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Research Article

Growth and Nutrient Use Efficiencies of Yams (*Dioscorea* spp.) Grown in Two Contrasting Soils of West Africa

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Fertilization is an important management strategy of yams (*Dioscorea* spp.) especially when grown in degraded soils. A field study evaluated the leaf numbers, leaf area indices, crop growth, yields, and nitrogen (N) and potassium (K) use efficiencies of *D. alata* and *D. rotundata* in Côte d'Ivoire when grown in two contrasting soils with and without fertilizer. *D. alata* had a lower number of leaves per vine, although leaf area indices were higher, and the leaves were retained for a longer period than in *D. rotundata*. In all situations, the yields of *D. alata* were significantly higher, and fertilizers promoted growth of shoots, roots, tubers, and, thus, final yields especially in the low fertile savanna soil. The beneficial impact of fertilizer on yields was significantly lower in the fertile forest soils. The nutrient use agronomic efficiencies indicated the impact of both N and K in promoting yields especially under nonfertilized conditions.

1. Introduction

Yams (*Dioscorea*) are a vital component of the agricultural sector of West Africa, both in terms of food, social, and cultural values [1]. In these regions, *D. alata* and *D. rotundata* are cultivated in a range of soils, from degraded smallholdings through low fertile savannas to newly cleared forest sites, which have a high degree of fertility. Most farmers of the region cultivate yams in smallholdings under low-fertility conditions, except in some instances where short fallows are incorporated into the cropping systems to rejuvenate the soil fertility [2]. Thus, despite increases in land areas being cultivated in West Africa, yam production has remained static [3], indicating a gradual decline in yields per unit land area. Crop management plays an important role in procuring high yields in tropical tuber crops [4]. A major constraint for enhancing yam productivity is low soil fertility, both in terms of macro- and micronutrient deficiency [5]. This is because yams are high-nutrient-demanding species [6], and when planted in low-fertility soils under subsistence conditions as done in smallholder systems of West Africa, yields are low, varying between 9 and 10 $t\,ha^{-1}$ compared with a potential yield of 51 $t\,ha^{-1}$ for *D. alata* and 27 for $t\,ha^{-1}$ *D. rotundata* [7]. Hence, research on possible methods to enhance yam productivity is needed to produce this culturally important and economically viable species especially under conditions of West Africa.

Research on the impact of fertilizers on *Dioscorea* yams is scarce. Some studies show the lack of yield response of *Dioscorea* to applied phosphorus [8], and to both nitrogen and phosphorus [9]. Diby et al. [10] reported the positive yield response of *Dioscorea* to fertilizers under field conditions. Furthermore, [11] attributed the low yam yield in infertile soils by a decrease in leaf area index for *D. alata* and by a decrease in radiation use efficiency for *D. rotundata*. However, the impact of fertilizers on the growth and yields of the two most common species of yams cultivated in West Africa, namely, *D. alata* and *D. rotundata* are not reported definitely under field conditions. Furthermore, even if fertilizers are added, the nutrient use efficiencies, especially in relation to nitrogen and potassium, the two macronutrients that would support and promote the growth of vines and tubers of *Dioscorea*, is not reported under conditions of West Africa. Thus, a field experiment was carried out in soils having contrasting levels of fertility to determine the impact of added fertilizers on the growth and yields of both *D. alata* and *D. rotundata*, and more importantly to determine the nitrogen and potassium contents of the plants and tubers to identify nutrient use efficiencies of the added nutrients in relation to tuber yields as chemical fertilizers are a very expensive commodity for the smallholder farmers of this important crop under conditions of West Africa.

2. Materials and Methods

2.1. Location and Climate. The study was conducted from May to December 2002 at the Field Research Station of the Swiss Center for Scientific Research, Cote d'Ivoire (CSRS). The two sites representing a fertile soil (Forest—6°40′ N, 5°09° W, 165 m asl) and a infertile savanna (6°40′ N, 5°08 W, 150 m asl) were situated 5 km apart in close proximity to the research station. The climates of the two sites were similar, and the rainfall received over the experimental period at the forest and savanna sites were 679 and 736 mm, from May and December. The mean temperature of the forest and the savanna sites over the growing season was 25.1°C and 25.4°C, respectively, with no significant variation between sites or months. The relative humidity values of the forest and savanna sites were 78.0% and 77.8%, respectively. The total radiation over the growing season was 2886 and 2880 $MJ\cdot m^{-1}$ in the forest and the savanna, respectively. Thus, the climates of the two sites were considered similar.

2.2. Site Preparation and Experimental Layout. In the middle of the rain season in May, two large blocks of dimensions 100 m × 100 m were prepared at the two sites, by cutting and removing the vegetation, without burning. Within each cleared unit, a block of dimensions 24 m × 28 m were prepared, and four subunits each measuring 17 m × 11 m were laid out within this block, for the four replicates of a randomized block design, which had four treatments (2 species × 2 fertilizer levels). The individual treatments were laid out on plots (6 m × 5 m) separated by a 1 m alley on all sides to overcome border effects within the replications.

2.3. Treatments. The two species selected were *D. alata* (TDa 95/00010) and *D. rotundata* (89/02461) and the two fertilizer regimes were zero as per farmer practice or a level of fertilizer calculated as per the requirement to produce 60 t fresh tubers ha^{-1} [12]. This level of fertilizer was as follows: 240 $Kg\cdot ha^{-1}$ of N, 269 $Kg\cdot ha^{-1}$ of K, 11 $Kg\cdot ha^{-1}$ of P, 8.5 Kg ha^{-1} of Ca, 11 $Kg\cdot ha^{-1}$ of Mg and 66 $kg\cdot ha^{-1}$ of S.

2.4. Crop Establishment and Management. Soon after land preparation, uniform setts of the two species were soaked in a solution containing 31.2 g oxamyl L^{-1}, 1 g Imazalil sulphate L^{-1}, and 0.34 g deltamethrine L^{-1} to protect against nematodes, fungi, and insects and air dried for 24 hours, as recommended by [13]. These were planted into mounds raised to a level of 20 cm and spaced at 2 mounds m^{-2}, at a rate of 1 set per mound in the preselected plots which had been ploughed to the depth of 20 cm. Soon after planting, each mound was mulched with a tuft of dried weeds removed from the plots during site preparation. The tuft was big enough to prevent sett desiccation and preserve soil moisture.

The fertilizer was prepared using urea, potassium sulphate, triple super phosphate, dolomite calcium, and magnesium sulfate, and 50% of the predetermined level was applied at 60 days after planting (DAP) and the balance at 100 DAP. The application was carried out using the sideband method [14], where the fertilizer was mixed with soil and applied manually in 3-4 cm grooves on the four sides of the mound, taking care to prevent any damage to the root systems.

Weeding was carried out when required, and no supplementary irrigation was provided.

2.5. Measurements. Before creating mounting soil, a soil core was taken from each plot to a depth of 20 cm from the savanna and forest sites, respectively, giving a total of 16 soil samples per site. Plant residues in the soil samples were removed, and the samples were ground to pass through a 2 mm sieve. These were analyzed for physical and chemical parameters using standard techniques [15].

In all treatments, germination was determined up to 50 days after planting. Leaf numbers per plant of both species were determined at periodic intervals until harvest or total leaf senescence. The leaf area per plant was measured by scanning a random sample of 30 leaves, and the area determined by the program *WinRHIZO regular version*, and calculating the area of all leaves. This data was used to determine the leaf area index (LAI).

Destructive sampling was carried out at the following growth stages—shoot emergence of more than 95% of the plants (57 DAP), tuber initiation (78 DAP), maximum growth of the above-ground organs (107 DAP), rapid growth of the tubers (136 DAP for *D. alata* and 107 DAP for *D. rotundata*), tuber maturity (160 DAP), and harvest (195 DAP for *D. rotundata* and 220 DAP for *D. alata*). On each sampling date, three adjacent plants per plot were harvested, except for the final harvest where six plants were harvested. At all four samplings, the plant parts were dried at 70°C to a constant weight and weighed. This data was used to calculate dry matter accumulation rates of shoots and roots and the bulking rates of the tubers using regression equations. Furthermore, the Nitrogen (N) and Potassium (K) contents of plant parts were also analyzed using subsamples obtained from *D. alata* and *D. rotundata* at the final harvest. The nitrogen concentrations in plant parts were measured with a carbon nitrogen analyzer, while K concentrations were measured with an ICP-OES after incinerating the organ to be analyzed at 550°C for 6 hours and solubilising the ashes in concentrated HNO_3. At the final harvest, fresh weights of tubers (moisture content 75–79%; economical yield) were also determined.

2.6. Data Analysis. The data was subjected to appropriate statistical analysis to determine treatment differences. Each species was first analyzed separately, and, thereafter, interactions between species and the treatments were studied using a GLM procedure of SAS version 8.2, and treatment differences were identified using SE mean and LSD values. Regression and correlation analysis was carried out to determine the relationships between nutrient contents and yields while nutrient use efficiency was determined based on the equation

$$\begin{aligned} &\text{Nitrogen or K use efficiency (NUE) \%} \\ &\quad = \text{ratio between tuber yield and total } N \text{ or } K \\ &\qquad \text{uptake by the plant at harvest } \times 100, \end{aligned} \tag{1}$$

based on the method of [16] for cassava.

The agronomic efficiency was calculated as follows:

$$\begin{aligned} &\text{Agronomic efficiency} \\ &\quad = g \text{ of tuber dry weight}/g \text{ of tuber nutrient.} \end{aligned} \tag{2}$$

3. Results and Discussion

3.1. Soil Fertility. The forest (fertile) soil had higher clay content than the savanna (infertile) soil (Table 1). The greater clay content contributed to the 85% increment in the CEC of the forest soils when compared to that of the savanna together with the greater (91%) increase soil organic carbon in the forest soil (Table 1). The forest soil had significantly higher concentrations of all measured nutrients except bicarbonate extractable P (Table 1). Phosphorus was not considered to be limiting as these species have low requirements in P (less than 10 kg P ha^{-1}) [17]. In all other measured nutrients, the magnitude of increase was generally over 50%, which again could be attributed to the greater soil C content of the forest soil. The soil pH was also greater in the forest soil. The data clearly presented the greater fertility of the forest soils.

3.2. Germination, Leaf Numbers, and Leaf Area Indices. Germination of both species was not affected by soil type, and over 90% germination was achieved within 45–50 days, indicating that dormancy had been overcome and also the presence of adequate soil moisture with the rains received at planting.

Dioscorea rotundata had a greater number of leaves per plant than *D. alata* (Figure 1), especially in the forest soils and with fertilizers, whereas in the absence of fertilizers in the savanna, *D. alata* had a greater number of leaves per plant than *D. rotundata*. *Dioscorea alata* had green functional leaves even at the time of harvest while *D. rotundata* had shed all its leaves at harvest. This indicated that the photosynthetic apparatus of *D. alata* was functional for a longer period than in *D. rotundata*, which would, thus, influence yields.

In contrast to number of leaves (Figure 1), leaf area indices (LAI) of *D. alata* were higher than in *D. rotundata* (Figure 2), which implied that the former had a smaller number of larger leaves when compared to a greater number of small leaves in *D. rotundata*. This also gives an advantage for the capture of radiation energy by *D. alata* when compared to *D. rotundata*, which could affect tuber yields. Furthermore, the LAI of *D. alata* was significantly higher at 107 days after planting (DAP) (Figure 2) which is just after the rapid tuber development phase. This could have a significant beneficial impact on tuber yields due to greater interception of radiation. In the savanna soils, the LAI of *D. alata* was highest at 136 DAP and was also lower than in the forest soil, which also could have an impact on yields. In *D. rotundata*, the highest LAI was at 107 DAP, but the value was significantly lower than in *D. alata*, which could also be a factor for its lower yields as confirmed by the positive correlation between the maximum LAI and the fresh tuber yield (Figure 3).

The addition of fertilizers increased leaf number per plant (Figure 1) and leaf area index (Figure 2) of both species when grown in the savanna soil.

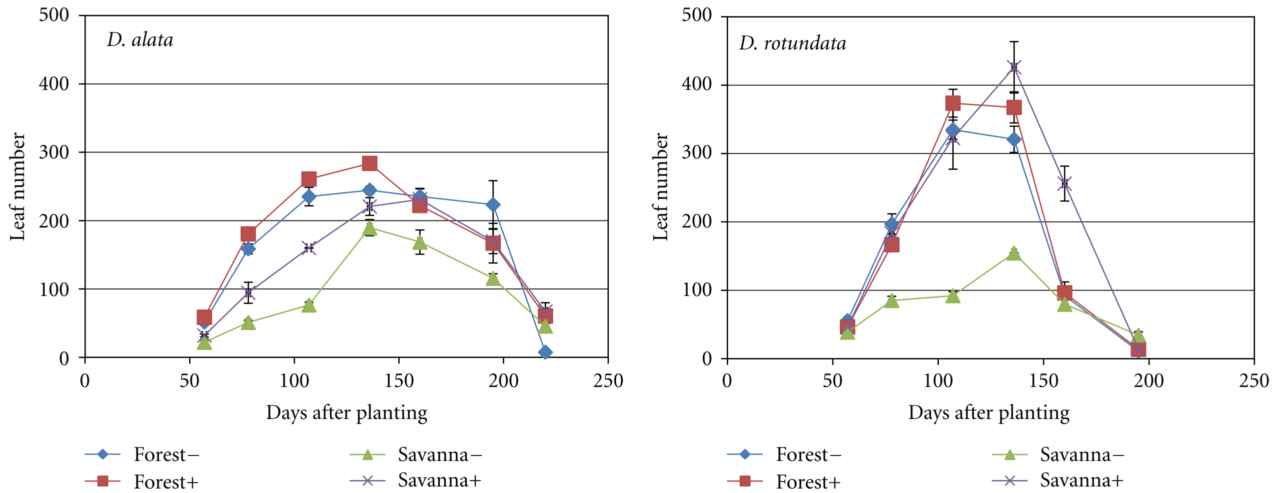
3.3. Growth Analysis. Dry matter accumulation of both *Dioscorea* species were similar when planted in the forest soil, even without added fertilizers (Table 2). However, the rates of dry matter accumulation of the shoots were lower in *D. rotundata*. This could be considered a species characteristic of *D. rotundata*, when compared to that of *D. alata*. In contrast, fertilizers increased shoot growth of both species in the savanna soil, and the impact was significantly greater in *D. rotundata*.

In contrast to shoot growth rate, root growth rates of both species were lowered by fertilizer in the forest soils (Table 2). This suggests that with adequate fertilization, the plants tend to partition a lower quantum of dry matter to roots as the roots need not scavenge for nutrients. Even in the savanna soil, application of fertilizers had no significant impact on root growth rate of *D. alata*, while that of *D. rotundata* was reduced. However, root growth rates in the forest and savanna soil in both species illustrate the higher root biomass accumulation in the soil with lower fertility. Furthermore, the root growth rates of *D. rotundata* were greater in the savanna soil, when compared to that of *D. alata*.

In both soils, *D. alata* maintained higher rates of tuber growth (Table 2) irrespective of fertilizers, and this could be considered a species characteristic. However, in the forest soil, tuber development of *D. alata* was not promoted by the application of fertilizers (Table 2), as these soils were high in nutrients, especially N and K. In contrast, the tuber growth of *D. rotundata* was enhanced by fertilizer application unlike shoot and root growth. In the savanna, tuber growth was reduced in both species due to the lower fertility level of soils, and again the rates were lower in *D. rotundata*. Application of fertilizers promoted tuber growth rates of both species, and a greater response was observed in *D. rotundata*, which indicated the greater response of this species to added nutrients under low soil fertility conditions.

Table 1: Mean values ± standard errors of selected soil parameters (0–20 cm) of the forest and savanna sites.

Soil properties	Forest site 0–20 cm	Savanna site 0–20 cm
Coarse sand (g kg^{-1} soil)	380 ± 9	472 ± 6
Fine sand (g kg^{-1} soil)	283 ± 6	297 ± 10
Coarse silt (g kg^{-1} soil)	77 ± 3	78 ± 4
Fine silt (g kg^{-1} soil)	46 ± 5	34 ± 2
Clay (g kg^{-1} soil)	205 ± 13	108 ± 7
pH water	6.35 ± 0.12	6.00 ± 0.13
Total N content (g kg^{-1} soil)	1.05 ± 0.08	0.46 ± 0.04
Soil organic C content (g kg^{-1} soil)	12.08 ± 0.92	6.46 ± 0.50
Bicarbonate extractable P (mg kg^{-1} soil)	13.4 ±0.87	9.4 ± 0.72
Exchangeable K (cmol+ kg^{-1} soil)	0.17 ± 0.03	0.11 ± 0.02
Cation exchange capacity (cmol+ kg^{-1})	5.7 ± 0.4	2.4 ± 0.31



(a) (b)

Figure 1: Leaf number of *Dioscorea* spp. grown in a forest and savanna sites with (+) and without (−) fertilizer application. Error bars represent standard error of means.

3.4. Tuber Yields. The impact of observed differences in growth rates are best highlighted by fresh tuber yields (75–79% moisture) (Table 3). The higher yielding ability of *D. alata* is clearly expressed in this study irrespective of soil fertility conditions, and the overall mean increment in tuber yield over that of *D. rotundata* was some 140%, which correlated well with the greater tuber growth rates of *D. alata* (Table 2). This data also correlates well with the leaf area indices (Figure 2), where *D. alata* had greater values for a longer period of time which would enable it capture radiation more efficiently for a greater duration than *D. rotundata*. This is similar to studies by [18], where potato biomass yield is proportional to the capture of radiation energy.

In the forest soil, a significant difference was observed between the two species (Table 3). The mean difference in yields between the two species was 125%, which increased to 142% in the savanna soil, with *D. alata* producing greater tuber yields at both sites. When comparing the two sites, the drop in mean yields of *D. alata* was 97% between the forest and savanna soils, while the reduction in *D. rotundata* was 130%. This indicated that the yielding ability of *D. alata* is maintained even in the low fertility site.

In the forest soil, the response of both species to added fertilizers was not significant, although the response of *D. alata* was greater (25% significant ($P = 0.05$)) when compared to that of *D. rotundata* (15%). This again highlights the greater yield potential of *D. alata* and its response to improved management.

Although no fertilizer effect was observed in the savanna soil, the response of both species to added fertilizer is significantly greater than that observed in the forest soil. The increments were 71% and 38% in *D. alata* and *D. rotundata* respectively. The lower biomass of *D. rotundata*, thus, seem to show a greater response to added fertilizer during shoot growth, which is not reflected in a greater response in overall tuber yields. The harvest indexes (HI) of these two species (Table 3) reflect significant changes with species and added fertilizers in the forest site, while significant changes were observed only between species in the savanna site. The higher

TABLE 2: Shoot, root, and tuber growth of *Dioscorea* spp. as affected by soil type and fertilizers (x: days after planting; y: dry matter in the considered organ; n : 28 for *D. alata*, and n : 24 for *D. rotundata*).

Soil type	Species	Fertilizer	Growth equations (based on dry weights)	
A shoot growth				
Forest	*D. alata*	None	$y = -0.3029x^2 + 2.3296x - 1.4887$	$r = 0.96$[a]
		Full rate	$y = -0.3032x^2 + 2.2935x - 1.1945$	$r = 0.82$
	D. rotundata	None	$y = -0.236x^2 + 1.6141x - 1.1447$	$r = 0.76$
		Full rate	$y = -0.2635x^2 + 1.858x - 1.4943$	$r = 0.82$
Savanna	*D. alata*	None	$y = -0.1021x^2 + 0.9137x - 0.7546$	$r = 0.58$
		Full rate	$y = -0.1415x^2 + 1.2386x - 1.0234$	$r = 0.70$
	D. rotundata	None	$y = -0.0916x^2 + 0.6708x - 0.431$	$r = 0.70$
		Full rate	$y = -0.2178x^2 + 1.5229x - 1.0748$	$r = 0.76$
B root growth				
Forest	*D. alata*	None	$y = -0.0043x^2 + 0.0295x + 0.0219$	$r = 0.63$
		Full rate	$y = -0.0027x^2 + 0.0158x + 0.0356$	$r^2 = 0.67$
	D. rotundata	None	$y = -0.0022x^2 + 0.0075x + 0.0423$	$r = 0.67$
		Full rate	$y = -0.0006x^2 - 0.0095x + 0.0557$	$r = 0.75$
Savanna	*D. alata*	None	$y = -0.0036x^2 + 0.0276x + 0.0024$	$r = 0.58$
		Full rate	$y = -0.0035x^2 + 0.0335x - 0.0096$	$r = 0.45$
	D. rotundata	None	$y = -0.0074x^2 + 0.0486x + 0.0048$	$r = 0.48$
		Full rate	$y = -0.0042x^2 + 0.0261x + 0.0139$	$r = 0.54$
C tuber growth				
Forest	*D. alata*	None	$y = 2.9059\text{Ln}(x) - 1.2839$	$r = 0.83$
		Full rate	$y = 2.8351\text{Ln}(x) - 1.3516$	$r = 0.79$
	D. rotundata	None	$y = 1.9668\text{Ln}(x) - 0.5224$	$r = 0.88$
		Full rate	$y = 2.1574\text{Ln}(x) - 0.6713$	$r = 0.88$
Savanna	*D. alata*	None	$y = 1.9881\text{Ln}(x) - 0.9843$	$r = 0.68$
		Full rate	$y = 2.5169\text{Ln}(x) - 1.3072$	$r = 0.71$
	D. rotundata	None	$y = 1.0306\text{Ln}(x) - 0.3848$	$r = 0.81$
		Full rate	$y = 1.4817\text{Ln}(x) - 0.4591$	$r = 0.78$

[a] Correlation coefficients based on raw data.

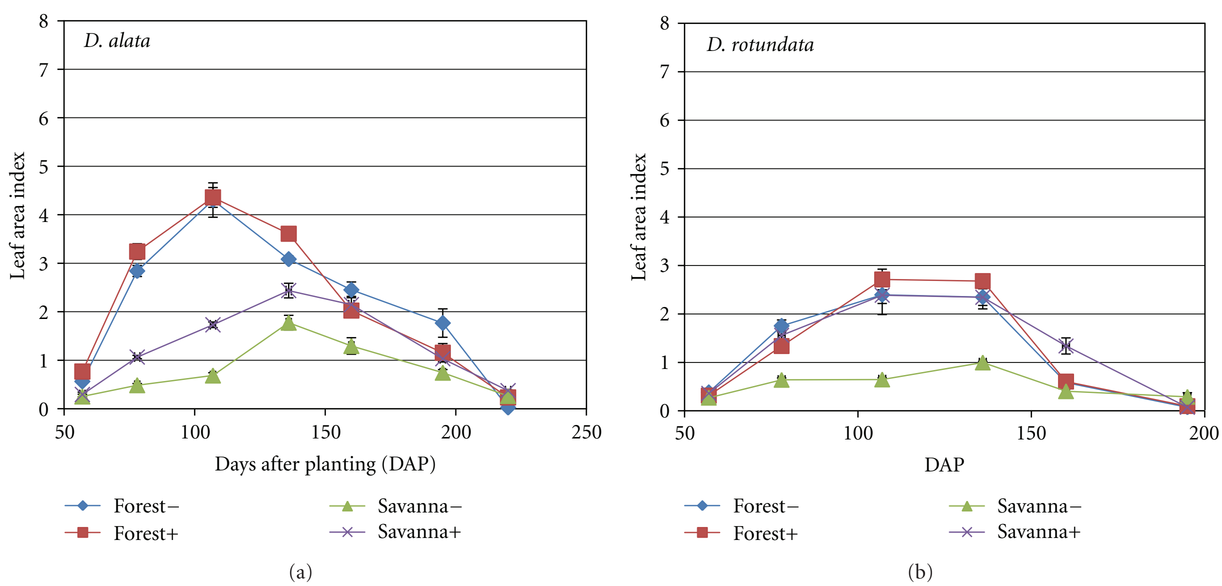


FIGURE 2: Leaf area index of *Dioscorea* spp. grown in a forest and savanna sites with (+) and without (−) fertilizer application. Error bars represent standard error of means.

Table 3: Impact of soil type and fertilizers on tuber yields and harvest index (HI) of *Dioscorea* spp.

Soil type	Species	Fertilizer	Yield (t fresh matter/ha)	Harvest indices
Forest	*D. alata*	None	28	0.96
		Full rate	35 (25%)**	0.93
	D. rotundata	None	13	0.99
		Full rate	15 (15%)**	0.96
			P values	
	Species		< 0.0001	0.0399
	Fertilizer		0.1764	0.0263
	Species × fertilizer		0.4376	0.8682
Savanna	*D. alata*	None	17	0.88
		Full rate	29 (71%)**	0.90
	D. rotundata	None	8	0.93
		Full rate	11 (38%)**	0.97
			P values	
	Species		0.0037	0.0135
	Fertilizer		0.0981	0.1598
	Species × fertilizer		0.2458	0.6461
SE mean ($n = 32$)			3.5	0.17

** Numbers in parenthesis indicate the increase/reduction in tuber yield in relation to the nonfertilized plots.

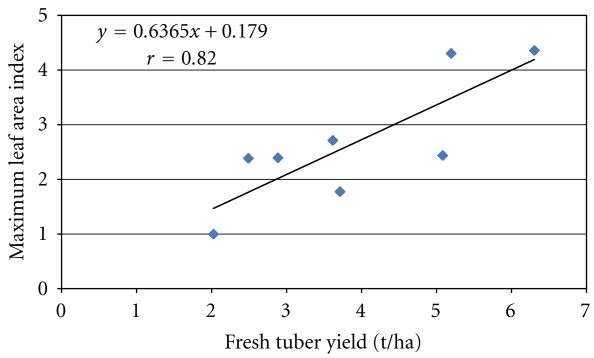


Figure 3: Relationships between the maximum leaf area index and the fresh tuber yield over the growing season of *Dioscorea alata* and *D. rotundata* grown with and without fertilizer application in a forest (fertile) and a savanna (infertile) sites in Central Cote d'Ivoire in 2002.

HI values of *D. rotundata* compared to *D. alata* are due to the senescence of the above ground organs (leaf and vine) of the former species at harvest. In the forest site, the lower HI in fertilized treatments suggests that the addition of fertilizers delayed the senescence.

3.5. Nutrient Use and Agronomic Efficiencies. In the forest soil, N use efficiency was higher in *D. alata* (Table 4), the higher yielding species, which also retained its vegetative growth, both in terms of leaf numbers and duration while *D. rotundata* shed over 95% of its leaf at harvest (Figure 1). In contrast, the K use efficiency of *D. rotundata* was higher than that of *D. alata* although the yields were lower. This suggests that the lower yielding species has a greater utilization capacity of this nutrient which is important for translocating photosynthates, when compared to that of *D. alata*.

In both species, N use efficiency was lower in the savanna soil (Table 4), which could be due to the lower N content of this soil and its inability to retain applied N, due to lower soil organic matter. The K use efficiencies of both species were increased in the savanna soil, which in contrast to that recorded in the fertile forest soil, and could be considered a result of the impact of K in overcoming abiotic stress in plants. However, what was unexpected was the significant increase in K use efficiency of *D. rotundata* in the savanna soil when compared to that of *D. alata*. This again could be a feature of the ability of this species to efficiently utilize K in overcoming stress although the benefits are not evident in terms of greater yields.

Application of fertilizers reduced *N* and *K* use efficiencies in both species (Table 4), thus, indicating that these species use *N* and *K* more efficiently when they are not readily available in the form of fertilizers. Furthermore, the reduction in nutrient use efficiencies of N due to added fertilizers was lower in *D. rotundata*, which suggested its greater ability to use added fertilizers efficiently than *D. alata*. In contrast, the reduction on K use efficiency with added fertilizer was lower in *D. alata*, which indicated a greater response to this nutrient. The reduction in nutrient use efficiencies due to added fertilizer was lower with K than with N, which illustrated the importance of K for these tropical tuber species, which store carbohydrates in the roots through translocation which is assisted by K as shown in potato and cassava [16, 19]. In addition, the nutrient use efficiency of 106 in *D. rotundata* for K in the savanna soil without fertilizer was an impressive value, which highlights the ability of this species to utilize K under limiting conditions in nonfertile soils. The possible reasons were inefficient applications and the lack of congruence between indigenous soil supply and applied fertilizers. However, the use of excessive fertilizers could also reduce the nutrient use efficiencies as shown

Table 4: Nitrogen and potassium use efficiency and agronomic use efficiency of *Dioscorea* spp. as affected by soil type and fertilizers.

Soil type	Species	Fertilizer	Nutrient use efficiency (g of total biomass at harvest/g of total nutrient uptake)		Agronomic efficiency (g of tuber dry weight/g of tuber nutrient content)	
			N	K	N	K
Forest	*D. alata*	None	82	67	87	66
		Full rate	52	61	56	59
	D. rotundata	None	69	76	72	72
		Full rate	51	66	51	65
Savanna	*D. alata*	None	43	79	46	74
		Full rate	35	71	38	67
	D. rotundata	None	49	106	48	100
		Full rate	36	82	36	81
SE mean ($n = 32$)			9.3	13.5	9.6	12.9

by [20] with nitrogen. As this aspect has not been identified in *Dioscorea* yams earlier, the causal phenomenon clearly warrants further study.

Agronomic efficiencies of the two *Dioscorea* species in relation to N and K content follow that of nutrient use efficiencies (Table 4). In the fertile forest soils, the agronomic efficiency of N is higher than in the savanna soils, in both species. In contrast, the agronomic efficiency of K is increased in the savanna soil, both of which follow that of nutrient use efficiencies. As in nutrient use efficiencies, the application of fertilizers lowers the agronomic use efficiency of both N and K, with a greater reduction in the agronomic efficiency of N. This again illustrates the importance of K as a nutrient for tropical tubers such as *Dioscorea* yams, a phenomenon not reported earlier. The causal mechanisms of this reduction in the agronomic efficiency, and also the nutrient use efficiencies could be due to the greater yields with fertilizers (Table 3).

4. Conclusion

Dioscorea is an important crop is West Africa, both as a food and for cultural purposes. It is widely grown in a range of soils under improved and subsistence cultivation techniques. This field study conducted on two sites with soils having high and low-fertility clearly highlighted that although *D. alata* has a lower leaf number, the LAI is greater, and leaves last on the vine for a longer period than in *D. rotundata*, thus enabling it to produce greater yields than *D. rotundata*. Crop growth is promoted by fertilizers, with a greater impact of the added nutrients in the low fertile savanna soils in terms of shoot, root, and tuber growth. This also helps to procure greater yields especially in *D. alata*, in both soil types, with a greater impact in the low fertile savanna soils.

The nutrient use efficiencies and agronomic efficiency of N and K also highlighted the impact of both N and K in promoting yields of this crop. Although application of fertilizer enhanced yields, this process reduced the N and K use efficiencies and thus the agronomic efficiencies. The reduction in N use efficiencies due to fertilizer was greater for N in the forest soils and for K in the savanna soils. The results illustrated that nutrient utilization efficiencies of both N and K, which are mobile nutrients, can vary in these species and that application of fertilizers may even reduce their impact due to lowering of efficiencies. This calls for further studies on fertilizer responses for these species, as blanket applications in different soils could cause losses of added nutrients, thus causing financial losses due the high costs of fertilizers and also soils and water pollution problems, especially in fragile environments such as those of West Africa.

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