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This study aimed to characterize the effects of the application of different types of litters and fertilizer on the growth and productivity of maize (*Zea mays* L. *var.*) in Senegal. A split plot experiment was conducted in a low fertile soil at Thiès. Three factors corresponded to: inorganic fertilizer as urea at two levels (0, 2), insecticide as fipronil at two levels (0, 2) and litter type at 5 levels (D, A, B, E, F). Zero (0) represented the controls without fertilizer, insecticide or litter application. Two (2) corresponded to an application of 71.4 kg ha^{-1} N fertilizer, and 7.5 L ha^{-1} insecticide, both sequentially applied 3 times during the trial. D, A, B, E, F corresponded to the control, 5.7 t ha^{-1} of *Andropogon gayanus* Kunth, *Casuarina equisetifolia* (Forssk), *Pennisetum glaucum* (L.) R. Br. and *Faidherbia albida* (Chev.) litters, respectively, applied 73 days before sowing. This gave a total of 20 experimental units with 3 replications each. With no inorganic or insecticide application, the effect on growth parameters (plant height, medium collar diameter, number of leaves per plant) was not significantly different among the different applied litters. Litter application positively affected the growth parameters compared to the control. *F. albida* litter increased the quantic maximal output of the photochemical activity by 6% and the energy use efficiency by 26%, compared to the other litter types. At harvest, litters of *F. albida*, *C. equisetifolia* and *P. glaucum* increased grain yields by 94.3% over the control. The addition of inorganic fertilizer and/or insecticide improved the stem collar diameter and plant height and grain yield. In conclusion, the incorporation of locally available litters (more specifically that of the leguminous plants *F. albida* and *C. equisetifolia*) and their combination with inorganic N fertilizer and insecticide are good alternatives to increase maize production in tropical croplands.

Key words: litter, photochemistry, growth, productivity, corn

INTRODUCTION

Achieving food security in its totality continues to be a challenge not only for developing nations, but also for the developed world. In the 1996 Rome Declaration on World Food Security, food security is defined as: food that is available at all times, to which all persons have means of access; that is nutritionally adequate in terms of quantity, quality, and variety; and is acceptable within a given culture (Madeley, 2002). Therefore, food insecurity is not simply a failure of agriculture to produce sufficient food at the national level, but instead a failure of livelihoods to guarantee access to sufficient food at the household level. Thus, availability, access, and affordability are all elements of food security. Food security is affected by a complexity of factors. The root cause in developing countries, Africa in general and Sub–Saharan Africa in particular, is the inability of people to gain access to food due to poverty (IAC, 2004). The major challenge for Africa in terms of food security is its underdeveloped agricultural sector that is characterized by over–reliance on primary agriculture, low soil fertility, minimal use of external farm inputs, environmental degradation, significant food crop loss both pre– and post–harvest, minimal value addition and product differentiation, and inadequate food storage and preservation that results in significant commodity price fluctuation. In Senegal, as in all other West–African countries, the food situation is far from being satisfactory, and more than 32% of households live under the poverty line (Daps, 1990). Ninety five percent of the food in Sub–Saharan Africa is grown under rain fed agriculture (IAC, 2004). Hence, food production is vulnerable to adverse weather conditions. Since the 70's, agriculture in the Sahelian area has been characterized by erratic rainfalls (Davis–Carter, 1989). There is an overall decline in farm input investment including fertilizers, seeds, and the adoption of technology. The soils continue to degrade leading to the reduction of farm productivity. Other factors that negatively affect agriculture in Africa include the decline in the use and length of fallow periods, the expansion of agricultural production into marginal and fragile areas, the removal of vegetation through over grazing, the rapid population growth leading to land pressure, the limited access to agriculture–related technical assistance, and the lack of knowledge

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about profitable soil fertility management practices leading to expansion into less–favourable lands. Food crops draw more nutrient elements from soils than they return in the year. Along this line, Badiane (1993) reported that a decrease in soil fertility in the tropical area of Senegal is related to low nutrient replenishment, depleting the soil of organic matter and mineral elements such as N and P. The loss of productivity of soils in Sub–Saharan Africa is often related to the decrease of soil organic matter and nutrient status. It is well known that the amendment of plant residues can improve soil's nutrient content, physical properties and biological activity, as well as crop performance (Aggangan *et al.*, 1999; Caravaca, 2002; Roldan, 1996). Application of organic inputs, such as crop residues, has to be considered for the development of sustainable agricultural systems (Quintana, 1988).

In order to reverse the tendency of food importation dominated by rice, the Senegalese government has implemented a follow–up policy of cereal production through the Local Cereal Promotion Programme (Broutin and Sokona, 1999). This programme in part, encourages the consumption of locally produced cereals in order to promote growth in production. Apart from millet, sorghum, and rice; which are the most cultivated cereals, maize constitutes one of the staple foods in the central and southern parts where it is well cultivated. This plant has high potassium, nitrogen and phosphorus requirements (Anon, 1997), and thus requires a good fertile soil. Taking into account the management of land fertility in agricultural practices is one of the most appropriate strategies against land degradation in most cereal–producing developing countries. Hence, it is necessary to broaden the knowledge of options for preserving the soil's organic material in an environment characterized by a low availability of manures and a high cost of fertilizers (Scoones, 1990). Besides, for many decades efforts have been put into on the recovery of the harvest waste and plant materials, directly or indirectly via animals, to improve the organic manuring practice (Hamon, 1968; 1972). Murwira and Kirchmann (1993) indicated that nutrient use efficiency may increase through the combination of manure and fertilizer.

The effect of nutrient sources, such as litters of highly available weeds and multi–purpose tree litters, on soil quality and crop production remains poorly studied in Senegal. However, litters of the tree species such as *Casuarina equisetifolia* (exotic), *Faidherbia albida* (native); herbaceous species (*Andropogon gayanus*), and cultivated crops (*Pennisetum glaucum*) are highly available in the agro–ecosystems. This study was designed to investigate the effect of the application of these species' litters on the growth and production of maize (Across Pool 16 variety). It also aimed to determine to which extend the combination of these litters with organic fertilizer and insecticide could affect the growth and the production of maize. As reported by Diallo *et al.* (2005), the C/N ratios of *Andropogon gayanus, Casuarina equisetifolia, Faidherbia albida* and *Pennisetum glaucum* litters are 51, 35, 21.4, and 50, respectively.

MATERIALS AND METHODS

Experimental site

This study was conducted at the Centre of Agricultural Technical Application (CATA) of the *Ecole Nationale Superieure d'Agriculture* (ENSA) in Thiès, located in South–Central Senegal (14°42′ N and 16°57′ W). The site is set up on a dead–beat tropical ferruginous land of a "Dek–dior" type, with a high soil C/N ratio ranging from 13 to 18.35 in the first 30 cm soil depth. The organic material rate (0.62–1.26%) in the top layer of the experimental site is satisfactory enough for a sandy–clayey soil. Delville (1996) determined a range of 0.6 to 1% organic material for sandy soils. The region belongs to a cover zone between the Sudano–Sahelian savannas and the Sahelian formations (MEPN, 1997) located under the dune system of the coastal sector. The plant species encountered in the region are mainly *Adansonia digitata, Faidherbia albida, Acacia raddiana, Acacia seyal, Balanites aegyptiaca, Borassus aethiopium* and *Acacia ataxacantha*. The climate of the region is characterized by a short wet season (June–October) and a long dry season (October–June), with erratic rainfalls. During the 2002 rainy season, the amount of accumulated rainfall (243.5 mm) was less than the average rain of the previous ten years (425 mm). The month of July was particularly drier with only two rains in a 20 day interval. To fill the water deficit, extra irrigations (118.5 mm) were carried out to give a total of 362 mm for this cropping season (Fig. 1).
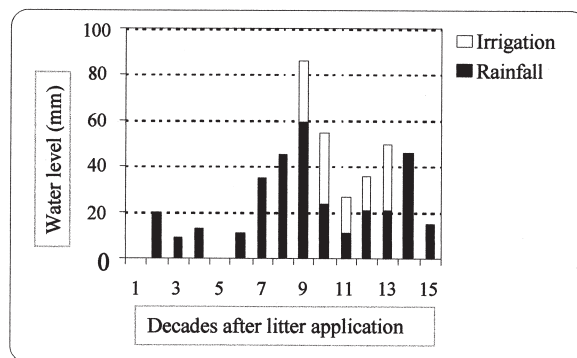

Fig. 1. Decade distribution of rains and extra irrigation during the cultivation period.

Plant material

This study was carried out using the maize (*Zea mays*) genotype Across Pool 16 issued from the ISRA (*Institut Senegalais de Recherches Agricoles*) series (Ndiaye, 1994). The basic genetic material, introduced in Senegal in 1986, originated from IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria), and later gave the Across 86 Pool 16 variety. The plant matures between 75 to 80 days, with the female blossoming appearing at 48 days. At maturity, the grains appear a white colour. It is a plant material recommended for

the South zone of the groundnut Basin (Médina Sabakh, Missirah Walo, Porokhane and Keur Samba Guèye villages) and villages in the Thiès region, after multi–annual tests in the real environment and in a research station.

Experimental design

Three factors (litter type, inorganic fertilizer, and insecticide) were tested in a split plot design. The litter type factor included the 5 levels D, A, B, E, F; where "D" corresponded to a control without mulching, and "A, B, E, F" corresponded to 5.7 t ha^{-1} of *Andropogon gayanus* Kunth, *Casuarina equisetifolia* (Forssk), *Pennisetum glaucum* (L.) R. Br. and *Faidherbia albida* (Chev.) litters, respectively. These litters were selected because they are abundantly found in the area. The inorganic fertilizer and insecticide factors corresponded to the application of urea and fipronil at 2 levels (0, 2) each. Zero (0) represented controls without urea or fipronil application, while two (2) corresponded to a total application of 71.4 kg ha^{-1} of fertilizer and 7.5 L ha^{-1} of insecticide; both sequentially supplemented 3 times during the course of the experimentation. The combination of the three factors (litter × fertilizer × insecticide) with their respective levels (x_i) gave a total of 20 treatments. Such combination resulted to the following: 5 treatments corresponding to the 5 levels of litter factor, when we consider the zero levels of fertilizer and insecticide (D, A, B, E, and F); 5 treatments corresponding to the combination of 7.5 L ha^{-1} insecticide with the 5 litter levels (N0F2, AN0F2, BN0F2, EN0F2, and FN0F2); 5 treatments corresponding to the combination of 71.4 kg ha^{-1} of fertilizer with the 5 litter levels (N2F0, AN2F0, BN2F0, EN2F0, and FN2F0); and the remaining 5 treatments including litter, fertilizer, and insecticide (N2F2, AN2F2, BN2F2, EN2F2, and FN2F2). "D" treatment was without litter, fertilizer, or insecticide and was equivalent to "N0F0". "N0F2" corresponded to the only presence of fipronil (insecticide), "N2F0" was the only application of nitrogen (fertilizer), and "N2F2" corresponded to the treatment with only nitrogen and fipronil. These 20 treatments were replicated 3 times each, giving a total of 60 experimental units (plots). Plot size was 7 m^2 with 4 lines of 3.5 m. There was 50 cm spacing between lines and 70 cm between hills in a line (total 20 hills). A space of 1.5 m and 4 m was left between plots and between the blocks, respectively.

The experimental area was primarily ploughed dry at 10 cm depth, using a mechanical ploughing machine. Litters were applied at 4 kg per plot (5.7 t ha^{-1}) 73 days before the sowing (to allow for decomposition before the first rains). Four previously thiramius–treated (1 g kg^{-1} dose) maize grains were sown per hill on August 14 after a rain of 24 mm. At the planting period, P and K fertilizers were applied in the whole area at 57 kg ha^{-1} each as a starter, to facilitate early seedling growth. Nitrogen as urea was applied at the rate of 71.4 kg ha^{-1} in total on three occasions (at sowing, at 32th and 64th days after the sowing –DAS–). As for the fipronil (insecticide), a total dose of 7.5 L ha^{-1} was sprayed (a 1.5 L ha^{-1} application during mulching and two applications of 3 L ha^{-1} 15 days apart). Cultivation and weeding were carried out as needed during the developing cycle.

Studied parameters

Apart from leaf area index, three plants were randomly selected from each plot, and the following measures were carried out once a week up to maturity. At harvest, the central 9 plants (3.15 m^2) out of the total 20 plants of the plot were considered to estimate the yield components.

Soil humidity

The soil humidity was measured using the gravimetrical method. Soil samples were taken at a 10, 30, and 60 cm depth in each plot and at each sampling period. The fresh weight (FW) of the samples was determined using a METTLER precision scale. After oven drying at 105°C for 48 hours, the dry weigh (DW) was recorded. Thus, the soil humidity weight (Hw) in a plot was calculated from the equation: Hw (%)=[(FW–DW)/DW]×100, and the mean value of each treatment was calculated.

Leaf area index (LAI)

The leaf area index (LAI) was measured weekly between 9 h 30 mn and 10 h 30 mn, with a surface analyzer of a Licor model LAI 2000 type 2000 (Licor, Nebraska, USA). In each plot, one measure was taken above and four below (diagonally between two lines) the same canopy, with 2 repetitions.

Physiological and agro–morphological parameters

The physiological measures mainly concerned the chlorophyll fluorescence, measured using a fluorimeter of Hansatech model PEA (Plant Efficiency Analyser, Hansatech Instruments Ltd, King's Lynn, England) type. It allows one to determine the photochemical activity of the plants, which is closely related to the photosynthetic activity. During plant growth, agro–morphological parameters such as the number of leaves per plant (NLP), the plant height (PH) and the plant medium collar diameter (MCD) were recorded. At harvest (77 DAS), fresh plant material was first dried in the laboratory in open–air for two weeks, and later under shelter for one week. The maize ears at harvest were left to dry for 21 days. The different agronomic parameters determined included the number of ears per plant (NEP), the number of grains per ear (NGE), the total grains yield (GY), and the weight of 1000 grains (WTG).

Statistical analysis

Analysis of variance (ANOVA) and discriminating factoring (AFD) were performed using STATITCF (Version 5, ITCF) software for all the determined agronomic parameters. The Newman–Keuls test was used for means comparison.

RESULTS

Monitoring of the soil humidity

The evolution of the soil humidity balance was monitored along the cultivation period (Fig. 2). The results of the analysis of variance didn't show any significant dif-
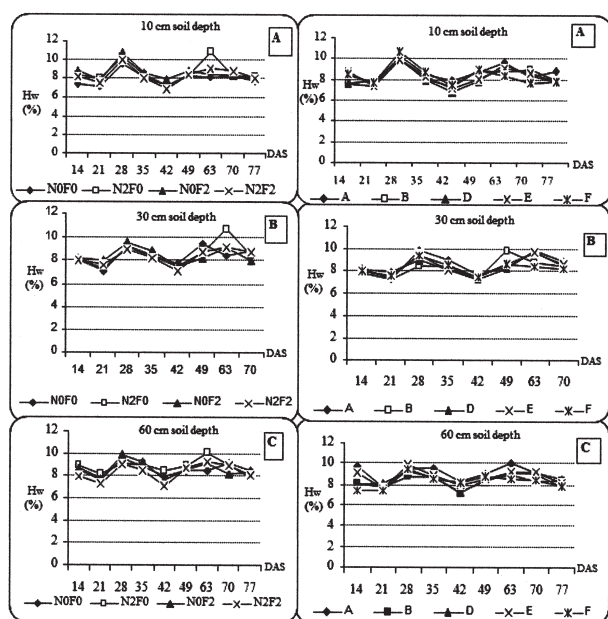
Fig. 2. Evolution of the humidity weight (Hp) balance at 10, 30 and 60 cm soil depths in relation with the different treatments
Values for each soil depth at each sampling period are means of 3 replicates plots. Results from "fertilizer × insecticide" interaction and litter types are shown. N0F0=no nitrogen and fipronil; N2F0=only nitrogen; N0F2=only fipronil; N2F2=combination of nitrogen and fipronil; A=*Andropogon gayanus*; B=*Casuarina equisetifolia*; D=*Control*; E=*Pennisetum glaucum*; F=*Faidherbia albida*; Hp=ponderal humidity; DAS=days after sowing.

ference between the three soil depths of 10, 30, and 60 cm, neither for the fertilizer × insecticide combination (except at 63th DAS for the 10 cm and 30 cm depths where the treatment with only urea application showed higher soil humidity), nor for the different litter type treatments (except at 14th DAS for the 60 cm depth where soil humidity in the control without mulching was higher, followed

by the *Pennisetum glaucum* treatment). Correlating to Fig. 1, 14th and 16th DAS correspond to the 9th and 14th decades after litter application with the highest amounts of rain (60 mm and 44 mm, respectively). Without mulching, water infiltration is faster and accumulates in deeper depths, while the incorporation of plant debris contributes to the maintenance of surface soil humidity, which is beneficial for plant growth.

Physiological and agronomic outputs

The analysis of variance made on the growth parameters didn't reveal any significant difference in the "litter × fertilizer × insecticide" interaction (Table 1). However, significant differences were observed when the litter treatment was separated from the "fertilizer × insecticide" combination. Therefore, results of the combination of the 3 factors are not reported. The plant height (PH) was only significantly different between treatments in the "fertilizer × insecticide" interaction. The evolution of PH (Fig. 3) follows the same trend for all treatments. It is characterized by a slow growing phase (25 cm height at the 35th DAS), followed by a fast growing period reaching the maximum height at the 63th DAS. At the maturing phase, extending from the 63th DAS up to the 76th DAS, the plant growth stopped and the yellowing of leaves increased. During the growing period between 40 to 50 DAS, the plant height was significantly lower in the control without fertilizer and insecticide compared to the other treatments (Fig. 3A). The plant height was also lower in the control without mulching but it was not significantly different with the other litter types. At 70th DAS, although not significant, the plant height was higher in the presence of both urea and fipronil compared to the presence of the two components taken separately. Similarly, when we consider the litter types, the *Faidherbia albida* litter led to a greater plant height, while the *Pennisetum glaucum* litter led to the poorest growth (Fig. 3B).

Table 1. Results of the ANOVA (test Student Newman–Keuls *p*=0.05) on the variables related to the growth and productivity

Parameters	Fertilizer × Insecticide (F×I)		Litter (L)		Interaction L × F × I	
	Probability	F–value	Probability	F–value	Probability	F–value
PHmax	**0.0003**	***	0.1482	ns	0.6081	ns
NLPmax	0.9165	ns	0.5893	ns	0.3509	ns
MCDmax	**0.0018**	**	0.1843	ns	0.4231	ns
NEP	**0.0373**	*	0.416	ns	0.5985	ns
NGE	0.4586	ns	**0.0104**	*	0.1583	ns
LAImax	0.6147	ns	0.668	ns	0.3693	ns
WTG	**0.0387**	*	0.9629	ns	0.8806	ns
GY	**0.045**	*	**0.0034**	**	0.102	ns
BY	**0.0022**	**	0.4912	ns	0.6089	ns

In bold, probabilities for the significant tests.*, ** and *** = significant test at 5, 1 and 0.1%; ns=not significance at 5%. PHmax=maximum height of the plant. NLPmax=maximum number of leaves per plant; MCDmax=maximum medium collar diameter; NEP=number of ears per harvesting area; LAImax=maximum leaf area index; WTG=weight of thousand grains; NGE=number of grains per ear; GY=grains yields; BY=biomass yields

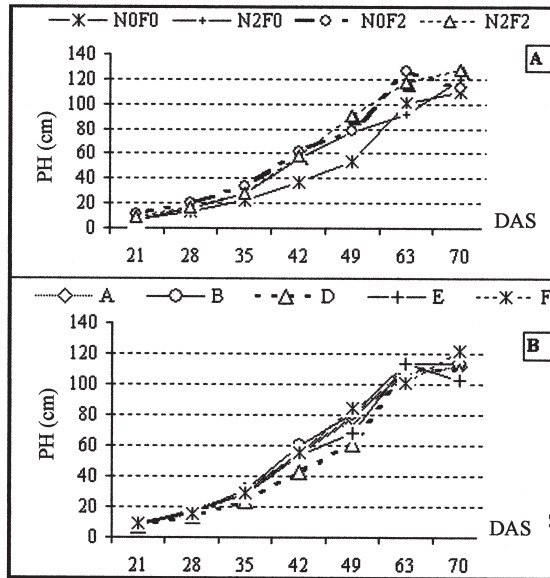**Fig. 3.** Plant Height evolution during the cultivation period as affected by the "fertilizer × insecticide" interaction (A) and litter types (B)
Results at each sampling period are means from 3 replicates plots per treatment. PH=Plant height N0F0=no nitrogen and fipronil; N2F0=only nitrogen; N0F2=only fipronil; N2F2=combination of nitrogen and fipronil; A=Andropogon gayanus; B=*Casuarina equisetifolia*; D=Control; E=*Pennisetum glaucum*; F=*Faidherbia albida*; DAS=days after sowing

Fig. 4. Stem diameter evolution during the cultivation period as affected by the "fertilizer × insecticide" interaction (A) and litter types (B)
Results at each sampling period are means from 3 replicates plots per treatment. MCD=medium coller diameter, N0F0=no nitrogen and fipronil; N2F0=only nitrogen; N0F2=only fipronil; N2F2=combination of nitrogen and fipronil; A=*Andropogon gayanus*; B=*Casuarina equisetifolia*; D=Control; E=*Pennisetum glaucum*; F=*Faidherbia albida*; DAS=days after sowing

Fig. 5. Evolution of leaf area index during the cultivation period as affected by the "fertilizer × insecticide" interaction (A) and litter types (B)
Results at each sampling period are means from 3 replicates plots per treatment. LAI=Leaf area index; N0F0=no nitrogen and fipronil; N2F0=only nitrogen; N0F2=only fipronil; N2F2=combination of nitrogen and fipronil; A=*Andropogon gayanus*; B=*Casuarina equisetifolia*; D=control; E=*Pennisetum glaucum*; F=*Faidherbia albida*; DAS=days after sowing

The ANOVA revealed significantly different data at 1% level for the medium collar diameter (MCD) when we consider the fertilizer × insecticide interaction (Table 1). Figure 4 shows the evolution of the MCD of the variety with the fertilizer and insecticide combination (Fig. 4A), and litter type (Fig. 4B). Figure 4A reveals a significantly smaller MCD of the control plant (no fertilizer, no insecticide), especially at the 42th and 49th DAS, compared to when fertilizer and/or insecticide is applied. The control treatment without any litter application also gave smaller MCD but the difference was not significant (Fig. 4B) with the other litter types; by contrast the *Faidherbia albida* litter gave a relatively larger MCD. At 70th DAS, indifferent to the type of litter to be considered, the treatment with urea application gave significantly larger MCD (1.5 cm), and the control without fertilizer and insecticide had the smallest MCD (0.67 cm). A positive correlation was observed between plant height, MCD, and time, in that at given periods plants with a larger MCD had the highest height, which was affected by the applied treatment.

The leaf area index (LAI) was measured to follow the evolution of the canopy during the experimentation period (Fig. 5). It appears that the LAI shows the same trend for all studied factors during the cycle, and there was no significant difference among them (Table 1). The index increased to reach the maximal value of 0.78 at the 63th DAS (Fig. 5A, 5B). This period corresponded to the 14th decade after litter application, characterized by optimal soil humidity. Afterwards, the index got reduced until reaching the 71th DAS with an average value of 0.71.
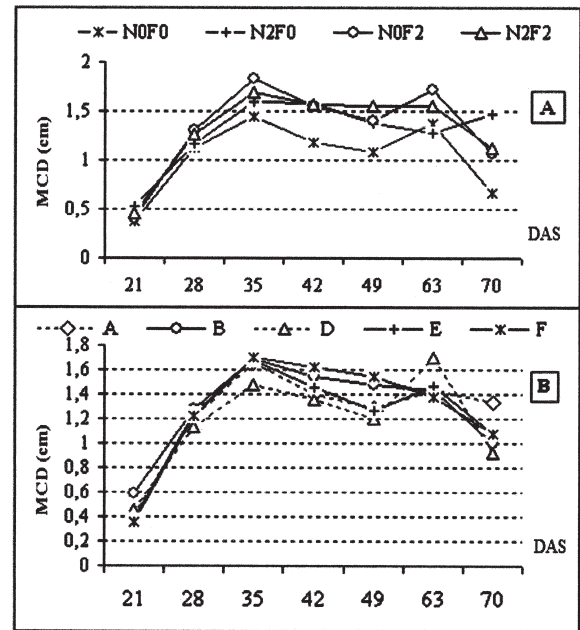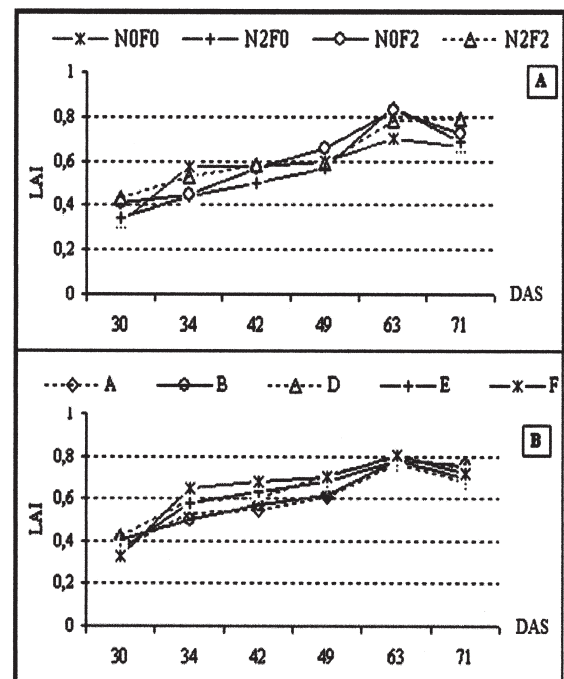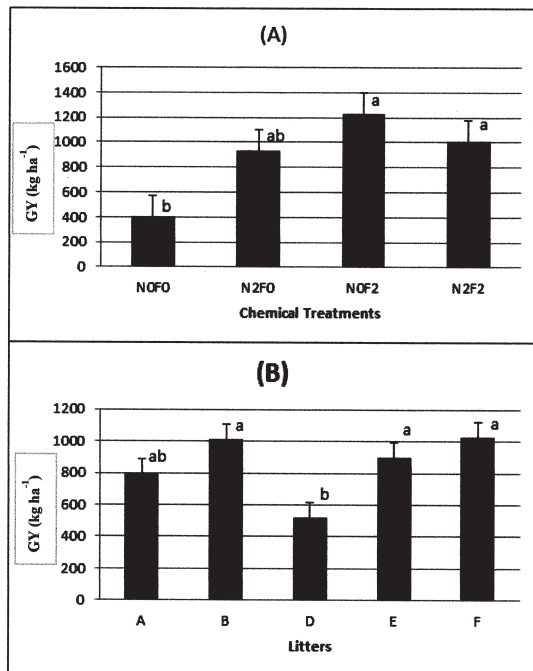
Fig. 6. Grain yields of maize as affected by the "fertilizer × insecticide" interaction (A) and litter types (B)
Results at each sampling period are means from 3 replicates plots per treatment. GY=Grain yield; N0F0=no nitrogen and fipronil; N2F0=only nitrogen; N0F2=only fipronil; N2F2=combination of nitrogen and fipronil; A=*Andropogon gayanus*; B=*Casuarina equisetifolia*; D=Control; E=*Pennisetum glaucum*; F=*Faidherbia albida*

The number of ears per plant (NEP) and the weight of 1000 grains (WTG) were significantly different at 1% level in the fertilizer × insecticide combinations, while the significance of the number of grains per ear (NGE) was observed in the litter type factor (Table 1). The unfertilized treatment without insecticide had a significantly lower NEP (NEP=2) compared to the average (NEP=5) of other treatments. However, no significant difference was observed between the litter treatments in terms of NEP. For the weight of 1000–grains (WTG), the only application of urea led to a significantly higher value of 155 g compared to the control (119 g). With only fipronil or with the combination of urea and fipronil, an average value of 143 g WTG was obtained. Concerning the number of grains per ear of maize, we observed three homogenous groups in the litter factor. One group included *F. albida* and *C. equisetifolia* with a similar NGE of 273, significantly higher than that of the control (178). The group including *P. glaucum* and *A. gayanus* litters had an intermediate impact with a NEG of 201, not significantly different with that of the control or with the group of *F. albida* and *C. equisetifolia*.

The statistical analysis revealed a significance of the fertilizer × insecticide interaction and litter factor (Table 1) for the grain yields (GY). As shown in Fig. 6A, the only application of fipronil or the combination of urea and fipronil gave significantly higher grain yields (1221 and 1000 kg ha^{-1}, respectively) in comparison with that of the control (without urea and fipronil) with 397.7 kg ha^{-1}. The application of only urea gave an intermediate maize pro-

Table 2. Results of the analysis of variance of the maximal quantic output of the photochemistry (ϕ_{P0}) and the use efficiency of the light (ϕ_{E0}) between 42 to 70 DAS

Factor level	42 DAS		49 DAS		63 DAS		70 DAS	
	ϕ_{P0}	ϕ_{E0}	ϕ_{P0}	ϕ_{E0}	ϕ_{P0}	ϕ_{E0}	ϕ_{P0}	ϕ_{E0}
N0F0	0.71[a]	0.27[a]	0.73[b]	0.31[b]	0.73[a]	0.33[b]	0.73[a]	0.34[a]
N2F0	0.73[a]	0.35[a]	0.77[a]	0.42[a]	0.75[a]	0.41[a]	0.73[a]	0.37[a]
N0F2	073[a]	0.33[a]	0.75[ab]	0.36[ab]	0.75[a]	0.39[a]	0.74[a]	0.37[a]
N2F2	0.75[a]	0.38[a]	0.77[a]	0.41[a]	0.76[a]	0.40[a]	0.75[a]	0.40[a]
fertilizer × insecticide" effect (F–value)	ns	ns	*	**	ns	*	ns	ns
A	0.72[b]	0.32[b]	0.75[a]	0.36[a]	0.75[a]	0.38[a]	0.75[a]	0.40[a]
B	0.72[b]	0.32[b]	0.77[a]	0.40[a]	0.75[a]	0.40[a]	0.74[a]	0.36[a]
D	0.71[b]	0.30[b]	0.75[a]	0.38[a]	0.74[a]	038[a]	0.76[a]	0.39[a]
E	0.72[b]	0.34[ab]	0.76[a]	0.37[a]	0.74[a]	0.37[a]	0.73[a]	0.36[a]
F	0.76[a]	0.38[a]	0.75[a]	0.38[a]	0.75[a]	0.39[a]	0.73[a]	0.35[a]
« litter » effect	*	**	ns	ns	ns	ns	ns	ns
"litter × fertilizer × insecticide" interaction: F–value	ns	ns	ns	ns	ns	ns	ns	ns
C.V.1 (%)	7.4	34.2	3.6	17.3	4.3	16.6	5.5	21
C.V.2 (%)	5	13.6	3	12.2	3.7	10.6	4.4	13.3

* and ** = significant at 1% and 5%, respectively; ns=non–significant at 5%. For each column, the reported averages with the same letters by factor are statistically identical at 5%. N0F0=no nitrogen and fipronil; N2F0=only nitrogen; N0F2=only fipronil; N2F2=combination of nitrogen and fipronil; A=*Andropogon gayanus*; B=*Casuarina equisetifolia*; D=Control; E=*Pennisetum glaucum*; F=*Faidherbia albida*; C.V.1=coefficient of variation of the factor "fertilizer x insecticide" combination; C.V.2=coefficient of variation of the "litter" factor

duction of 928.7 kg ha^{-1}. The Figure 6B shows the effect of the litter factor on grain yields. Grain yields triggered by the application of *F. albida*, *C. equisetifolia*, and *P. glaucum* litters were not significantly different from one another, but were significantly higher than the control's yields (519 kg ha^{-1}). With 795 kg ha^{-1} grain yield, the A. gayanus litter showed an intermediate effect between these two groups (the control and the other litters). In the end, *F. albida*, *C. equisetifolia* and *P. glaucum* litters increased maize productivity in grains by 94.3% on average, while the *A. gayanus* only improved it by 53% compared to the control without litter.

The photochemical activity

As shown in Table 2, the analysis of variance didn't reveal a significant effect of the "litter × fertilizer × insecticide" interaction on the quantification parameters of the photochemical activity: maximal quantic output of the photochemistry (ϕ_{P0}), and light use efficiency (ϕ_{E0}). However, considering only the "fertilizer × insecticide" combination, a significant effect was obtained at 49th DAS. The two nitrogenized treatments, with and without insecticide, had a better quantic output (0.77), significantly higher than that of the control without fertilizer and insecticide (0.73). The treatment with only insecticide (fipronil) application gave an intermediate value of quantic output (0.75). At the 63th DAS, the light use efficiency in the nitrogenized and/or insecticide applied treatments was significantly higher (0.41) than that of the control (0.31). Considering the "litter" factor, there was a significant effect on ϕ_{P0} and ϕ_{E0} only on the 42th DAS. At this period, it appeared that *F. albida* litters gave a significantly higher ϕ_{P0} (0.76) than that of the other litter types, which did not differ from the control (0.71). Similarly, the same litters of *F. albida* significantly led to a higher ϕ_{E0} (0.38) in comparison to the other litter treatments.

DISCUSSION

Sandy soils are widely distributed in the tropics where they occupy most of the arid and semi–arid areas. These soils are characterised by a low level of soil organic carbon, a low cation exchange capacity (CEC), a high risk of nutrient leaching, low structural stability, and high sensitivity to erosion. Both chemical fertilizer and physical stability are weak in these soils (Pieri, 1992; Sanchez and Logan, 1992). Due to these facts, the influence of organic matter on the properties of these soils, on their potential of productivity, and on the sustainability of agricultural systems is thus fundamental (Pieri, 1992; Feller, 1995b). Soil organic matter (SOM) in fine and medium fractions influences the capacity of a soil to store and exchange nutrients. In this respect, Hien (2004) indicated that the application of manure along with a N fertilizer is favourable for preferential storage of C in the fine fractions. In parallel, the role of plant debris in the biogeochemical functioning of sandy soils appears fundamental. This is especially true for N, as in sandy soils N initial reserve and storage potential are low and SOM turnover is rapid

(Blondel, 1971; Ruiz *et al.*, 1995). From an agronomic point of view, there is a need to favour agricultural practices that allow an important and constant restitution of plant or animal debris (Ganry, 1991; Feller, 1995a; Manlay *et al.*, 2002). To this respect, litters of locally available species in combination with N fertilizer and insecticide were tested on maize growth and production, in a tropical sandy soil of Central Senegal (Thies). Extra irrigation was carried out for satisfactory hydrous conditions, important for the nitrogen dynamic as reported by Ganry *et al.* (1995).

Our results on photochemical activity (ϕ_{P0} and ϕ_{E0}) distinguished the treatments with inorganic N application and *F. albida* litter (higher activity) from the other treatments, which showed lower activity. The good photochemical activity observed in these treatments could be related to higher chlorophyll content and in complex pigment–proteins, respectively involved in the absorption of photons, and in the trapping and transfer of energy towards the reaction centres. Guèye (2002) reported the possibility of using the chlorophyll content as an indicator of tolerance to the hydrous constraint. According to this author, the effects of mineral deficiencies (with nitrogen in particular) are similar to those induced by the hydrous deficit. Other authors (Jung 1967; Louppe *et al.*, 1996) have reported the important release of nutrient elements, nitrogen in particular, from *F. albida* litter during its decay. The release of nitrogen, slow in dry season (11%), would be more important in the rainy season (55%) as reported by Diallo (1999) and would have a similar effect as that of the urea contribution in this present study. Hence, the good photochemical activity from these two treatments in the middle of the growing stage could be linked to N contribution, and the absence of a significant difference at the end could result from a decrease of the photosynthetic activity due to plant senescence.

Considering the different growth parameters and yield components, the application effect of *F. albida* and *C. equisetifolia* litters was most positive and was comparable to that of nitrogenized treatments. The influence of litter quality on decomposition and impact on soil quality has been a subject of study and a significant amount of literature has come out in the last two decades. In terms of agronomical aspects, litter quality refers to the relative ease of decomposition by decomposing organisms and associated mineralization of nutrients (Paustian *et al.*, 1997). On the other hand, retardation in the rate of decomposition favors more resident period for the input C and this environmental aspect of litter quality is gaining importance in the soil C sequestration efforts to minimize the CO_2 build up in the atmosphere (Janzen, 2006). Although we did not follow their decomposition rate, litters were applied 2 months and half before the starting of the experiment, to ensure a good decomposition. *F. albida* followed by *C. equisetifolia* results in lower C/N ratios of 21.4 and 35, respectively, in comparison with *P. glaucum* and *A. gayanus* with 50 and 51 C/N ratios, respectively. Litters of *F. albida* and *C. equisetifolia* with desirable C/N ratios contributed to significant N release for use by subsequent maize crop. These litters

have the particularity of having good nitrogen content according to the results of researches carried out by Olivier *et al.* (1990) and Louppe *et al.* (1996). The output in maize grain yields the following application of these litters was 93.4% higher than that of the control. This output improvement is widely beyond that reported by Pieri (1986) who obtained 10% maize grain improvement when 10 t ha⁻¹ of sorghum litter was applied and a 22% gain over the control when the litter was combined with 60 kg N ha⁻¹. Litters with high C/N ratios may lead to N immobilization, which needs to be overcome by additional N. Elsewhere in the tropics; Grant (1981) stated that when old fallow soils in Zimbabwe are tilled for cropping, the problem of low fertility of sandy soils is compounded by competition for available nutrients with soil micro–organisms that proliferate. As micro–organisms need nitrogen to develop, Delville (1996) stated that a straw contribution should be, if possible, accompanied with a mineral nitrogen contribution to counter the depressive effect.

On the other hand, litter quality controlled by the content of polysaccharides, lignin/tannin, and polyphenols, has an impact on the decomposition rate. The polysaccharides are good substrates for microbes and hence degrade rapidly in soils. The presence of species such as lignin/tannin tend to slow down the decomposition process of litter considerably and are reported to be the most recalcitrant materials among the naturally occurring organic compounds (Hammel, 1997). Several studies have mentioned the negative effect of polyphenols on the N mineralization process (Palm and Sanchez, 1991). Diallo *et al.* (2005) investigated the effect of 5 leaf litters of different qualities on soil nitrogen mineralization patterns during a mid–term field experiment (12 months), and reported that any relationship could be between litter quality (N content, cellulose, hemicellulose, and lignin) and N mineralization. During a laboratory incubation experiment, Sall *et al.* (2003) compared the effect of *A. gayanus*, *C. equisetifolia*, *F. albida* on C and N dynamics in the presence or not of inorganic N. They found a similar immobilization in soil amended with *A. gayanus*, *C. equisetifolia*, despite the fact that these materials have different C/N ratios, and related this situation to the abundant polyphenol content in *C. equisetifolia* litters. The addition of inorganic N modified the patterns of CO_2–C respiration and net N immobilization, and the magnitude of these modifications varied according to the litter quality. The inclusion of inorganic fertilizer and insecticide as part of a mixture in our experiment resulted in improved grains, total above–ground biomass yields and 1000–grain mass. The supply of N may have shortened the period of immobilization, and may have stimulated nutrient mineralization at a time when nutrients were required by plants; while the insecticide application may have enhanced the wealth of the plant for better physiological response and nutrient uptake dynamic.

In conclusion, productivity of ecosystems characterized by sandy soils is generally low because of erratic rainfall and poor nutrient availability. It appears from this study that sustainable management of locally available plant residues integrating the use of inorganic N and insecticide, can greatly contribute to elevated soil quality for subsequent yield increase. In this study, litters of *Faidherbia albida* (Chev.) were shown to improve the quantic maximal output of the photochemistry (ϕ_{P0}) and use efficiency of the energy (ϕ_{E0}) by 6 and 26%, respectively. Similarly, the nitrogenized treatments increased the activity by 5 and 40%. Together with that of *Casuarina equisetifolia* (Forssk), litters of *Faidherbia albida* (Chev.) lead to a significant increase in the number of grains per ear. Therefore, it appears that the inclusion of inorganic N would be more beneficial with higher C/N ratio litters such as *P. glaucum* and *A. gayanus* to maximize their effect.

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