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Alley Cropping of Maize and *Gliricidia sepium* in the Sudanese Sahel Region : Some Technical Feasibility Aspects

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An association in un alley cropping experiment of a short-term maize variety and a tree legume (Gliricidia sepium) *adapted to the Sudanese Sahel region wus studied from the point of view of the nitrogen balance and plot yields. Isotopic labelling applied in the field enabled the contribution to maize nitrogen nutrition from different nitrogen sources (fertilizer, prunings, and soil) to be quantified. For equal cultivated areas, ulley cropping provides a maize* yield *greater thun thut of maize grown in pure stand without nitrogen fertifizer. However this yield is only 40% of thut obtained in pure stands with fertilizer nitrogen. Alley cropping gives a very favourable Lund Equivalent Ratio (LER) of 0.90 and 1.58 compared with N-fertilized and non-N-fertilized plots, respectively. These LERs demonstrate* the *increased biological efficiency of the cultivated soil in un agroforestry system. The percentage of the total nitrogen in the muize coming from prunings (Nfdp) varies between 30 and 35% and the true coefficient of nitrogen utilization of the prunings (TCUp) varies from 15–25%. In the* environment *of central Senegal,* the *percentage of total nitrogen* of G. sepium *coming from* N_2 *fixation is quite low (Ndffix = 25%), and consequently, in the maize,* the *nitrogen coming from* N_2 *fixation (Ndffix) is only 8%. It is therefore necessary to improve the efficiency of nitrogen fixation of* Ci. sepium *in* this zone *to assure the sustainability of the agroforestry system.*

Keywords Agroforestry, ^{15}N method, truc coefficient of utilization of N, LER, nitrogen fixation

In spite of the interest which it arouses in regions of high population pressure (Adegbehin and Igboanugo 1990), alley cropping is still far from being perfect. In fact, even from simply the technical angle, only its implementation is still difficult. When the soil fertility is low, applications of organic matter originating from hedges

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TABLE 1 Mean analytical properties for the experimental field

Component	Unit	Depth 0-20 cm	Depth 20-40 cm
Particle size[a]			
clay (< 2 µm)	%	5.3	6.2
slit (2-20 µm)	%	2.5	2.7
total sand (20-50 µm)	%	92.2	91.1
Organic matter			
Organic matter	%	0.47	0.38
Organic carbon[b]	%	0.27	0.22
Total nitrogen[c]	$g\ kg^{-1}$	0.34	0.29
C/N ratio		8	8
Available P			
Olsen-Dabin method	$mg\ kg^{-1}$	21.4	19.7
Adsorbant complex[d]	$cmol_c\ kg^{-1}$		
Ca^{2+}	$cmol_c\ kg^{-1}$	1.12	0.93
Mg^{2+}	$cmol_c\ kg^{-1}$	0.21	0.18
K^+	$cmol_c\ kg^{-1}$	0.05	0.05
Na^+	$cmol_c\ kg^{-1}$	0.03	0.04
Mn^{2+}	$cmol_c\ kg^{-1}$	0.02	0.03
S(Ca, Mg, K, Na)	$cmol_c\ kg^{-1}$	1.41	1.21
CEC	$cmol_c\ kg^{-1}$	1.53	1.40
S/CEC[f]	%	0.88	0.82
pH[g]			
(1/2.5) water pH		6.7	6.6
(1/2.5) KCl molar pH		6.0	5.7

[a] Granulometric analysis by sedimentation, pipette method (AFNOR 1999a).
[b] Carbon by dry combustion method (AFNOR 1996a), organic matter = 1.727 x C.
[c] Total nitrogen by Kjeldhal method (AFNOR 1996b).
[d] Cobaltihexamonium chloride method (AFNOR Xx31-130, 1985; Orsini Rémy, 1976).
[e] CEC: cation exchange capacity.
[f] S: sum of cations.
[g] pH (1/2.5 soil/water or KCl 1*M*) suspension (AFNOR 1999b).

of the usual height does not result in an improvement in fertility, and the system remains dependent in most cases on applications of extra mineral fertilizer (Ghuman and Lal 1990). Competition for light, mineral nutrients and water can be difficult to manage because cultivation hampers the growth of the woody species in the establishment phase. Later on, this situation is reversed, the growth of the plants near the hedges being greatly reduced, and it is often necessary to do some trimming during the course of crop growth (Jama, Gehutan, and Ngugi 1990). The role of a refuge and source of spread for various pests (insects, rodents, birds, various spores fungi) or, conversely, of a trap for certain fungal diseases should also not be overlooked (Schroth 1994).

In Senegal, in certain conditions, the presence of trees in (*Acacia albida* Del.) or around cultivated fields is a feature which the peasants try to preservc. However, for about 20 years this association has evolved, with the developmcnt of plantings of hedges of trees such as cashew, mango, eucalyptus, and Prosopis, between which are grown cercals in rotation with groundnut (PRECOBA 1982). Recent experiments on

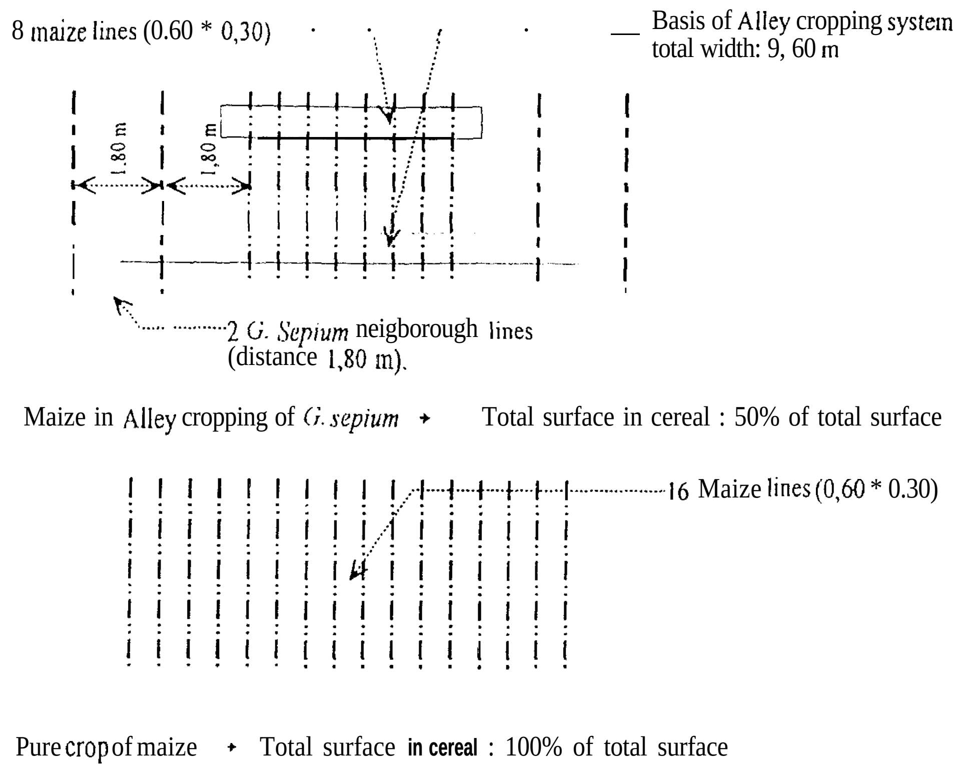

FIGURE 1 Schema of experimental design.

the introduction of leguminous tree *species* such *as Gliricidia sepium* (Jacq.) Steud. and *Senna siamea* (Lam.) Irwin & Bam. (ISRA 1992) have revealed a considerable potential for agroforestry. However, before introducing agroforestry systems, particularly in the semiarid zone, we should first consider the sustainability of such systems and the details of their implementation in different environments (soil, climate, population pressure) and with different farming systems (farmers' objectives and means, and socio-economic constraints). In this area, all sources of nitrogen for fertilizer use are very precious, and the addition of nitrogen by planting trees is a possibility in a context where the use of fertilizer, particularly nitrogen, is less and less easy for the peasant, and where the nitrogen deficit of cropping systems is aggravated by the abandonment of the groundnut-cereal rotation. This study is an attempt to follow Young's (1989) hypotheses in order to quantify the contribution of nitrogen in the agroforestry system from a woody N_2 fixing plant and the recycling of nutrient elements, notably nitrogen. For this purpose we quantify, by the use of ^{15}N fertilizer, the various potential sources of N : prunings, fertilizer, and soil pool.

Materials and Methods

Study Environment

The study was carried out at the research station of Nioro du Rip (13" 45' N-15" 47' E) in south-central Senegal. In this region, the annual mean temperature is 28°C, annual rainfall is currently 650 mm with a short rainy season between June and

October, the daily evapotranspiration vary between 1 to 3 mm in the raining season and 4 to 11 mm in the dry season. These conditions are representative of the southern region of the Senegal groundnut growing area.

The soils of this area (Table 1) are, according to Bertrand (1971), slightly leached ferruginous tropical soils (CPCS 1967) or Alfisols (USDA 1992) deveioped on quaternary sands of fluvial and marine origin. These soils, which are very widespread in the study zone, are deep, but also poor in fine fractions and depleted in organic matter. Consequently, their fertility is low, and they are prone to acidification. The available P (Olsen-Dabin method; Dabin 1967) content is acceptable in view of the low clay content but there is a serious risk of K deficiency.

In the agroforestry system studied, maize is grown, between *G. sepium* hedges. Before setting up the experiment, the uniformity of the experimental plot was checked by analyzing samples of soil (taken from the O-20 and 20-40 cm depths following a systematic grid pattcrn), so that the results gave an indication of the natural variability of the soil. An unfertilized maize "homogeneization crop" was grown in the year before setting up the experiment, and harvestcd by quadrats corresponding to the future experimental plots, to measure the natural yield variation of this cereal on plot.

Experimental Design

The details of the experimental design are presented in Figure 1. Three parallel strips corresponding to the three treatments tested were established: Pure Crop of Maize (PCM), Alley-Cropped Maize (ACM), and Pure Crop of *Gliricidia sepium* (PCG). Four independent "measuring plots" 4.50 m long were marked out within each strip, thus providing four interna1 replications of the treatments. Seedlings of *G. sepium* were grown in a neighbouring nursery. In the PCM strip the maize was sown at 0.60 m between rows and 0.30 m within the row at 3 seeds per hill, and thinned to one plant per hill 15 days after sowing. The PCG strip was made up of four hedges spaced 1.80 m apart, with a spacing between trees within the hedge of 0.50 m. This strip, together with the strip set aside for the hedges of the ACM, was not fertilized. In the ACM strip the paired hedges were spaced 1.80 m apart and were established from plants taken from a nursery at the end of the rainy *season* preceding the two years of the experiment. The distance between trees within a hedge was 0.50 m. The hedges were trimmed at the time of sowing the maize to a height of about 0.50 m (9 months after transplanting the young trees) and only the branches less than 10 cm circumference and the leaves were spread uniformly on the soil, the rest of the prunings being used for domestic purposes. This application amounted to 3 Mg ha-' of prunings with an average nitrogen content of 3.5%.

The areas used for maize received phosphate fertilizer (13 kg P ha $^{-1}$ as triple superphosphate) and potassium (25 kg K ha $^{-1}$ as KCl) at sowing. Nitrogen fertilization was done at the sowing time at a rate of 100 kg ha^{-1} of N (as ammonium sulphate) for the PCM strip and at 20 kg ha $^{-1}$ of N in the same form for the ACM strip. This application of nitrogen fertilizer on the ACM strip was necessary for the use of ^{15}N experimentation, but it also acted as a minimum investment of nitrogen starter recommended by Blonde1 (1971). Within each plot, this nitrogen application was made over an area of 2.6 m^2 in liquid form with a solution of $(^{15}NH_4)_2SO_4$ at 1% and 5% ^{15}N atom excess respectively for PCM and ACM strips. This application of ^{15}N allows, thanks to the "A value" rnethod, calculating the contribution of the different sources of N (soil, prunings, fertilizcr) to the maize nitrogen content.

The maize was harvested by separating the stems + leaves, the grain, and the rachis + spathes for the determination of dry matter production and N and ^{15}N content. The results shown here are for two successive crops. After previous verification of the field homogeneity (see results section), data are treated by a Xlstat procedure (Famhy 1995) for the determination of means and standard deviation of the replicates in the same strip.

Results and Discussion

Preliminary Fertility Variability Trial to Act as a Control for the Experiment

The thorough soil sampling carried out over a systematic grid pattern in the alleys of the experiment enabled the variability in the physico-chemical characteristics of the soil to be assessed at the time of establishment of the agroforestry test (Table 2). The mean values observed for each of the strips may be regarded as identical if one takes account of the fairly large standard error (intrastrip variability) observed for each of the variables. This large intrastrip variability could be due to the upper slope position of the field and to the perpendicular direction of each strip to the general slope. This physico-chemical analysis results are completed by the yields obtained for homogenization crop (Table 3).

The yields observed on each of the strips are similar to one another; the maximum error of the means is 25% for the grain and less than 5% for the straw.

TABLE 2 Mean values of analytical parameters and standard errors of the mean, ( ), for each of the three strips of the experiment

Strip	Exch. K $Cmol_c\ kg^{-1}$	CEC Cmol, kg^{-1}	(A + L)* (%)	Olsen Dabin mg P kg^{-1}	Total C %
ACM†	0.05 (0.02)	1.63 (0.02)	7.8 (0.3)	8.9 (1.9)	0.29 (0.02)
PCM‡	0.06 (0.03)	1.59 (0.46)	8.4 (0.5)	11.2 (5.0)	0.26 (0.03)
PCG§	0.05 (0.03)	1.19 (0.24)	7.8 (0.4)	7.8 (2.4)	0.29 (0.02)

* (A + L): particles of size < 20 µm.
† ACM : Alley cropped maize.
‡ PCM: Pure crop of maize.
§ PCG: Pure crop of *Glyiricidia.*

TABLE 3 Spatial variation in maize yield for the homogenization crop. Mean values and standard errors of means, ( ). The strips are identified by the abbreviation for the treatment applied to them during the experiment

	Total experimental area n = 12	PCM* n = 4	ACM† n = 4	PCG‡ n = 4
Components	Yield (kg ha-‘)			
Grain	759 (81)	634 (84)	667 (76)	603 (62)
Straw	1400 (77)	1427 (91)	1368 (53)	1.393 (62)
Total	2159 (141)	2223 (171)	2076 (96)	2 146 (89)

* ACM : Alley cropped maize.
† PCM : Pure crop of maize.
‡ PCC : *Pure* crop of *Glyricidia.*
n = number of plots (8.4 m x 4.5 m) harvested for each strip (PCM, ACM and ACG).

Comparison of Effectiveness of Prunings and Nitrogen Fertilizer

The concept of the "A value" (Fried and Dean 1952) enables one to quantify the respective contribution of fertilizer (Ndff), prunings (Ndfp), and soil (Ndfs) in the total N of the maize:

$$A_{\text{kg equivalent fertilizer ha}^{-1}} = N_F\left(\frac{E_F}{E_P} - 1\right),$$

where N_p is amount of N fertilizer in kg ha $^{-1}$, E_F is the isotopic excess of used fertilizer, and Ep is the isotopic excess of cultivated plant. Notice that the "A value," expressed in equivalents of ammonium sulphate nitrogen (the fertilizer used in the study), is an essential link in the calculation chain for Ndff and Ndfp, if it does not measure the size of the source compartment it provides a good representation of it. Table 5 allows the comparison of "A values" for the soil (A,), the soil + prunings (A, + $_p$), and the prunings alone (A,).

The TCU ('True Coefficient of Utilization') of the fertilizer in pure stands is of the order of 30%, and is in agreement with the values normally found (25-45%) for the maize (Ganry 1990) and with those in the literature for the semiarid zone of West Africa (Pieri 1989). These values are low because considerable losses (Cissé 1984) of nitrogen in form of nitrate may occur.

The Ndfp is 36% in the first year and 27% in the second. It is close to the Ndff% for similar amounts of N applied, however, it is less than that of fertilizer because the yield of the aerial parts is lower. The TCU, of the prunings (TCU_p) (Table 6) are 25% and 16% respectively, values which are lower than for fertilizer (30%). This last result is explained by the fact that the prunings contain a non-mineralizable part estimated at 20% (Ndiaye 1997).

The "A value" provides a quantitative comparison between minera1 fertilizer and prunings in terms of yield and nitrogen (Zapata ·1990). In terms of yield, 1 kg of ammonium sulphate fertilizer is equivalent to 4.8 kg dry matter (DM) (year '1) and 8.0 kg DM (year 2) of prunings (i.e., a mean of 6.4 kg DM), and in terms of N, 1 kg N as ammonium sulphate is equivalent to 0.8 kg N (year 1) and to 1.3 kg N (year 2) of prunings (i.e., a mean of 1.0 kg N). Thus in terms of nitrogen, in the field, the efficiency of *Gliricidia sepium* prunings is identical to that of ammonium sulphate.

Contribution of N_2 Fixation by G. sepium, *via its Prunings, to the Nitrogen Nutrition of Maize*

The percentage: of nitrogen fixed (Ndffix %) by G. *sepium* is about 25% of total N plant content at Nioro (Ndiaye and Ganry 1997). On the basis of this data,. the

TABLE 6 Ndff and TCU of fertilizer and prunings

Year	Fertilizer (ammonium sulphate) Ndff* %	kg ha-'	TCU_f † %	Pruning (*Gliricidia sepium*) Ndfp‡ %	kg ha-'	TCU, %
First year	31	31	31	36	26	25
Second year	33	28	28	2-l	17	16

* Ndff: nitrogen derived from fertilizer.

† TCU: True coefficient of utilisation of nitrogen (TCU_f) from fertilizer (TCU_p) from pruning.

‡ Ndfp: nitrogen derived from emonds.

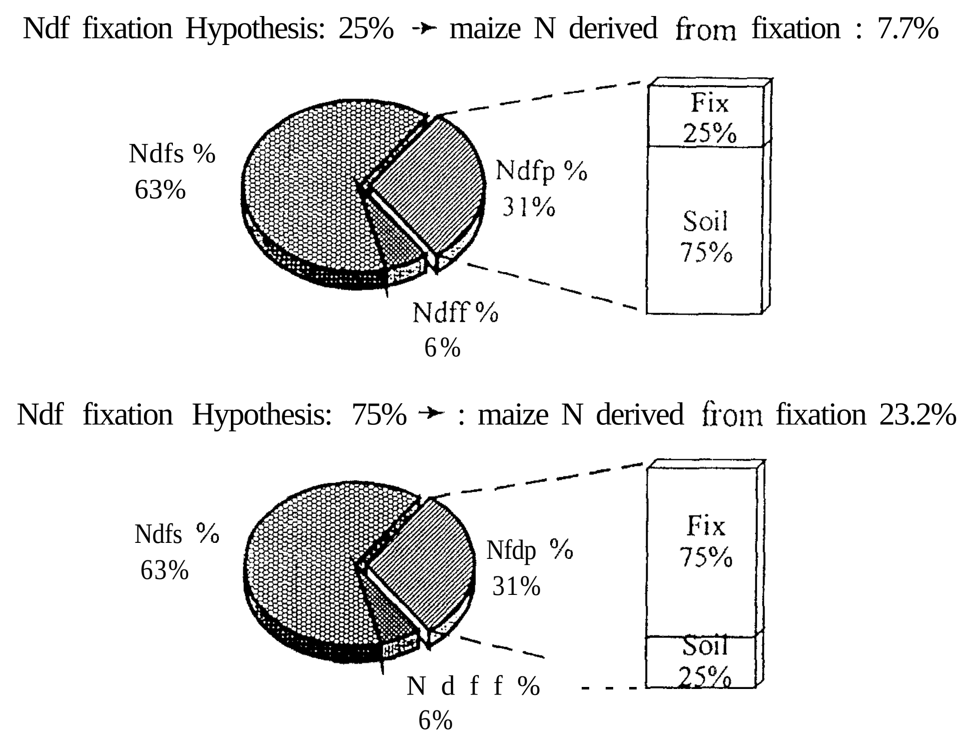

FIGURE 2 Nitrogen fixation contribution at nitrogen maize supply according to hypothesis of nitrogen fixation efficiency.

proportion of fixed N_2 contained in the prunings can be estimated, and, consequently, so can its contribution to the nitrogen nutrition of the maize (Figure 2). This contribution is in the order of 7.5%, and is thus quite small in the Nioro soil. However, we have also shown (Ndiaye 1997) that the fixation of N_2 can reach 75% in the presence of efficient specific strains of *Bradyrhizobium,* in a more favourable environment such as southem Senegal. In these conditions, the contribution of nitrogen from the prunings of G. *sepium* coming from N_2 nitrogen fixation can reach 20–25% of the total N in the maize, which would be very significant for the introduction of a sustainable agroforestry system.

Estimation of the Land Equivalent Ratio (LER)

By considering the production of the cereal and the production of the tree at the same time in the maize-tree association, we can calculate the Land Equivalent Ratio (LER) which is an indicator of the efficiency of the intercropping system. The results (Table 7) are based on total DM yields (without roots). The maize pure crop without N (PCM) is distinguished from that given N (PCM + N), the values for the latter coming from a plot grown nearby outside the experiment.

Pure Crop of Maize with N

The mean relative DM of maize in ACM system as a PCM with N is 0.44 and that of *Gliricidia sepium* is 0.46, giving a LER of 0.90. The biological efficiency of land use

TABLE 7 DM yields of *G. sepium* and of maize and the LER calculated from the total yield (field experiment; years 1994 and 1995)

Year	*G. sepium*			Maize					ISE	
	PCM*	ACM†	Lg‖	PCM+N	CCM	PCM	Lm, **	Lm_{nf} ††	LER_f ‡‡	LER_{nf} §§
	Total DM§ kg ha^{-1}			Total DM kg ha^{-1}						
First year	6198	2729	0.44	5585	2573	—	0.46	—	0.91	—
Second year	6121	2898	0.47	5606	2388	2154	0.43	1.11	0.90	1.58
Mean	6159	2814	0.46	5595	2480	—	0.44		0.90	—

* PCM : Pure crop of maize.
† ACM : Alley cropped maize.
‡ PCG: Pure crop of *gliricidia*.
§ Total DM = total dry matter; G. sepium (prunings + branches), maize (grain + straw).
‖ Lg = relative yield of G. sepium.
** Lm, = relative yield of maize (in pure stand of maize with fertihzer).
tt Lm_{nf} = relative yield of maize (in pure stand of maize without fertilizer).
‡‡ LER, = LER calculated using yields of maize grown in pure stand with fertihzer.
§§ LER,, = LER calculated using yields of maize grown in pure stand without fertilizer.

is almost as good in an agroforestry system without fertilizer as in pure crops with a large dose of fertilizer (100 kg N ha^{-1}).

Pure Crop of Maize without N

In a trial carried out on the same site in 1995, the yield of maize without N was 511 and 1643 kg ha-' for grain and straw respectively. The relative yield is thus 1.11 and that of *Gliricidia* is, for that year, 0.47, making a LER of 1.58. This result shows that the biological efficiency of land use is much greater with an agroforestry system than with a traditional cropping system: an increase in dry matter production of 58% is found by comparison with pure stands. This advantage is considerable in regions of high population density such as the groundnut growing region of Senegal, where land is a scarce resource.

Conclusion

The prunings have a marked effect that can be compared to that of minera1 nitrogen fertilizer on the yield and total N content of the maize, which is explained, at least partly, by the increase in nitrogen absorption by maize from the soil N pool enriched by the prunings applied. These effects on yield and on plant total N are in agreement with the nutritional properties of these prunings, already demonstrated by our work (Ndiaye 1997). The prunings supply 30–35% of the total N in the maize, values close to those obtained for fertilizer for a similar amount of applied nitrogen; the value of the N_2 fixing tree is to contribute "free" to this percentage, and to the soil N pool. Basing the N_2 fixation at 25% in G. *sepium* as obtained in the environment of central Senegal (Ndiaye and Ganry 1997), the contribution of this N_2 fixation to the total N in maize is 8%. Hence it is not much; we suggest that the reason lies in the limited fixing ability of the rhizobial strains. If this constraint could be removed, the fixed contribution could reach 20–25% in maize if the N_2 fixation of G. *sepium* reached the value of 75% in south Senegal (Ndiaye 1997). This value of 20–25% is within the range of values found by numerous authors notably Kang, Wilson, and Lawson (1984) in a more humid climate. They showed, moreover, that this benefit increased progressively because of the increase in productivity and the cumulative effect of the prunings.

Finally, the agroforestry system, with a LRE of 1.58, is a system which has a biological land use efficiency greater than that of the sum of the two individual crops each tested as pure stands. This advantage is vital in areas where the soil is a scarce resource as in the groundnut zone of Senegal. During the rainy season, the agroforestry system would also offer the possibility of growing cow pea (*Vigna unguiculata L.*) in relay cropping before maize harvest between the G. *sepium* hedges, which could be an additional source of income for the farmer. This crop, together with the wood production, would make up for the "loss" of cultivable land.

References

Adegbehin, J. O., and A. B. I. Igboanugo. 1990. Agroforestry practices in Nigeria. *Agroforestry Systems* 10: 1-22.

AFNOR. 1996a. Dosage du carbone organique et du carbone total après combustion sèche. (Association Française de Normalisation) NF ISO 106 94, pp. 189–200 in AFNOR, *Qualité des sols*. Paris, France.

AFNOR. 1996b. Dosage de l'azote total-Méthode de Kjeldahl modifiée. (Association Française de Normalisation) NF ISO 1 1-261, pp. 257-264, in AFNOR, *Qualité des sols.* Paris, France.

AFNOR. 1999a. Analyse granulométrique par sédimentation. Méthode de la pipette. (Association Française de Normalisation) NF X 31-107, pp. 57-72 in AFNOR, *Qualité des sols*. Paris, France.

AFNOR. 1999b. Détermination du pH. (Association Française de Normalisation) NF ISO 103 90, pp. 339-34X in AFNOR, Qualité *des sols.* Paris, France.

Bertrand, R. 1972. Morphopédologie et orientations culturales des régions soudaniennes du Siné Saloum (Sénégal). *L'Agronomie. Tropicale, 27: 1115-l 190.*

Blondel, D. 1971. Contribution á la connaissance de la dynamique de l'azole minéral ensol sableux (Dior) au Sénégal. Agronomie Tropicale 26: 1303-1333.

Cissé, L. 1984. Estimation des pertes moyennes en eau et en éléments fertilisants dans les systèmes de cultures arachide-mil de la zone soudano-sahélienne du Sénégal. Réunion de synthèse de la Division Conjointe FAO/AIEA sur "l'emploi des radioisotopes et des rayonnements dans les études pour une utilisation rationnelle de l'eau et des engrais dans les zones semi-arides", Vienne 6-11 Février 1984, *Document Interne.* Institut Sénégalais de Recherches Agricoles. Dakar, Senegal.

Commission de Pédologie et de Cartographie des Sols (CPCS), 1967. Classification des sols---Edition 1967. 96 pages.

Dabin, B. 1967. Sur une méthode d'analyse du phosphore dans les sols tropicaux., I., pp. 99-l 15 in *Colloque sur la fertilité des sols Tropicaux.* Tananarive, Madagascar.

Fahmy, T. 1995. *XLSTAT*, Software add-in Microsoft Excel. http://www.xlstat.com.

Fried, M., and L. A. Dean. 1952. A concept concerning the measurement of available soil nutrients. *Soil Science 73 :* 263–274.

Ganry, F. 1990. Application de la méthode isotopique à l'étude des bilans azotés en zone tropicale sèche. Thèse de doctorat d'Etat, Université de Nancy 1. Nancy, France.

Ghuman, B. S., and R. Lal. 1990. Nutrient addition into soil by leaves of *Cassia siamea* and *Gliricidia sepium* grown on an ultisol in Southern Nigeria. *Agroforestry Systems* 10: 131-133.

ISRA. *1992. Rapport Technique, Direction de Recherches sur les Productions Forestières.* Institut Sénégalais de Recherches Agricoles, Dakar, Senegal.

Jama, B., A. Gehutan., and D. N. Ngugi. 1990. Shading effects of alley cropped *Leucaena leucocephala* on weed biomass and maize yield at Mtwapa, Coast Province, Kenya. *Agroforestry Systems* 13: l-l 1.

Kang, B. T., G. F. Wilson, and T. L. Lawson. 1984. Alley cropping sequentially cropped maize and cowpea with Leucaena on a sandy soil in southern Nigeria. *Plant und Soil* 85: 267-277.

Ndiaye, M. 1997. Contribution des légumineuses arbustives à l'alimentation azotée du maïs (Zea mays L.)—Cas d'un système de culture en allées dans le Centre Sud Sénégal, Thèse de doctorat de I'INPL, Nancy, France.

Ndiaye, M., and F. Ganry. 1997. Variation in the biological N_2 fixation by tree legumes in three ecological zones from the north to the south of Senegal. *Arid Soil Research and Rehabilitation* 11:245- 254.

Orsini, L., and J. C. Rémy. 1976. Utilisation du chlorure de cobaltihexammine pour la détermination simultanée de la capacité d'échange et des bases échangeables des sols. *Bulletin de l'AFES* 1976:269–276.

Pieri, C. 1989. *Fertilité des terres de savanes: bilan de trente uns de recherche et de développement agricole* nu *Sud du Sahara.* Paris, Ministère de la Coopération et du Dével-oppement et CIRAD-IRAT, France.

PRECOBA. 1982. Etude sociologique: la motivation et les actions des populations à l'égard de l'arbre. *Rapport Technique No. 1 Projet de Reboisements Communautaires dans le Bassin Arachidier du Sénégal.* ISRA, Dakar, Senegal.

Schroth, G. 1994. Above and below-ground interactions in alley cropping with *Gliricidia sepium* as compared to conventional and mulched sole cropping on a high base status soil in the African rainforest zone. Ph.D. dissertation, University of Bayreuth, Germany.

Soil Survey Staff. 1992. Keys to Soil Taxonomy. SMSS Technical Monograph No. 19. Fifth Edition Pocahontas Press, Inc., Blacksburg, Virginia. 556 pages.

Young, A. 1989. Dix hypothèses pour la recherche sols/agroforesterie *l'Agroforesterie Aujourd'hui* 1 : 13-16.

Zapata, F. 1990. Isotope techniques in soil fertility and plant nutrition studies In *Use of Nuclear Techniques in Studies of Soil-Plant Relationships. Training Course series No. 2*, edited by G Hardarson (pp. 61-127) International Atomic Energy Agency, Vienna, Austria.

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