

EFFECTS OF PLANT DENSITY AND SOIL MOISTURE ON GROWTH INDICES OF TWO UPLAND RICE VARIETIES

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ABSTRACT

A field study conducted on the ORSTOM farm at Adiopodoumé (Southern Côte d'Ivoire) with two upland rice varieties [IRAT 112 (V1) and IDSA 6 (V2)] and two plant densities [12 plants/m² (D1) and 60 plants/m² (D2)] led to the following results :

Leaf area index of the high density rice decreased very rapidly under water stress conditions. Soil water deficit substantially reduced net assimilation and relative growth rates but to a lesser extent, crop growth rate. With similar leaf area index at the end of the growing season, the low density rice had a better net assimilation rate after the water stress had ceased. The low plant density was favorable to net assimilation and relative growth rates throughout the growing season while it was favorable to crop growth rate only at the end of the growing season.

Key words : Upland rice, Growth analysis, Leaf area index, Leaf area ratio, Net assimilation rate, Growth rate, Plant density, Soil moisture, Soil water potential.

RÉSUMÉ

*EFFETS DE LA DENSITÉ DE SEMIS ET DU STOCK HYDRIQUE DU SOL
SUR LES INDICES DE CROISSANCE DE DEUX VARIÉTÉS DE RIZ PLUVIAL*

Une étude conduite à la ferme du Centre ORSTOM d'Adiopodoumé (Basse Côte d'Ivoire) avec deux variétés de riz pluvial [IRAT 112 (V1) et IDSA 6 (V2)], à deux densités de semis, [12 plants/m² (D1) et 60 plants/m² (D2)], a donné les résultats suivants :

L'indice foliaire du riz a baissé très rapidement pour la forte densité en condition de stress hydrique. Le déficit hydrique a réduit substantiellement l'assimilation nette et le taux de croissance relative mais à un degré moindre, le taux de croissance pondérale. Avec un même indice foliaire en fin de cycle, la faible densité a eu une meilleure assimilation nette après la

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disparition du stress hydrique. La faible densité a été favorable à l'assimilation nette et au taux de croissance relative pendant tout le cycle alors qu'elle ne l'a été pour le taux de croissance pondérale qu'en fin de cycle.

Mots-clés : Riz pluvial, Analyse de croissance, Indice foliaire, Assimilation nette, Taux de croissance, Surface foliaire massique, Densité de semis. Humidité du sol, Potentiel hydrique du sol.

INTRODUCTION

Crop yield reduction due to water stress is very common in the intertropical zones (Shouse et al., 1981 ; Denmead and Show, 1960). There is, however, little information on the effect of water stress on the growth indices which should help to explain yield losses. Radford (1967) presented the growth analysis concept as a means of quantitative analysis of the plant growth which is often used by physiologists (Watson, 1952; 1958; Williams et al., 1965). The objective of this study was to analyze the effects of water stress on the development of upland rice by the use of growth indices under field conditions.

MATERIALS AND METHODS

The experimental site was located on the agronomy farm of the ORSTOM Center of Adiopodoumé (Southern Côte d'Ivoire) about 17 km west of Abidjan, 5° 19' N, 4° 14' W at 29 m of altitude on deep sandy soils. In general, the soils of Adiopodoumé are ferrallitic with a very low percentage of saturation, modal and developed from tertiary sand (Table 1). Total N content in the topsoil (25 cm) ranges from 0.71 to 0.72 meq/100g and soil pH ranges from 5.2 to 5.3.

Two upland rice varieties, V1 (IRAT 112) and V2 (IDSA 6) were hand sown on 14 and 15 March 1986 at two plant densities, D1 (12 plants/m²) and D2 (60

Table 1 : Physical and chemical properties of the soils at the experimental site (After Goué et al. 1986).

Soil depth (cm)	Clay ----- (%) -----	Silt ----- (%) -----	Sand ----- (%) -----	Ca ⁺⁺ ----- (meq/100g) -----	Mg ⁺⁺ ----- (meq/100g) -----	K ⁺ ----- (meq/100g) -----	Total OM
0-15	6.1	4.6	87.5	0.48	0.01	0.06	1.5
15-35	6.5	4.8	88.5	0.22	0.07	0.03	1.0
35-50	8.5	4.8	85.9	0.10	0.05	0.02	0.7
50-70	12.1	5.1	82.8	0.24	0.07	0.03	0.6
70-90	16.5	6.0	76.9	0.18	0.05	0.02	0.8
90-100	22.8	4.9	72.4	0.22	0.03	0.03	0.8

OM = organic matter

plants/m²). IRAT 112 was derived from a cross between IRAT 13 and Dourado in 1978 and it is a short-season (105 days) cultivar. Its height ranges from 90 to 105 cm and it can yield up to 4.0 tonnes/ha. IDSA 6 was derived from a cross between Colombia and M 312 A in 1982. IDSA 6 which is also called IRAT 216, is a mid-season (125 days) cultivar and can be used as either a rainfed or a flooded cultivar. IDSA 6 is 110 cm high and can yield up to 5.2 tonnes/ha (Poisson and Doumbia, 1987). The experimental design was a 2 x 2 factorial with five replications for a total of 20 plots. Each plot covered 62.5 m² (12.5 m x 5 m) in area and consisted of 16 sowing rows with 33 cm between rows. Two seeds were sown per hill at a distance of 25 cm for D1 and 5 cm for D2. The crop was hand-thinned to one plant per hill to obtain plant populations of 12 and 60 plants/m² for D1 and D2 respectively. Missing plants were replaced during the thinning period from 18 to 21 days after sowing (DAS).

Five hundred kg ha⁻¹ of NPK (10-18-18) were added to the soil before plowing. Urea was put in the row at the beginning of tillering and stem elongation at a rate of 100 kg ha⁻¹. The field was irrigated on the 26th and 35th days after sowing bringing 14 and 24 mm of water respectively.

Soil moisture was monitored weekly by the gravimetric method in the top soil and by the neutron scattering method down to 100 cm. Soil water potential was also monitored from 20 to 100 cm depth using a series of tensiometers. Rainfall was recorded at the experimental site. Solar radiation was monitored with a Ballani pyranometer at a nearby weather station.

Beginning on day 21 after sowing, weekly samplings of 4 plants/plot were made to determine plant dry weight. From day 34 after sowing, the green leaf area of sampled plants was measured by using an area-meter (Type : Milliplan). Leaf area index (LAI) was calculated by considering leaf area per plant and plant density.

Crop Growth Rate (CGR), Relative Growth Rate (RGR), Leaf Area Index (LAI), Leaf Area Duration (LAD), Leaf Area Ratio (LAR) and Net Assimilation Rate (NAR) were calculated in order to analyze the development of upland rice under field conditions.

The following equations were used to calculate the different growth indices :

- Crop Growth Rate (CGR)

$$CGR = (1/S) dW/dt \quad (1)$$

$$CGR = (1/S) (W_2 - W_1)/(t_2 - t_1) \quad (2)$$

where W = above-ground plant dry weight

S = land area

t = time.

- Relative Growth Rate

$$RGR = (1/W) dW/dt \quad (3)$$

$$RGR = (\text{Log } W_2 - \text{Log } W_1)/(t_2 - t_1) \quad (4)$$

- Leaf Area Index (LAI), Leaf Area Duration (LAD), Leaf Area Ratio (LAR)

$$LAI = A/S \quad (5)$$

$$LAD = \int_{t_1}^{t_2} LAI dt \quad (6)$$

$$LAR = A/W \quad (7)$$

$$LAR = (LAR_1 + LAR_2)/2 \quad (8)$$

Where A = leaf area/plant

- Net Assimilation Rate (NAR)

$$NAR = (1/A) dW/dt \quad (9)$$

$$NAR = (W_2 - W_1) (\text{Log } A_2 - \text{Log } A_1) / (t_2 - t_1) (A_2 - A_1) \quad (10)$$

Let us point out that RGR, LAR and NAR are related as shown in the following equation :

$$RGR = LAR \times NAR \quad (11)$$

RESULTS

The analysis of soil water potential (Fig.1) indicates that most of the evapotranspired water came from the first 60 and 40 cm of soil for IRAT 112 and IDSA 6, respectively. This result suggests that IRAT 112 may have a deeper and more developed root system. The analysis of moisture data from the first 60 cm of soil over the growing season, reveals two drying cycles due to low amount of rainfall (Fig.2). The first one was short and started early in the growing season. The second, however, was long, starting between days 40 and 50 after sowing and ending around day 70. During this second drying cycle, soil moisture fell below the wilting point between days 60 and 70 after sowing, therefore, affecting the plant development. Solar radiation fluctuated throughout the growing period but is particularly lower at the end of the season

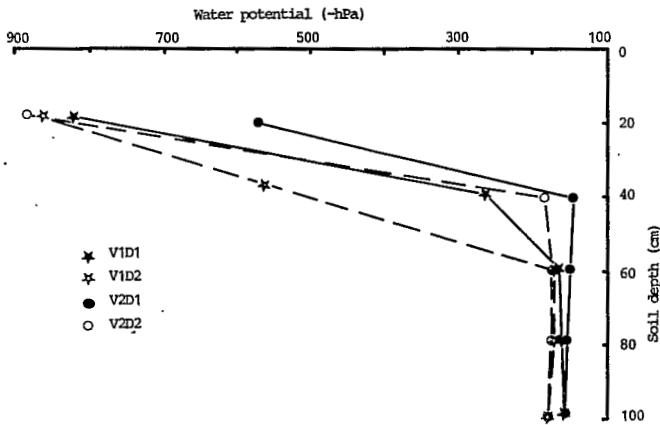


Figure 1 : Soil water potential profiles for May 12, 1986 under two rice varieties V1 (IRAT 112) and V2 (IDSA 6) and two plant densities D1 (12 plants/m²) and D2 (60 plants/m²).

because of the greater number of rainy days recorded during this period. (Fig.2)

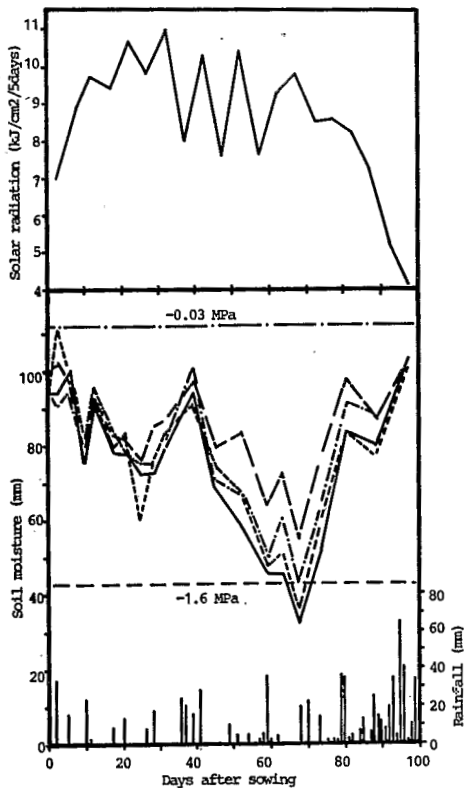


Figure 2 : Evolution of soil moisture in the first 60 cm and rainfall and solar radiation during the growth season.

_____ V1D1, _____ V2D1, _____ V2D2,
 _____ V1D2.

Figure 3 presents the evolution of dry matter accumulation per plant (g/plant) and per unit land area (g/m²) (Remison and Lucas, 1982; Buttery, 1969a). These results show similarity in the growth of the two varieties suggesting that they react to environmental conditions in the same way. Thus, their dry matter accumulation rate was reduced accordingly by the dry period recorded between days 55 and 70 after sowing.

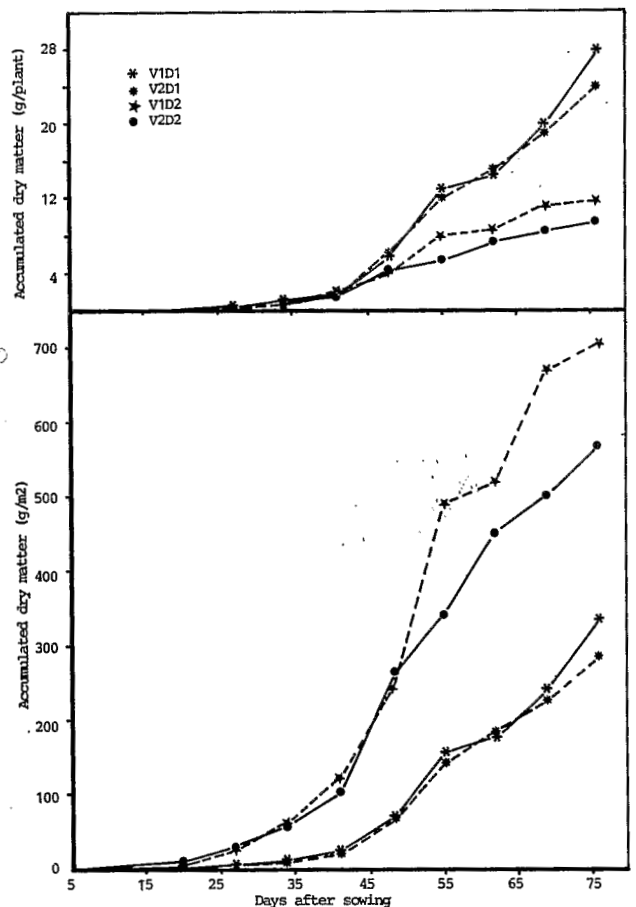


Figure 3 : Dry matter accumulation of two rice varieties V1 (IRAT 112) and V2 (IDSA 6) at two plant densities D1 (12 plants/m²) and D2 (60 plants/m²).

Figure 3 also shows that plant density had a significant effect on growth (g/plant) and yield (g/m²). The high plant density led to reduced growth while the low density, despite the good plant growth resulted in a smaller crop yield. This indicates that 12 plants/m² was below the optimum plant density. The

better development of IRAT 112 as compared to IDSA 6 under high plant density suggests a differential root development as indicated by the water potential data.

Figure 4 presents the evolution of CGR during the growing season. The high increase rate of CGR between days 35 and 50 after sowing occurred at the beginning of stem extension when soil moisture content was high. During the second half of the stem extension period, CGR rapidly decreased following a dry period. The next increase in CGR occurring between days 60 and 70 after sowing (thus, during the dry season) was related to heading and early grain filling. Plant density had a positive effect on CGR only under good moisture conditions.

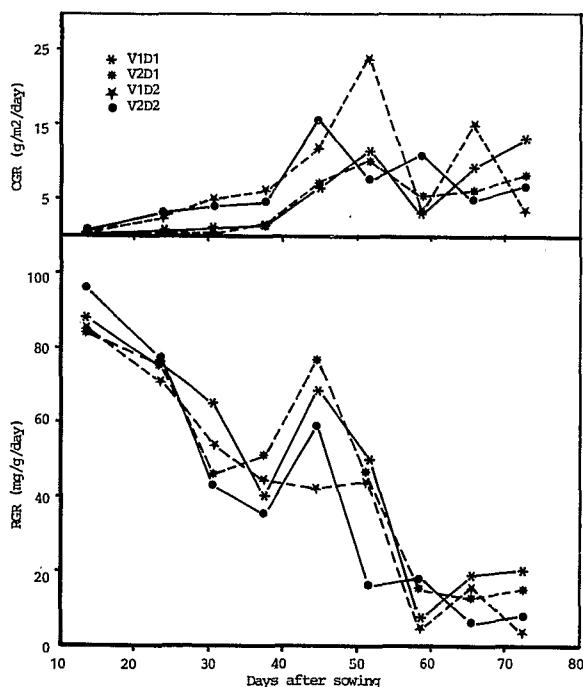


Figure 4 : Crop growth rate (CGR) and relative growth rate (RGR) of two rice varieties, V1 (IRAT 112) and V2 (IDSA 6) at two plant densities, D1 (12 plants/m²) and D2 (60 plants/m²).

The relative growth rate (Fig.4) reached its maximum early in the plant development (Scott and Batchelor, 1979),

then rapidly decreased during the first drying cycle before rising again. This increase in RGR was associated with stem elongation and good rainy period. Starting about 50 days after sowing, RGR decreased very rapidly reaching a minimum value around day 60 before increasing slightly under the low plant density. At the beginning of the growing season, RGR was similar for all treatments but starting from day 35 after sowing, the low plant density treatments had higher RGR.

Leaf area index (LAI) of the high density treatments was significantly (5%) higher than that of the low density treatments until day 70 after sowing (Fig.5). However, LAI of the two varieties had a similar trend. From day 40 to day 50, the rapid increase in LAI was associated with stem elongation. During the dry period (55 to 65 days after sowing) LAI increase rate was negligible (Cutler et al., 1980) but the important leaf wilting during that period led to leaf senescence between days 65 and 75 after sowing resulting in lower LAI especially under high plant density. Under low plant density conditions, maximum LAI was 1.0 while under high density conditions maximum LAI was 2.2 (Fig.5).

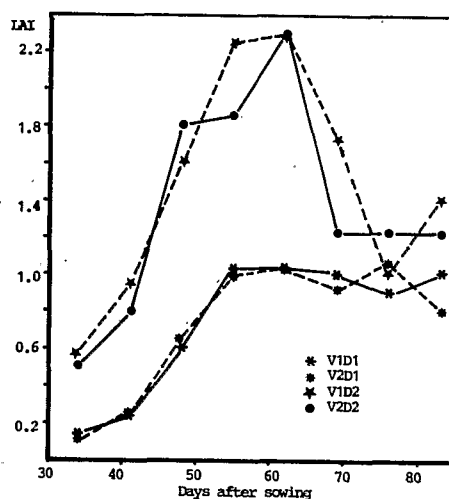


Figure 5 : Leaf area index (LAI) of two rice varieties, V1 (IRAT 112) and V2 (IDSA 6) at two plant densities, D1 (12 plants/m²) and D2 (60 plants/m²).

Leaf area duration (LAD) between days 34 and 83 after sowing was 40.6, 42.3, 76.5 and 82.7 days for V2D1, V1D1, V2D2 and V1D2 respectively.

Leaf area ratio (LAR) was similar for all treatments but declined with time. It was observed, however, that the declining rate was slow between days 55 and 65 after sowing (Fig.6) only for the high density treatments. This result is due to the fact that leaf area remained the same while the relative growth rate was very minimum especially for the high density treatments (Fig. 4 and 5).

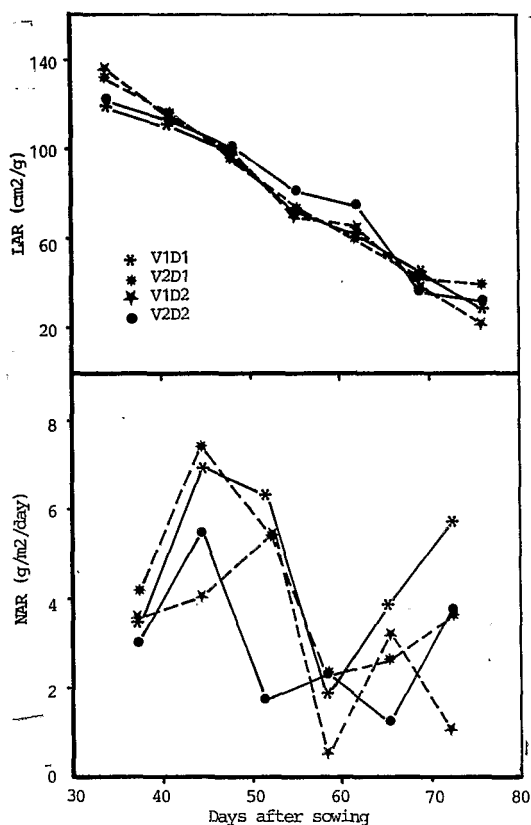


Figure 6 : Leaf area (LAR) and net assimilation rate (NAR) of two rice varieties V1 (IRAT 112) and V2 (IDSA 6) at two plant densities D1 (12 plants/m²) and D2 (60 plants/m²).

Net assimilation rate (NAR) which is a physiological index associated with photosynthetic activity is generally higher under low density conditions (Buttery, 1969b). NAR declines very rapidly during the dry period from days 50 to 65 after sowing. NAR recovery was regular

and constant for all treatments except V1D2 after the dry period (Fig.6). Despite the important role that light intensity plays in photosynthesis, solar radiation recorded at the experimental site was not limiting as demonstrates Figure 7. The absence of a close linear relationship ($NAR = 0.274 SR - 0.127$, $r = 0.449$) between net assimilation rate and solar radiation was an evidence that other factors were limiting photosynthetic activity.

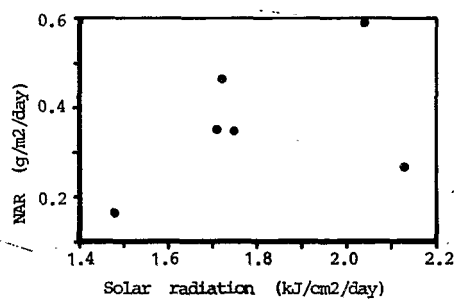


Figure 7 : Relationship between net assimilation rate and solar radiation.

DISCUSSION

As expected, plant density significantly affected dry matter accumulation of upland rice (Remison and Lucas, 1982; Buttery, 1969a). On the unit plant basis, the yield reduction under high density conditions may result from competition between plants for water, nutrient elements and light (Hoyt and Bradfield, 1962; Simmons *et al.*, 1982). However, the better development of IRAT 112 as compared to IDSA 6 under high density conditions may be associated with a deeper root system of IRAT 112. As a matter of fact, soil water potential profiles during the dry period demonstrate that IRAT 112 withdrew water down to 60 cm depth while IDSA 6 water withdrawal was mainly limited to the first 40 cm. The good development of IRAT 112 was also associated with its high leaf area duration.

The effect of the water stress (days 50 to 70 after sowing) on the rice development was expressed by a reduction in the CGR rather than a decrease in the plant weight. Similar results were reported by Cutler et al. (1980) and Hsiao and Acevedo (1974). The decline in CGR during the first half of the dry period (Keating et al., 1982) was associated with a declining RGR and low NAR which can be partly explained by low photosynthetic activity due to stomatal closure (Palta, 1983, El Sharkaway and Cock, 1984). During the second half of the dry period, the relative increase in CGR and RGR was associated with a high NAR due to high assimilate demand for grain filling (Koller et al., 1970), therefore, compensating for the loss of dry matter by rapid leaf senescence. Severe water stress leading to low photosynthetic activity without any immediate leaf area loss resulted in higher leaf area ratio.

CONCLUSIONS

These results show that a severe water stress has a negative effect on most of the growth indices (crop growth rate, CGR; relative growth rate, RGR; leaf area index, LAI; leaf area duration, LAD; net assimilation rate, NAR) except the leaf area ratio (LAR). They also show that the evolution of RGR is mainly dependent on NAR since LAR has a constant declining rate.

A strong assimilate demand during grain filling may increase net assimilation during water stress. Despite the importance of light intensity in photosynthetic activity, global solar radiation does not constitute a limiting factor for the rice net assimilation.

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AGRONOMIE AFRICAINNE

Revue Internationale publiée
par l'Association Ivoirienne des
Sciences Agronomiques (A.I.S.A)

*International Journal published by
the Ivorian Association for
Agricultural Sciences (A.I.S.A)*

20 BP 703 ABIDJAN 20
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Agron. Afr., 2 (1) : 1- 52

