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Arthropod Populations and Rice Yields in Direct-Seeded and Transplanted Lowland Rice in West Africa

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Abstract

Two methods for planting rice in irrigated lowland were evaluated during the wet seasons of 1994 and 1995 to determine their effect on rice arthropod numbers, insect-caused rice plant damage, and rice grain yield. The six treatments tested were: hand transplanting of seedlings at spacings of 14 cm × 14 cm, 20 cm × 20 cm, and 30 cm × 30 cm; and direct-seeding of rice at 60 kg seeds ha^{-1}, 90 kg seeds ha^{-1}, and 120 kg seeds ha^{-1}. The most abundant arthropods in the study were the diopsid flies, *Diopsis longicornis* Maquart and *D. apicalis* Dalman; the green leafhoppers *Nephotettix* spp.; the white leafhoppers *Cofana unimaculata* (Signoret) and *C. spectra* (Distant); spiders; dragonflies and damselflies; and stem borers. There was no overall difference between transplanting and direct-seeding, or between plant densities, in regard to sweep net counts of *Cofana* spp. and spiders. *Diopsis longicornis* and *D. apicalis* adult numbers were highest in the 20 cm × 20 cm transplanted plots in 1994, but no significant differences occurred in 1995. *Nephotettix* spp. adult numbers were highest in the 120 kg seeds ha^{-1} direct-seeded plots in 1995, but no significant differences occurred in 1994. The percentage of tillers infested with stem borers was highest in the three transplanted and the 120 kg seed ha^{-1} direct-seeded treatments in 1994 and the three transplanted treatments in 1995. In 1995, the percentage of whiteheads (empty panicles) caused by stem-borer feeding was highest in the direct-seeded treatments, increasing from the low rate of 60 kg seeds ha^{-1} to the highest rate of 120 kg seeds ha^{-1}. Grain yields were generally similar in the transplanted and direct-seeded plots. Implications of planting methods and plant density as management practices in rice IPM and labor requirements for rice production are discussed.

Keywords: Côte d'Ivoire, West Africa, *Oryza sativa* L., rice insect pests, planting method, leafhoppers, spiders, stem borers, dragonflies, damselflies

1. Introduction

In West Africa, the most common method of planting of rice in irrigated lowland fields is by the transplanting of seedlings that have been grown in a nursery bed. However, in recent years there has been considerable interest in seeding (broadcast or drilled in rows) directly in the field. According to Poussin (1997), both planting methods present certain advantages and disadvantages.

A major consideration, regarding the choice of transplanting or direct-seeding of rice, is weeding. In West Africa, weeds are a major constraint upon rice production (Dingkuhn, 1993; Johnson, 1997). Direct-seeded rice requires more accurate field leveling and more precise water management (Béliéres et al., 1994). Early flooding just after broadcasting of seeds, and poor drainage, are major constraints upon adoption of direct-seeded rice in Thailand (Konchan and Kono, 1996). Lack of standing water in direct-seeded rice results in weed growth. Hand weeding is difficult because of the necessity of avoiding stepping on the closely spaced seedlings and because certain weed species are similar in appearance to rice seedlings. As a result, herbicide application may be necessary. Transplanting rice seedlings in the field, on the other hand, allows the farmer to maintain standing water in the field, which mitigates weed growth and provides a comparative height advantage for the newly established rice seedlings over those of the weeds. Moreover, transplanting in rows facilitates manual weeding. At plant spacings of 20 cm × 20 cm or wider, it is easy for the farmer to enter the field and hand-remove weeds. Direct-seeding is thus most suitable to areas where there is a labor shortage, mechanization is available for land preparation, and where irrigation water can be effectively managed. In the West African Senegal River Valley, the use of direct-seeding has been linked to large irrigation schemes while transplanting is most common in the village irrigation schemes (Poussin, 1997).

De Datta (1986) reported that rice production in Asia requires 32 man days ha^{-1} preharvest for a direct-seeded crop compared with 63 days for a transplanted crop. Direct-seeded rice culture on irrigated rice farms in the Philippines releases labor, mostly that of women, for other agricultural activities (Tisch and Paris, 1994).

Primarily because of the labor-saving advantage of direct-seeding rice, there has been worldwide interest in this planting method. Konchan and Kono (1996) reported that there was a drastic shift from transplanting of rice to direct-seeding in the northeastern part of Thailand. The farmers in Thailand consider minimizing labor input in rice cultivation of greater importance than maximizing grain yields. With the current shortage and increasing cost for agricultural labor in West Africa, direct-seeding rice presents a distinct advantage.

In the development of rice IPM strategies for West Africa, there is a need to consider the impact of changing planting methods on rice insects and subsequent grain yields. Several studies have been conducted to determine the importance of spatial properties of rice on the population dynamics of various arthropods. In studies conducted at the same location as the current study, Oyediran et al. (1999) found that when rice seedlings were transplanted, populations of diopsid flies *Diopsis longicornis* and *D. apicalis*, percentage of tillers with deadhearts or whiteheads caused by stem-borer feeding, and grain yields were generally higher at a close spacing of 10 cm × 10 cm (100 hills m^{-2}) compared with a wider spacing of 30 cm × 30 cm (10 hills m^{-2}). In Nigeria, infestation by the rice gall midge *Orseolia oryzivora* Harris and Gagne was increased with close plant spacing of transplanted crops (Ukwungwu, 1987a). In the USA, Thompson and Quisenberry (1995) reported that the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, laid more eggs at lower plant densities. In India (Singh et al., 1990; Sathiyanandam et al., 1991), plant spacing did not affect the incidence and extent of damage by the yellow stem borer, *Scirpophaga incertulas* (Walker) on rice. In studies conducted in Guinea, Chiasson and Hill (1993) reported that damage by *Diopsis* spp. was three times more severe in transplanted rice than in direct-seeded rice in the dry season, but no significant differences in damage between planting methods occurred during the wet season. Based on these studies, it is apparent that the effect of planting methods and planting density depends on the insect species being studied and the season, the most common effect being some increase in insect populations and insect damage with a close plant spacing.

Published studies comparing the effect of transplanting and direct-seeding on rice insect populations in West Africa have been limited to that of Chiasson and Hill (1993) on *Diopsis* spp. populations. However, in the development of IPM strategies for lowland rice in West Africa, more information is needed to determine the effect of each of these rice-planting methods on insect pest and natural enemy numbers. This study was conducted to generate information on the effect of transplanting and direct-seeding, at different plant densities, on the abundance of beneficial and pest arthropods, plant damage caused by insects, and rice grain yield.

2. Methods

This study was conducted in a lowland area on the West Africa Rice Development Association (WARDA) M'bé Research Station near Bouaké, Côte d'Ivoire during the wet seasons (August to November) in 1994 and 1995. This station is located in the transition zone between the humid forest and derived savanna.

The lowland plots were prepared by using the wetland tillage method described by De Datta (1981). Plot size was 10 m × 12 m. Two planting methods were tested:

1. Seeds of rice cultivar Bouaké 189 were sown in nurseries, and at 21 days after sowing, seedlings were transplanted in puddled soil at three spacings: 14 cm × 14 cm, 20 cm × 20 cm, and 30 cm × 30 cm. These plant spacings correspond to plant populations of 50, 25, and 10 hills m^{-2}, respectively.

2. On the same date that transplanting was done, Bouaké 189 seeds were sown directly into plots of puddled soil by hand-broadcasting at three seed rates: 60 kg ha^{-1}, 90 kg ha^{-1}, and 120 kg ha^{-1}. Bouaké 189 is a commonly grown commercial cultivar in Côte d'Ivoire (Becker and Diallo, 1992) and neighboring West African countries, having a growth duration from planting to harvest of 100–105 days.

Fertilizer (NPK 10-18-10) was incorporated into the soil at the rate of 150 kg ha^{-1} just prior to time of planting. Urea (45%) at 75 kg ha^{-1} was broadcast at 30 and 60 days after transplanting (DT) or after seeding (DS). The experiment was planted in a randomized complete block design with four replications.

Arthropod populations were determined by taking 50 sweeps per plot (120 m^2 area), with a sweep net at fortnightly intervals from the second to the 12th week after planting. To determine the percentage of tillers damaged by stem-borer larvae, deadhearts were counted fortnightly through the vegetative stage by examining 50 randomly selected hills per plot. Percentage of stem borer–infested tillers was determined by dissecting the tillers on 10 randomly selected hills per plot at 30, 50, and 70 DT or DS. Whiteheads (chaffy or empty whitish colored panicles) caused by stem-borer feeding during the reproductive phase or rice production were counted on all productive tillers of 50 randomly selected hills per plot just prior to harvest. To determine yield, a 36 m^2 area in the center of each plot was harvested, weighed, and the grain corrected for 14% moisture. Data were subjected to ANOVA and means separated by the LSD test ($P < 0.05$).

3. Results

The most abundant insects in sweep net catches over the 2-year period were the stem-boring stalk-eyed flies, *Diopsis longicornis* Maquart and *D. apicalis* Dalman. Populations of both species were highest in 1995. Significant differences between treatments occurred only in 1994 (tables 1 and 2). In 1994, populations of *D. longicornis* were highest in the high plant density plots transplanted at 14 cm × 14 cm (TP1) and 20 cm × 20 cm (TP2), and lowest in the low plant density plots transplanted at 30 cm × 30 cm(TP3) (figure 1, A). There was no significant difference between the three direct-seeding rates.

Table 1. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for *D. longicornis*, 1994*

Source of variation	df	MS	$P > F$
Replication	3	749.6	0.014
Treatments	5	461.4	0.043
Error	15	151.4	

MS, mean squares (from type III sum of squares)
*1995 data NS

Table 2. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for *D. apicalis*, 1994*

Source of variation	df	MS	$P > F$
Replication	3	53.5	0.487
Treatments	5	157.1	0.056
Error	15	62.8	

MS, mean squares (from type III sum of squares)
*1995 data NS

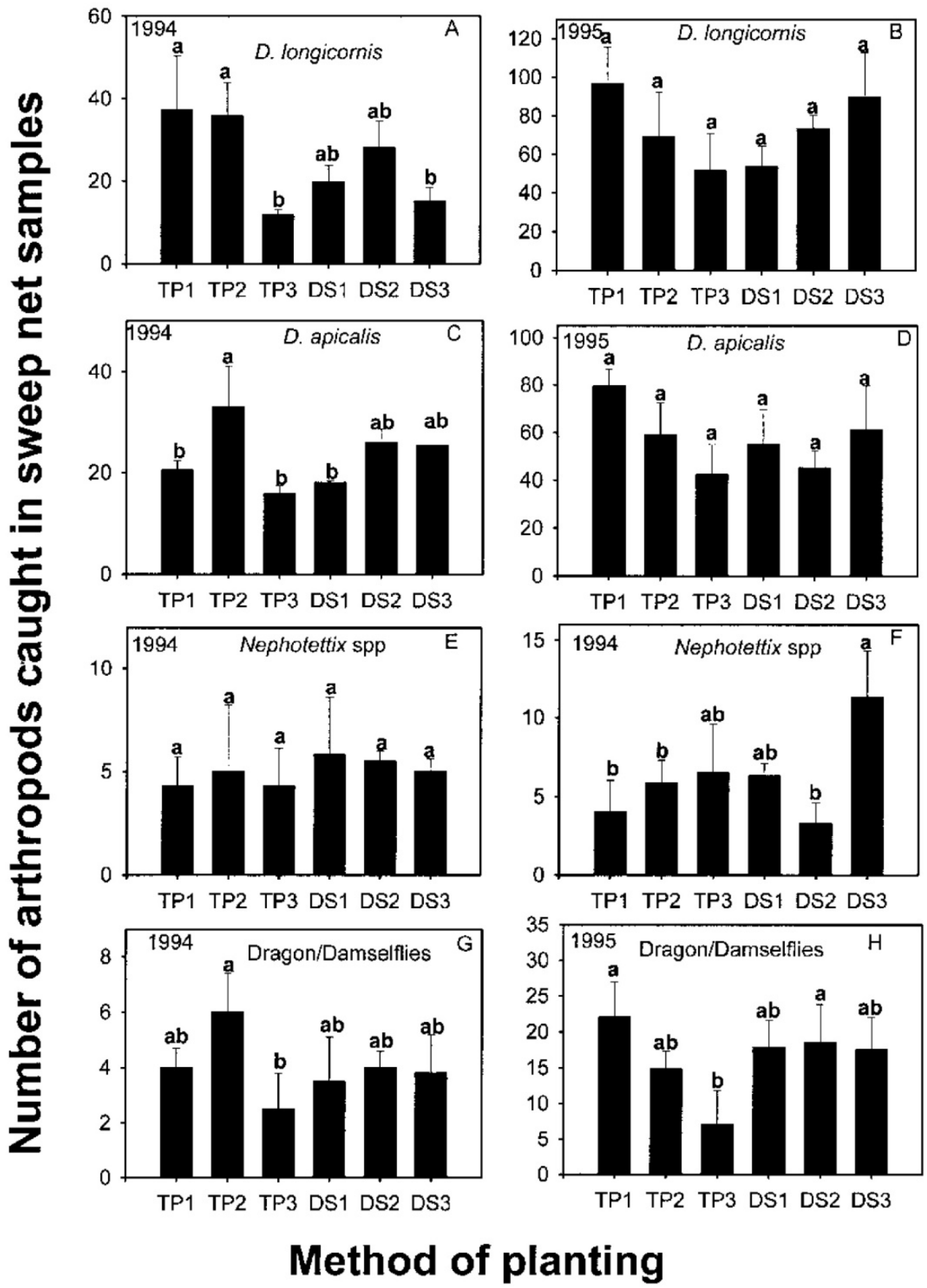

Figure 1. Number of insects per 50 sweeps with a sweep net in an irrigated lowland rice cultivar Bouaké 189, as affected by method of planting (transplanting and direct-seeded) over a 2-year period 1994–1995 (A–H). Transplanted at a spacing 14 cm × 14 cm within and between rows (TP1), 20 cm × 20 cm (TP2), and 30 cm × 30 cm (TP3). Direct-seeded rice at 60 kg of seed ha^{-1} (DS1), 90 kg ha^{-1} (DS2), and 120 kg ha^{-1} (DS3). Standard error bars (*P* = 0.05) compare statistical significance between the different planting methods. WARDA M'bé Research Station, Bouaké, Côte d'Ivoire.

Diopsis apicalis numbers in 1994 (figure 1, C) were highest in the 20 cm × 20 cm transplanting treatment (TP2). Similar to *D. longicornis* (figure 1, A), there were no significant differences in *D. apicalis* numbers in the direct-seeding treatments (figure 1, C).

Nephotettix spp. numbers were low in both 1994 and 1995 (figure 1, E, F). Significant differences were observed only in 1995 (figure 1, F) (table 3). In 1995, the highest *Nephotettix* spp. numbers occurred in the highest direct-seeded rate of 120 kg ha^{-1} (DS3) (figure 1, F).

Table 3. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for *Nephotettix* spp., 1995*

Source of variation	df	MS	$P > F$
Replication	3	46.4	0.038
Treatments	5	31.5	0.054
Error	15	12.8	

MS, mean squares (from type III sum of squares)
*1994 data NS

The numbers of the two *Cofana* species were not affected by the different planting methods in either 1994 or 1995.

Spiders were considered as a group and were not taxonomically classified to the generic level. However the major canopy-dwelling spider species in lowland rice on the site of this study are: *Pardosa injucunda* (Lawrence) (Lycosidae); *Tetragnatha jaculator* Tullgren and *T. javana* (Thorell) (Tetragnathidae); *Araneus* sp., *Argiope* sp., and *Neoscona* sp. (Araneidae); *Dolomedes* sp. (Pisauridae); and *Runcinia* sp. (Thomisidae) (Oyediran and Heinrichs, 1999). The spider numbers, which ranged from 5 to 11 per 50 sweeps in 1994 and 5 to 7 in 1995, were not affected by planting method or plant density.

Planting methods significantly affected the populations of the predators, the dragonflies (Odonata: Libellulidae including *Palpopleura* sp.), and the damselflies (Odonata: Libellulidae including *Lestes* sp. and Coenagrionidae including *Agriocnemis* sp.) in both years (tables 4 and 5). In 1994, the highest population was found in rice transplanted at 20 cm × 20 cm (TP2) and the lowest was in 30 cm × 30 cm (TP3) spaced treatments (figure 1, G). In 1995, the highest population occurred in the plots transplanted at 14 cm × 14 cm (TP1) and the lowest in the 30 cm × 30 cm (TP3) treatment (figure 1, H).

Table 4. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for dragon/damselflies, 1994

Source of variation	df	MS	$P > F$
Replication	3	10.7	0.067
Treatments	5	5.8	0.058
Error	15	3.6	

MS, mean squares (from type III sum of squares)

Table 5. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for dragon/damselflies, 1995

Source of variation	df	MS	$P > F$
Replication	3	190.5	0.044
Treatments	5	103.8	0.054
Error	15	55.3	

MS, mean squares (from type III sum of squares)

Percentage tillers infested with stem-borer larvae was significantly affected by planting methods in 1994 and 1995 (figure 2) (tables 6 and 7). Stem-borer larvae were not separated to the species level, but the major species infesting rice in the locale of this study are the dipterous larvae of the stalk-eyed flies, *Diopsis longicornis* and *D. apicalis*, and the lepidopterous larvae of the genera *Maliarpha*, *Chilo*, and *Scirpophaga* (Oyediran and Heinrichs, 1999). In 1994 (figure 2, A), tiller infestation was highest in the three transplanting treatments and the high rate of direct-seeding at 120 kg seeds ha^{-1} (DS3). The lowest level was in the low seeding rate of 60 kg ha^{-1} (DS1). Tiller infestation in 1995, was again high in the three transplanting treatments and lowest in the DS1 treatment (figure 2, B).

Table 6. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for percentage tillers infested, 1994

Source of variation	df	MS	$P > F$
Replication	3	15.2	0.064
Treatments	5	4.4	0.056
Error	15	2.4	

MS, mean squares (from type III sum of squares)

Table 7. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for percentage tillers infested, 1995

Source of variation	df	MS	$P > F$
Replication	3	17.8	0.194
Treatments	5	22.3	0.057
Error	15	10.1	

MS, mean squares (from type III sum of squares)

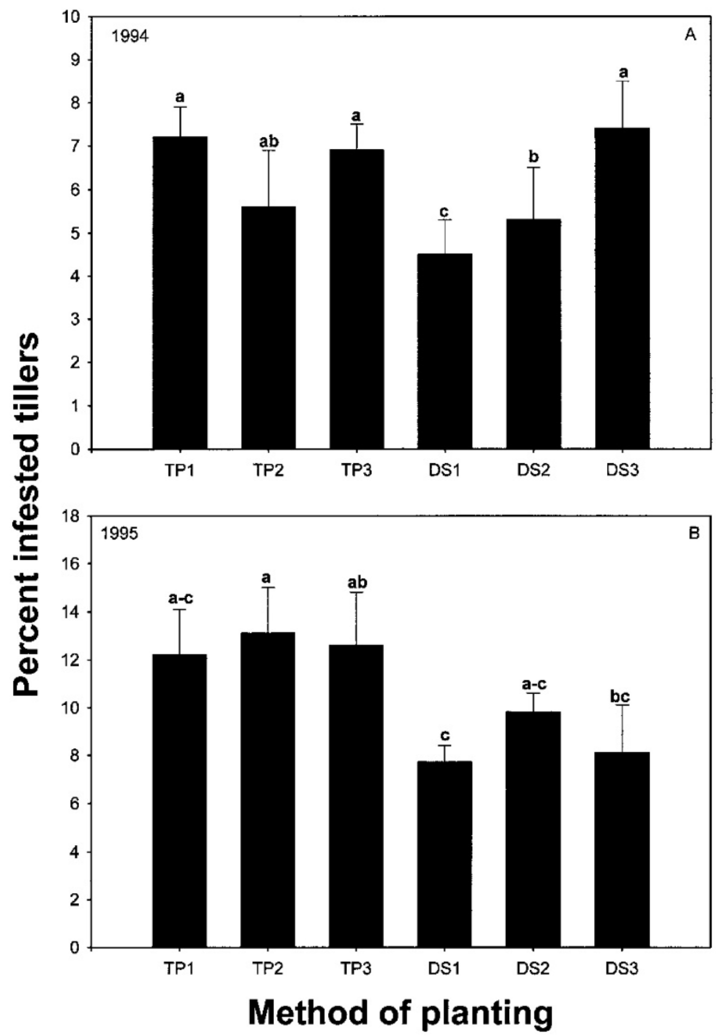

Figure 2. Stem-borer damage (% tillers with stem-borer larvae) in an irrigated lowland rice cultivar Bouaké 189, as affected by method of planting (transplanting and direct-seeded) over a 2-year period 1994–1995 (A–B). Transplanted at a spacing 14 cm × 14 cm within and between rows (TP1), 20 cm × 20 cm (TP2), and 30 cm × 30 cm (TP3). Direct-seeded rice at 60 kg of seed ha^{-1} (DS1), 90 kg ha^{-1} (DS2), and 120 kg ha^{-1} (DS3). Standard error bars ($P = 0.05$) compare statistical significance between the different planting methods. WARDA M'bé Research Station, Bouaké, Côte d'Ivoire.

Percentage deadhearts caused by stem-borer feeding was affected by planting method in 1994 (table 8). The lowest percentage deadhearts was in the lowest seeding rate of 60 kg ha^{-1} (DS1) (figure 3). Percentage whiteheads did not vary significantly between treatments in 1994. In 1995 significant differences between treatments occurred (table 9) with the direct-seeded plots having the highest whitehead percentage (figure 4). Percentage whiteheads in the 120 kg seed ha^{-1} treatment (DS3) was about twice that of the TP1 and TP2 treatments.

Table 8. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for deadhearts, 1994*

Source of variation	df	MS	$P > F$
Replication	3	3.6	0.003
Treatments	5	1.4	0.056
Error	15	0.5	

MS, mean squares (from type III sum of squares)
*1995 data NS

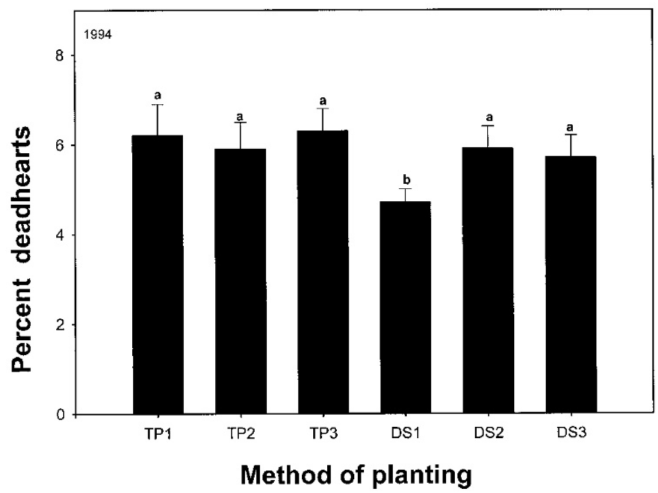

Figure 3. Stem-borer damage (% dead tillers, "deadhearts") in an irrigated lowland rice cultivar Bouaké 189, as affected by method of planting (transplanting and direct-seeded) in 1994. Transplanted at a spacing of 14 cm × 14 cm within and between rows (TP1), 20 cm × 20 cm (TP2), and 30 cm × 30 cm (TP3). Direct-seeded rice at 60 kg ha^{-1} (DS1), 90 kg ha^{-1} (DS2), and 120 kg ha^{-1} (DS3). Standard error bars ($P = 0.05$) compare statistical significance between the different planting methods.

Table 9. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for whiteheads, 1995*

Source of variation	df	MS	$P > F$
Replication	3	53.0	0.416
Treatments	5	141.3	0.052
Error	15	52.6	

MS, mean squares (from type III sum of squares)
*1994 data NS

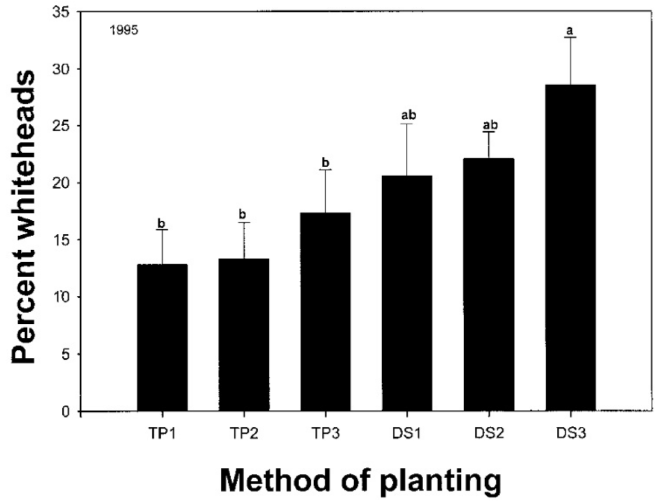

Figure 4. Stem-borer damage (% damaged panicles, "whiteheads") in an irrigated lowland rice cultivar Bouaké 189, as affected by method of planting (transplanting and direct-seeded) over a 2-year period 1994–1995 (A–B). Transplanted at a spacing 14 cm × 14 cm within and between rows (TP1), 20 cm × 20 cm (TP2), and 30 cm × 30 cm (TP3). Direct-seeded rice at 60 kg of seed ha^{-1} (DS1), 90 kg ha^{-1} (DS2), and 120 kg ha^{-1} (DS3). Standard error bars ($P = 0.05$) compare statistical significance between the different planting methods. WARDA M'bé Research Station, Bouaké, Côte d'Ivoire.

Grain yields were about 25–40% higher in 1994 than in 1995. Grain yields were significantly affected by planting methods in 1994 (table 10) but not in 1995 ($P > F = 0.280$). Highest yields (5,200 kg ha^{-1}) in 1994 were recorded in the 30 cm × 30 cm transplanted plots (TP3) and the lowest (3,450 kg ha^{-1}) were in direct-seeded rice at 90 kg seed ha^{-1} (DS2) (figure 5).

Table 10. ANOVA indicating source of variation, degrees of freedom, mean squares, and probability with F test ($P > F$) for rice grain yields in kg ha^{-1}, 1994*

Source of variation	df	MS	$P > F$
Replication	3	489,484	0.519
Treatments	5	3,634,265	0.004
Error	15	619,987	

MS, mean squares (from type III sum of squares)
*1995 data NS

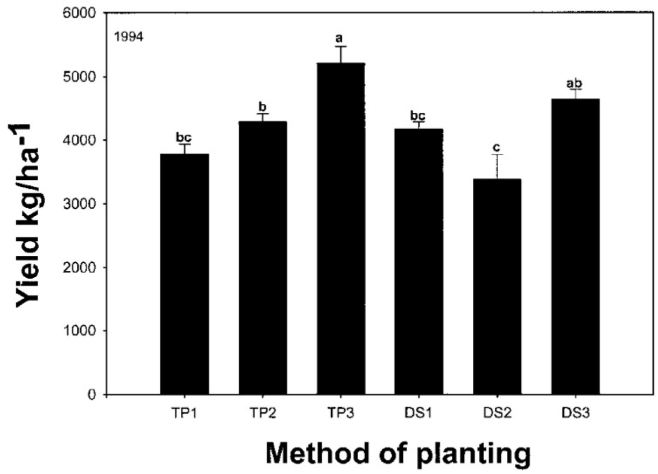

Figure 5. Grain yields kg ha^{-1} of an irrigated lowland rice cultivar Bouaké 189, as affected by method of planting (transplanting and direct-seeded) in 1994. Transplanted at a spacing 14 cm × 14 cm within and between rows (TP1), 20 cm × 20 cm (TP2), and 30 cm × 30 cm (TP3). Direct-seeded rice at 60 kg of seed ha^{-1} (DS1), 90 kg ha^{-1} (DS2), and 120 kg ha^{-1} (DS3). Standard error bars ($P = 0.05$) compare statistical significance between the different planting methods. WARDA M'bé Research Station, Bouaké, Côte d'Ivoire.

4. Discussion and conclusions

The effect of planting method (transplanting vs. direct-seeding) and plant density (spacing of transplanted seedlings and seed rate ha^{-1}) on sweep net counts of insects, insect damage and grain yield was not distinct, and varied between 1994 and 1995. *Diopsis* populations tended to be highest in close plant spacings, whether transplanted or direct-seeded (figure 1, A–D). Results of another study conducted at this same location in 1996 indicated highest adult *Diopsis* numbers in closely transplanted hills (Oyediran et al., 1999). Alghali (1984) reported a three-fold increase in *Diopsis* eggs per hill with a decrease of plant density from a 15 cm × 15 cm to 30 cm × 30 cm spacing between hills, but the percentage deadhearts due to *Diopsis* feeding did not differ. Chiasson and Hill (1993) compared the effect on *Diopsis* damage of transplanting at 20 cm × 20 cm between hills with direct-seeding (seed rate ha^{-1} not indicated). Their results indicated that, in both years of their study, *Diopsis* damage in transplanted rice was three times that in direct-seeded rice in the dry season, but in the wet season crop, damage was more in the direct-seeded rice one year, and there was no significant difference the next year. Percentage infested tillers (partially due to *Diopsis* spp.) in our study, which was conducted during the wet season, was highest in the transplanted treatments in 1995, but differences in 1994 varied within each planting method (transplanting and direct-seeding (figure 2). It is apparent that *Diopsis* numbers and *Diopsis*-caused plant damage are affected by some factor(s) differing from one year to another, which tend to confound the effects of the planting methods.

Planting method and plant spacing had little effect on percentage deadhearts caused by stem-borer feeding. In studies conducted in India, Singh et al. (1990) and Sathiyanandam et al. (1991) reported that rice plant spacings had no effect on incidence of the yellow stem borer, *Scirpophaga incertulas* (Walker). Studies in Malaysia indicated no difference in incidence of the stem borer *Chilo suppressalis* (Walker) between transplanted and direct-seeded rice fields (Lee and Ma, 1997).

Planting method and plant density had a statistically significant effect on rice grain yield only in 1994. In 1994, rice transplanted at 30 cm × 30 cm had the highest grain yield (figure 5). Ukwungwu (1987b) reported an 800 kg ha^{-1} yield increase from a 15 cm × 15 cm spacing of transplanted hills to a spacing of 30 cm × 30 cm between hills. This is similar to our results in 1994 (figure 5, TP1 = 14 cm × 14 cm vs. TP3 = 30 cm × 30 cm). However, in the 1995 test no significant differences among treatments occurred. Oyediran et al. (1999) conducted a spacing study with transplanted seedlings at this same site. They reported that widely spaced plants are able to compensate, to a certain extent, by producing more tillers per plant than closely spaced plants, thus resulting in similar yields for close and widely spaced plants. Thus, compensation may have been greater in 1995 than in 1994.

In the development of rice IPM strategies for lowland rice in West Africa, insect pest problems should not be a major concern in the decision as whether to transplant or direct-seed rice. Cultural practices such as irrigation and weeding, and their labor requirements, should be of greater concern to farmers.

References

Alghali, A. M., 1984. Effect of plant spacing on the infestation levels of rice by the stalk-eyed borer, *Diopsis thoracica*, West (Diptera: Diopsidae) *Tropical Agriculture (Trinidad)*, 61, 74–75.

Becker, L., and Diallo, R., 1992. *Caracterisation et Classification des Ecosystemes Rizicoles de la Côte d'Ivoire* (Bouaké, Côte d'Ivoire: ADRAO), 255 pp.

Béliéres, J. F., Camara, S., and Touri, A., 1994. *Les Exploitations Agricoles du Delta et leurs Résultats Technico-Éconmiques Pour la Production Rizicole en 1993* (St Louis, Sénégal: Société Nationale d'Aménagement et d'Exploitation des teres du Delta du fleuve Sénégal et des vallées du fleuve Sénégal et de la Falémé (SAED)), 70 pp. + annexes.

Chiasson, H., and Hill, S. B., 1993. Population density, development and behaviour of *Diopsis longicornis* and *D. apicalis* (Diptera: Diopsidae) on rice in the Republic of Guinée. *Bulletin of Entomological Research*, 83, 5–14.

De Datta, S. K., 1981. *Principles and Practices of Rice Production* (NewYork, USA: John Wiley and Sons), 618 pp.

De Datta, S. K., 1986. Technology development and the spread of direct-seeded flooded rice in southeast Asia. *Experimental Agriculture*, 22, 417–426.

Dingkuhn, M., 1993. Contraintes de rendement dans un périmétre irrigug du Sahel. *Annual Report for 1992* (Bouaké, Côte d'Ivoire: West Africa Rice Development Association), pp. 40–41.

Johnson, D. E., 1997. *Weeds of Rice in West Africa* (Bouaké, Côte d'Ivoire: West Africa Rice Development Association), 312 pp.

Konchan, S., and Kono, Y., 1996. Spread of direct seeded lowland rice in northeast Thailand: farmers' adaptation on economic growth. *Southeast Asian Studies*, 33, 523–546.

Lee, S. C., and Ma, K. C., 1997. Occurrence of major insect pests in machine transplanted and direct seeded rice paddy field. *Korean Journal of Applied Entomology*, 36, 141–144.

Oyediran, I. O., and Heinrichs, E. A., 1999. Seasonal abundance of rice-feeding insects and spiders in continuously cropped lowland rice in West Africa. *Insect Science and Its Application*, 19, 121–129.

Oyediran, I. O., Heinrichs, E. A., Traore, A. K. A., and Johnson, D. E., 1999. Plant spacing effect on insect pest abundance and yields of irrigated lowland rice in Côte d'Ivoire. *Journal of Plant Protection in the Tropics*, 12, 55–67.

Poussin, J. C., 1997. Direct seeding or transplanting? The example of the Senegal middle valley. In K. M. Miézan, M. C. S. Wopereis, M. Dingkuhn, J. Deckers and T.F. Randolph (eds.) *Irrigated Rice in the Sahel: Prospects for Sustainable Development* (Dakar, Senegal: West Africa Rice Development Association), pp. 191–200.

Sathiyanandam, V. K. R., Logiswaran, G., and Sundarababu, P. C., 1991. Influence of varieties, spacings and pest management on the incidence of three major pests of rice. *Madras Agricultural Journal*, 78, 10–14.

Singh, P., Sukhija, H. S., Gill, P. S., and Bangoo, B. S., 1990. Influence of agronomic manipulations on stem borer *Scirpophaga incertulas* Walker incidence in rice. *Journal of Insect Science*, 3, 148–151.

Thompson, R. A., and Quisenberry, S. S., 1995. Rice plant density effect on rice water weevil (Coleoptera: Curculionidae) infestation. *Environmental Entomology*, 24, 19–23.

Tisch, S. J., and Paris, T. R., 1994. Labor substitution in Philippine rice farming systems: an analysis of gender work roles. *Rural Sociology*, 59, 497–514.

Ukwungwu, M. N., 1987a. Effects of spacing and nitrogen fertilizer on infestation by the rice gall midge *Orseolia oryzivora* Harris and Gagné (Diptera: Cecidomyidae) in Nigeria. *Tropical Pest Management*, 33, 164–165.

Ukwungwu, M. N., 1987b. Some effects of plant densities and carbofuran on the damage by *Diopsis thoracica* West. and *Maliarpha separatella* Rag. and yield of rice in Nigeria. *Tropical Pest Management*, 33, 280–282.