit for use as food, in drinks, and as condiment. *Pterocarpus soyauxii,* a nitrogen fixing legume, is described as a perennial leafy vegetable (Okafor 1983). *Treculia africana* (African breadfruit) fruit is widely used for human food and animal feed (Okafor 1990). *Gmelina* wood forms a good quality source for pulp, and its tremendous coppiceability has enhanced its value in fuelwood plantations.

Data collection and analysis

Stump diameters were measured at 25 cm and 1.3 m above ground, as recommended by Loetsch *et al.* (1973); tree heights and top diameters were measured with spiegel relascope, complying with the 5 cm merchantibility limit. Five test trees were randomly selected in each plot for these measurements. This complies with the minimum 1% sampling intensity used in tropical forest inventory (Maimo 1987). Four composite surface (0-15 cm) soil samples were collected from under each woody species at both locations. For comparison, surface (0-15 cm) soil samples were collected from an adjacent plot that was under grass vegetation (as a control). For soil bulk density measurements, 250 ml sampling cores were used. Soils were analyzed for their chemical properties, using the procedure described by Juo (1981). Visual observations were also made on canopy closure, tree form, vigour, and fruit production for *Irvingia.* Total fruit produced by five sample trees at each site was assessed in 1991 and 1992, to evaluate its productivity. Insufficient information is presently available on most native fruit trees in lowland West Africa. Data on the growth of these trees were subjected to statistical analysis, using SAS (1985).

Experimental results

Performance of woody species

Growth measurements at both locations (Table 1) were done in January 1989, about ten years after establishment.

Performance of *Cordia alliodora* at the two sites was not statistically different. There was also no marked difference in plant vigour between *Cordia* plants grown at both sites. This species has the best stem form (increasing cylindricity) and a light small canopy at both sites. Survival of trees at Ibadan was, however, 40% lower than at Onne.

Dialium guineense showed larger stem diameter, plant height, total wood volume, and bole height at Onne than at Ibadan. There was no difference in diameter at breast height (DBH) between both locations.

Gmelina arborea showed good performance at both locations, but the trees were taller at Onne. Although other measured growth parameters were also higher at Onne than at Ibadan, the differences were not significant. At Onne, *Gmelina* showed the best overall performance in vigour compared to the other species.

Irvingia gabonensis showed better growth at Onne than at Ibadan, although differences in growth parameters were not significantly different between the two site. Fruiting (between June and July) was also more profuse at Onne. Plant canopy was very low and dense at both locations, especially at Onne, thus providing favourable microclimatic conditions for earthworm casting activities. At 12 years of age variety *gabonensis* produced 1064 fruits per tree at Onne (Table 2). This variety produced less fruit than variety *excelsa* grown at the same location. This relationship was also observed at Ibadan,where 360 and 640 fruits per tree were produced for variety *gabonensis* and *excelsa* respectively.

Leucaena leucocephala (variety K28) performance was significantly better at Ibadan than at Onne. Except for bole height, other growth parameters measured at Ibadan were double or more than those at Onne. While the plants showed vigorous growth at Ibadan, an open canopy and poor growth were observed at Onne.

Pterocarpus soyauxii also showed more vigorous growth and better canopy closure in Ibadan than at Onne. All the growth parameters measured, including crown volume, were lower at Onne.

Table 1. Growth performance of selected woody species grown on an Alfisol (at Ibadan) and an Ultisol (at Onne) measured in 1989 and litterfall in Ibadan only

Woody species	Plant ht. (m)		Bole ht. (m)		DBH (cm)		Stump diam. (cm)		Total wood vol (m^3)		Litterfall (t ha^{-1})
	Ibadan	Onne	Ibadan	Onne	Ibadan	Onne	Ibadan	Onne	Ibadan	Onne	*Ibadan
Cordia alliodora	22.5	21.8	14.9	15.9	19.9	19.1	23.3	22.3	3.93	3.36	9.57
Dialium guineense	8.4	17.4	3.8	11.4	9.1	9.1	11.7	21.2	0.73	2.84	n.a
Gmelina arborea	19.5	27.1	9.8	16.9	26.3	28.9	31.9	37.1	3.91	4.82	5.50
Irvingia gabonensis	8.3	12.2	3.8	6.8	12.4	16.6	15.4	18.7	0.89	1.45	6.03
Leucaena leucocephala	20.4	11.7	7.1	6.5	23.8	9.9	28.2	11.5	2.06	0.90	4.64
Pterocarpus soyauxii	18.1	9.2	9.0	5.9	20.4	13.7	27.0	17.7	2.99	1.20	7.42
Treculia africana	15.5	24.2	9.2	14.1	18.6	21.7	27.9	39.0	2.65	4.63	8.84
LSD (0.05)											
For same species	4.0		2.9		6.1		7.0		0.99		
For different species at same location	4.1		3.4		6.5		8.0		0.99		2.98

*During dry season (November-January)
n.a.: not available

Table 2. Two-year mean productivity of *Irvingia gabonensis* varieties *gabonensis* and *excelsa* at Ibadan and Onne

Variety	Mean number of fruit tree^{-1}		Mean fresh wt. of fruit (g)	
	Onne	Ibadan	Onne	Ibadan
I. gabonensis var. *gabonensis*	1064	360	180.8	61.2
I. gabonensis var. *excelsa*	1180	640	138.2	74.9

Treculia africana showed significantly better growth at Onne than at Ibadan for all the parameters measured. Plant height reached 24.2 m at Onne while it was 15.5 m at Ibadan. *Treculia* also had the largest stem diameter (39.0 cm). Plant height, bole height, stump diameter and wood volume were all significantly higher at Onne than at Ibadan.

Effect on soil properties

The effect of woody species on soil properties (Tables 3 - 5) indicates that soil bulk density values are higher than expected, which may be the result of regular mechanical mowing of the undergrowth. There were varying effects of woody species on soil bulk densities at both locations (Table 3). On the Alfisol site, bulk densities under woody species were lower than in the control treatment. On the Ultisol site, lower soil bulk densities than the control were only observed under *Cordia*, *Irvingia* and *Treculia*. High soil bulk densities were observed on both soils under *Dialium*, *Gmelina*, and *Pterocarpus*. *Treculia* showed low bulk densities at both locations. Under *Leucaena*, soil bulk density was low on the Alfisol and high on the Ultisol. In contrast, under *Cordia*, lower soil bulk density was observed on the Ultisol than on the Alfisol.

Table 3. Surface soil bulk density (g cm^{-3}) under selected woody species grown on an Alfisol (at Ibadan) and an Ultisol (at Onne)

Woody species	Alfisol	Ultisol
Cordia alliodora	1.33	1.18
Dialium guineense	1.42	1.49
Gmelina arborea	1.42	1.41
Irvingia gabonensis	1.22	1.27
Leucaena leucocephala	1.13	1.52
Pterocarpus soyauxii	1.39	1.36
Treculia africana	1.22	1.26
Control	1.47	1.36
LSD (0.05)	0.23	

The effects of woody species on the chemical properties of the Alfisol (Table 4) are indicated by the higher pH, organic carbon, exchangeable K and Mg observed under them than in the control treatment. There was, however, no consistent effect on soil exchangeable Ca. A higher P level was observed in the control treatment than under the various woody species.

Table 4. Effect of woody species on some chemical properties of surface soil (0 - 15 cm) of an Alfisol at Ibadan, 1989

Woody species	pH-H_2O	Org. C (%)	1 N am. acetate exchangeable (meq 100 g^{-1})			Extr. Bray P-1 (µg g-1)
			K	Ca	Mg	
Cordia alliodora	6.6	1.32	0.41	3.88	1.09	3.5
Dialium guineense	6.4	0.84	0.23	4.64	0.83	2.5
Gmelina arborea	6.4	1.20	0.27	4.23	1.00	2.2
Irvingia gabonensis	5.8	1.06	0.19	2.81	0.74	3.3
Leucaena leucocephala	6.2	1.48	0.27	2.52	0.69	3.8
Pterocarpus soyauxii	6.2	0.68	0.10	2.72	0.54	4.6
Treculia africana	6.1	0.96	0.28	2.14	0.54	2.1
Contol	5.6	0.66	0.10	3.13	0.50	7.1

*Under grass

On the Ultisol site, higher pH, organic carbon, and extractable P levels were observed under the woody species (Table 5) than in the control treatment. The high level of soil extractable P of the Ultisol at Onne is attributable to its marine origin. There was no consistent effect of woody species on the soil exchangeable cation levels.

Table 5. Effect of woody species on some chemical properties of surface soil (0-15 cm) of an Ultisol at Onne, 1989

Woody species	pH-H_20	Org.C (%)	1 N am. acetate exchangeable (meq 100 g^{-1})			Extr. Bray P-1 (µg g^{-1})
			K	Ca	Mg	
Cordia alliodora	4.6	1.20	0.06	0.57	0.16	75.6
Dialium guineense	4.5	1.20	0.07	0.76	0.26	54.4
Gmelina arborea	4.4	1.15	0.06	0.56	0.12	84.7
Irvingia gabonensis	4.5	1.22	0.10	0.74	0.18	87.7
Leucaena leucocephala	4.5	1.14	0.08	0.72	0.07	53.2
Pterocarpus soyauxii	4.5	1.16	0.09	0.45	0.20	66.5
Treculia africana	4.4	1.20	0.09	0.83	0.38	58.4
Control*	4.0	1.02	0.07	0.62	0.11	48.1

*under grass

Discussion and conclusions

Data presented (Table 1) clearly show some site specificity of the species studied and this agrees with the findings of MacDicken and Brewbaker (1988). The performance of *Cordia* and *Gmelina* was not significantly affected by the site characteristics. *Leucaena* and *Pterocarpus,* however, performed better on the Alfisol site. The poorer growth of *Leucaena* on the acid soil is well documented (Brewbaker *et al.* 1985). *Dialium, Irvingia,* and *Treculia,* on the other hand, performed better on the poorer Ultisol site at Onne. This may be related to the higher rainfall and shorter dry season at Onne, and to the inherent adaptation of the species to this acid site.

The effect of woody species on physical and chemical soil properties appeared to be more pronounced on the Alfisol than on the low fertility and acidic Ultisol (Tables 3-5). On the Alfisol site, *Cordia* and *Gmelina* showed the best effect on soil chemcial properties and *Pterocarpus* showed the least effect. No distinct differential effect between the woody species on the soil chemical characteristics was observed on the Ultisol site. The lower extractable P level under the woody species at Ibadan may be the result of P uptake by the trees. It should, however, be noted that some of the P is held in the organic form which is not extracted with the Bray P-1 extractant.

Among the woody species, *Cordia, Gmelina, Pterocarpus* and *Treculia* showed a high amount of plant litterfall during the dry months (Table 1). This plant litter may have contributed to the improvement of the chemical soil properties under *Cordia* and *Gmelina.* However, this effect was less obvious under *Pterocarpus* and no explanation can be given. Despite the mulching effect from the plant litter, no explanation can also be given for the high soil bulk densities observed under *Gmelina* and *Pterocarpus.*

The fruit productivity of *Irvingia* differs among varieties, but the site effect was more obvious. Longer rain periods and the higher amount of rainfall at Onne could account for this; however, adaptation to acid soils cannot be overemphasized. There is a need for more accurate data on the productivity of native fruit trees to better assess their potential for commercial production. Ezike (1987) suggested that *Irvingia* fruit productivity can be substantially affected by the height of the trees, but field observation at the two sites does not support this. The intensity of branching appears to be the major factor for the fruit productivity of this species.

Considering the habits and performances of the seven woody species at both sites, the following recommendations can be made on their potential for use in agroforestry:

1. Although both *Cordia* and *Gmelina* performed equally well at both locations, *Cordia* because of its straight stem, low degree of branching, and smaller and less dense canopy, is a more suitable species for use in mixed agroforestry systems.
2. Both *Leucaena* and *Pterocarpus* are more suitable for use in agroforestry systems on the less acid soils, while *Dialium, Irvingia,* and *Treculia* are more

suitable for the high rainfall areas dominated by Ultisols. Because of their habits, *Irvingia* and *Treculia* are very suitable for use in multistorey compound farming, already practised by traditional farmers in West Africa. The need to provide farmers with genetically improved stocks cannot be over emphasized, however. The future inclusion of *Pterocarpus*, *Irvingia* and *Treculia* in MWS screening for agroforestry systems should be a logical outcome of the present study.

References

BREWBAKER, J.L., MACDICKEN, K. & WITHINGTON, D. (Eds.). 1985. *Leucaena Forage Production and Use.* Nitrogen Fixing Trees Association, Waimanalo, Hawaii.

CHALLINOR, D. 1968. Alterations of surface soil characteristics by four tree species. *Ecology* 49: 286 - 290.

CHIJIOKE, E. O. 1980. *Impact on Soil of Fast-growing species in Lowland Humid Tropics.* FAO Forestry Paper No. 21. FAO, Rome.

EZIKE, S.I.C. 1987. Assessment of fruit yield of *Irvingia gabonensis* in Anambra State, Nigeria. B.Sc. project report, University of Ibadan, Ibadan, Nigeria.

HAMILTON, C.D. 1965. Changes in soil under *Pinus radiata. Australian Forestry Journal* 29 : 275 - 89.

HUXLEY, P.A. (Ed.). 1983. *Methodology for Exploration and Assessment of Multipurpose Trees.* International Centre for Research in Agroforestry, Nairobi, Kenya.

JACKSON, J. K. & OJO, G.A. 1973. *Provenance Trials of Eucalyptus camaldulensis in the Savanah Region of Nigeria.* Forestry Research Station Series, No. 14. Samaru, Nigeria.

JUO, A.S.R. 1981. *Selected Methods for Soil and Plant Analysis.* IITA Manual Series No. 1. International Institute of Tropical Agriculture, Ibadan, Nigeria.

KANG, B.T., REYNOLDS, L. & ATTA-KRAH, A.N. 1990. Alley farming. *Advances in Agronomy* 43 : 315 - 359.

KANG, B.T. & WILSON, G. F. 1987. Development of alley cropping as a promising technology. Pp. 227 - 243 in Steppler, H.A. & Nair, P.K.R. (Eds.) *Agroforestry : A Decade of Development.* International Centre for Research in Agroforestry, Nairobi, Kenya.

KING, K.F.S. 1968. *Agrisilviculture (the Taungya Systems).* Bulletin No. 1. Department of Forestry, University of Ibadan, Nigeria.

LADIPO, D. O. & LEAKEY, R. R.B. 1986. *Progeny and Clone Site Interaction in Triplochiton scleroxylon. K. Schum.* Research Paper No. 61. Forestry Research Institute of Nigeria, Ibadan, Nigeria.

LUNDGREN, B. 1977. *Soil Conditions and Nutrient Cycling Under Natural and Plantation Forests in Tanzanian Highlands.* Reports Forestry Ecological and Soils, Vol. 31. Department of Forest Soils, Swedish University of Agriculture Science, Uppsala, Sweden.

LOETSCH, F., ZOREH, K. & E. HALLER 1973. *Forest Inventory, Vol. 1.* BLV Publishers, Germany. 436 pp.

MACDICKEN, K.G. & BREWBAKER, J.L. 1988. Growth rates of five tropical leguminous fuelwood species. *Journal of Tropical Forest Science* 1 (1): 85-93.

MAIMO, A.M. 1987. A study of forest management options for teak production in Gambari Forest Reserve, Nigeria. M.Sc thesis, Department of Forestry, University of Ibadan, Ibadan, Nigeria.

MOORMAN, F.R., LAL, R. & JUO, A.S.R. 1975. *The Soils of IITA.* International Institute of Tropical Agriculture, Ibadan, Nigeria.

OKAFOR, J. C. 1982. Promising trees for agroforestry in southern Nigeria. Pp. 103 - 107 in McDonald, L. H. (Ed.) *Agroforestry in the African Humid Tropics.* The United Nations University, Shibuyaku, Japan.

OKAFOR, J. C. 1983. Horticulturally promising indigenous wild plant species of Nigerian Forest Zone. *Acta Horticultura* 123 : 165 - 176.

OKAFOR, J.C. 1990. Development and selection of commercially viable cultivars from forest species for fruit. *Proceedings Twelfth Plenary Meeting of AETFAT, Mitt. Inst. Allg. Bot. Hamburg, Germany.* Symposium I: S 81-97.

SAS 1985. *SAS User's Guide.* Statistical Analysis System Institute, Cary, North Carolina, USA.

VAN DER HEIDE, J., VAN DER KRUIJS, A.C.B.M., KANG, B.T. & VLEK, P.L.G. 1985. Nitrogen management in multiple cropping systems. Pp. 269 - 284 in Kang, B.T. & Van der Heide, J. (Eds.) *Nitrogen Management in Farming Systems in Humid and Subhumid Tropics.* Institute of Soil Fertility, Haren, Netherlands.