Vegetative growth, resource optimisation and N productivity of oil palm (Elaeis guineensis Jacq.) as influenced by soil and fertilization

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Abstract

Oil palm is mainly grown on infertile soils in Southeast Asia with large amount of fertilizer input to sustain growth and production. The objectives of this paper are to examine the effects of soil and fertilization on the growth and biomass allocation of oil palm in relation to its N productivity, and to determine the critical plant N concentration for optimal growth of oil palm. Results from five long-term oil palm fertilizer response trials on Oxisols and Inceptisols indicated that vegetative growth and biomass allocation were consistent with the concepts of N productivity and resource optimisation, respectively. Plant N productivity at 0.08 kg dry weight/g N/year was higher on the more fertile Inceptisols due to better N uptake and larger storage of excess N in the stem. Their critical plant N concentration was also higher at 8.3 g N/kg dry weight compared with 7.1 g N/kg dry weight in Oxisols. Oil palm under N limiting conditions tended to allocate less biomass to the stem resulting in higher relative growth rate. Higher leaf N concentration reduced root:shoot ratio in Oxisols but had no effect in Inceptisols. The roots seemed insensitive to external soil N availability and maintained their internal N concentrations fairly well. These results could be included in future models of growth and N nutrition of oil palm to better predict its N requirement and N-use efficiency for sustainable production.

Media summary

Vegetative growth and biomass allocation in oil palm follow the concepts of plant N productivity and resource optimisation but soil fertility and fertilization affect them.

Key Words

Oil palm, RGR, plant N productivity

Introduction

The growth of many plant species under N limiting condition depends on internal plant N concentration, which responds to variation in external N availability. Ingestad (1979) explained this close relationship by introducing the concept of plant N productivity, which states that the relation between plant’s absolute growth rate (dW/dt) and the amount of plant N is linear:

$$\frac{1}{W}.\frac{dW}{dt} = Pn[Cn(t) - Cn,\min] \quad (1)$$

where W is the total weight of the plant (kg), t the time interval (year), Pn the N productivity, Cn(t) the plant N concentration at time t, and Cn,min the minimum plant N concentration for growth. The dependent variable in Equation (1) is also known as relative growth rate (RGR). Agren and Franklin (2003) have extended this relationship to derive the assimilation rate of plant as a function of plant N concentration and to optimise biomass allocation within a plant including the root:shoot ratio.

Oil palm contributes to 22 % of the world's oils and fats, and is planted on about 12 million hectares worldwide but mainly in Southeast Asia on generally infertile soils, where large growth and yield responses to N input have been obtained. However, the important relationships between growth and biomass allocation, and N productivity in oil palm have not yet been described. These relationships may vary with fertilization and the diverse soils where oil palm is now grown due to differences in external N availability. This may then affect the critical plant N concentration for optimal growth of oil palm. Furthermore, the absolute growth rate of oil palm is proportional to yield (Henson and Chang 2000), which in turn determines its profitability and sustainability. Therefore, the objectives of this paper are to study the effects of soil and fertilization on the growth and biomass allocation of oil palm in relation to its N productivity, and to determine the critical plant N concentration for optimal growth of oil palm. The goal is to include these results in future models of growth and N nutrition of oil palm to better predict its N requirement and N-use efficiency for sustainable production.

Materials and methods

Experimental sites and details

Five long-term fertilizer response trials on different soil series were studied. Three soils were classified as Oxisols derived from sedimentary and igneous parent materials, while the other 2 were Inceptisols on coastal clay. The palms were planted at 148 /ha or 138 /ha. The destructive samplings to measure the biomass allocation and N concentrations of different plant components were carried out on two treatments only: optimum fertilizer inputs (based on actual trial results at each site) and fertilizer withdrawal. The latter had been imposed for 7 to 11 years prior to sampling. The palm ages at the time of sampling were between 12.5 and 19 years old when vegetative growth rate was relatively constant. This study was conducted with two replicates per trial.

Measurements and sampling procedures

Prior to destructive sampling, non-destructive measurements for vegetative growth rate, including RGR, were carried out using the standard methods developed by Corley *et al*. (1971) for oil palm. The detailed destructive sampling procedures for oil palms were later described by Teoh and Chew (1988). Briefly, the oil palm was cut down and separated into leaf and stem. Their total fresh weights were measured in the field before a representative sample of each plant component was taken for fresh and dry weight determination. The roots were sampled by means of trenching. Three trenches each of 0.3 m width by 4 m length by 0.9 m depth were dug in different directions to represent the palm area. The excavated roots were cleansed of soil, washed and dried to constant weight. The total N in the different plant components was analysed using acid digestion and Kjeldahl method.

Statistical analysis

The data were grouped according to soil order following the USDA soil taxonomy. The replicates were nested within each soil order. The data were analysed using general linear model by Statistica version 6 (StatSoft 2001). The relative growth rates were adjusted for palm age using covariance analysis. Palm age had no effect on the other measurements and plant components.

Results and discussion

Biomass allocation and N concentration

Oil palm grown on either the infertile Oxisols or fertile Inceptisols had similar total biomass and allocation to the leaf, stem and roots although there was a trend showing better palm size on the latter soil order (Table 1). With fertilizer withdrawal, total biomass of oil palm declined significantly especially the shoot (leaf and stem). The leaf response to fertilization was larger for palms on Oxisols compared with Inceptisols resulting in bigger canopy mass in the former. This was consistent with the concept of resource optimisation where oil palm with minimal nutrient stress and under occasional water stress will partition higher biomass to the leaf (Henson and Chang 2000) probably to maximize growth since photosynthetic efficiency per leaf is lower. The decreases in stem mass with fertilizer withdrawal were similar in both soil orders. There were no significant differences in root mass between soil orders and fertilizer treatments. However, there was a clear trend of higher root mass in palms on Oxisols where fertilizers had been withdrawn ($p = 0.07$). This agrees with general observations that when nutrient availability increases, plants allocate relatively less to the roots since less effort is required to acquire nutrients (Agren and Franklin 2003).

Table 1. Biomass accumulation and allocation in oil palms as affected by soil order and fertilization

Soil Order	Fertilization	Plant dry mass (kg/palm)				
		Leaf	Stem	Root	Shoot	Plant
Oxisols	Withdrawn	110	406	101	516	617
	Continued	160	506	80	666	747
	Mean	135	456	91	591	682
Inceptisols	Withdrawn	129	420	87	549	636
	Continued	141	537	92	678	770
	Mean	135	478	89	614	703
Soil Order	LSD (p = 0.05)	27	101	36	107	80
Fertilization	LSD (p = 0.05)	28	98	35	109	129

Leaf N and stem N concentrations responded significantly to fertilization but not to soil order although there was a clear trend showing higher values on Inceptisols (Table 2). Similar responses were obtained for shoot and plant N concentrations. However, roots appeared insensitive to external soil N availability and could maintain their internal N concentrations fairly well. These results implied that the excess N absorbed by the oil palm, which was not required for immediate physiological use, was stored in the stem probably as a reserve.

Table 2. Effect of fertilization on N concentrations of different plant components of oil palms grown on different soil orders.

Soil Order	Fertilization	Plant N concentration (g N/kg dry weight)				
		Leaf	Stem	Root	Shoot	Plant

Oxisols	Withdrawn	9.20	2.55	3.22	3.97	6.06
	Continued	9.76	3.54	3.55	5.03	7.69
	Mean	9.48	3.05	3.38	4.50	6.87
Inceptisols	Withdrawn	9.38	3.74	3.53	5.04	7.33
	Continued	11.14	4.66	3.53	6.03	8.35
	Mean	10.26	4.20	3.53	5.53	7.84
Soil Order	LSD (p = 0.05)	2.70	2.01	0.40	2.45	1.84
Fertilization	LSD (p = 0.05)	1.06	0.63	0.63	0.70	0.74

Leaf N concentration and root:shoot ratio

Increasing leaf N concentrations generally led to reduced root:shoot ratios for oil palms on Oxisols only. It follows a declining saturation growth (hyperbolic) model (Figure 1):

$$root : shoot = \frac{0.041 * Leaf\ N concentration(g/kg)}{Leaf\ N concentration(g/kg) - 7.40} \quad (2)$$

with $r^2 = 0.96$ and s.e. = 0.03, after excluding 2 points as discussed below.

Hilbert (1990) demonstrated that this strong empirical relationship was an adaptive plant response where the decline at higher leaf N concentrations was due to the decreasing rate of marginal allocation to roots; only a smaller change in allocation to roots was necessary to increase leaf N concentration when it was high. The lack of a good relationship in Equation (2) for palms on Inceptisols could be due to the confounding effect of their relatively high water table of less than 90 cm from the soil surface resulting in better soil moisture regime. Further the two oil palms did not follow Equation (2): one due to an exceptionally large root mass whereas the other was very tall.

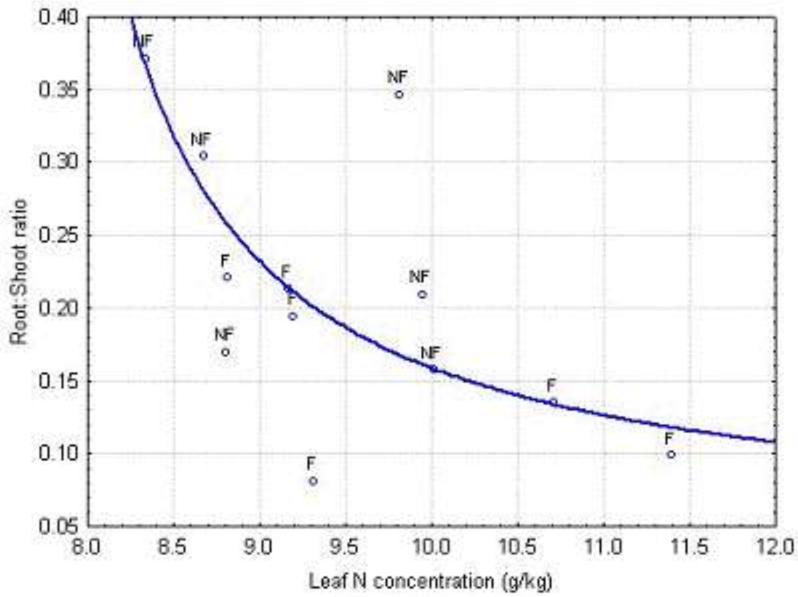

Figure 1. Effect of leaf N concentrations on root:shoot ratios of oil palms on Oxisols (F = continued fertilization; NF = fertilizer withdrawal)

Plant N productivity and RGR

The relationships between RGR and plant N concentration for oil palms on both soil orders followed Equation (1) up to the optimum leaf N concentrations (Figure 2) as found for other plants (Agren and Franklin 2003). However, oil palms on Inceptisols had higher plant N productivity of 0.08 kg dry weight/g N/year compared with 0.06 kg dry weight/g N/year on Oxisols. This might be attributed to the improved N uptake and photosynthetic efficiency in Inceptisols, which had better soil moisture regime. The critical plant N concentration in oil palms on Inceptisols at 8.3 g/kg was also higher due to increased N uptake and storage of excess N in the stem. The oil palms on Inceptisols had lower RGR again due to their larger stem mass.

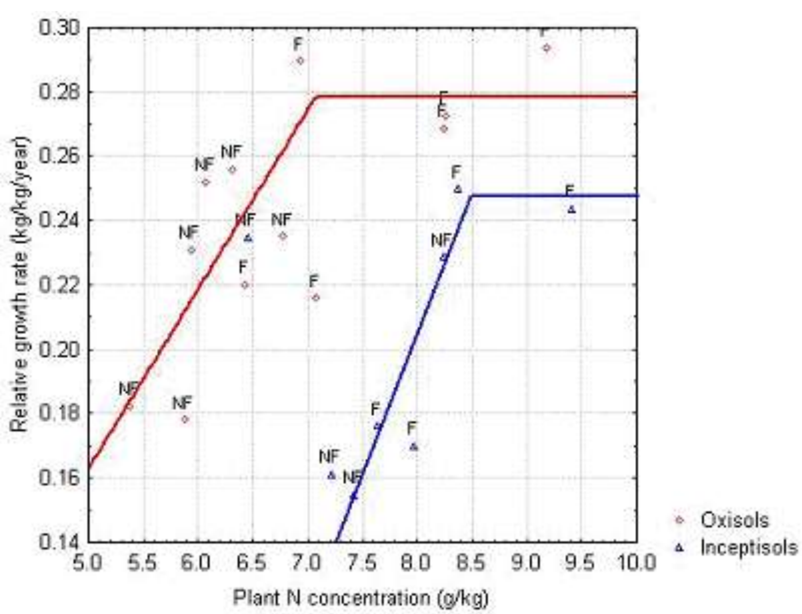

Figure 2. Effect of plant N concentration on relative growth rate of oil palms on Oxisols and Inceptisols (F = continued fertilization; NF = fertilizer withdrawal)

Conclusions

The behaviour of vegetative growth and biomass allocation in oil palm was consistent with the concepts of nitrogen productivity and resource optimisation, respectively. There was strong evidence of excess N being stored in the stem in oil palms on fertile Inceptisols, and their larger stem mass resulted in lower RGR. However, their plant N productivity was higher probably due to improved N uptake and photosynthetic efficiency caused by better soil moisture regime. Higher leaf N concentration reduced root:shoot ratio of oil palms on Oxisols but had no effect on Inceptisols. These factors should be included in future model of growth and N nutrition of oil palm in order to predict its N requirement and N-use efficiency for sustainable production.

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