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Fish By-Product as a Soil Amendment for Millet and Groundnut Cropping Systems in Senegal

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ABSTRACT

Soils of the groundnut (*Arachis hypogaea*) L. basin of Senegal are impovetished with low fertility and organic matter content. Previously, farmers maintained yields of millet (*Pennisetum glaucum* (L.) R. Br. and groundnut with subsidized inorganic fertilizers and fallow periods to restore soils. Fish meal or by-product in various forms is a commercial commodity worldwide, but in Senegal the non-edible portion of fish (intestines, bottes, scales and gills) are often discarded after processing. A three-year study was conducted on processed fish by-products as a soil amendment for millet and groundnut productivity. Chemical analysis showed that the processed fish by-products are high in major nutrients such as N, 5.35%; P, 4.17%; K, 0.92%; Ca, 9.77%; and Mg, 0.36% Consequently, the application of the processed fish by-products significantly ($p < 0.05$) increased millet grain from 0.29 Mg ha-' in the control plot (no fish by-producr) to 2.50 Mg ha-t with 6 Mg ha-' fish by-product. Millet stover yield was also increased. Groundnut yields increased ($p < 0.01$) from 0.23 Mg ha-' in the control plots to about 1.00 Mg ha^{-1} with 2 Mg ha^{-1} fish by-product. Response curves for millet and groundnut were curvilinear with the incorporated fish remains explaining 98 and 99% of variability in yields of millet and groundnut respectively. Residual effect of fish by-product after one year significantly ($p < 0.05$) improved yields of millet and groundnut compared with inorganic fertilizer and equalled yields of the same crops with inorganic fertilizer after two years. However, stability analysis indicated that millet yieids with fish by-product were less stable (se. = 0.31) than yields with inorganic fertilizer (s.e. = 0.16) reflecting the non-unifonnity of the by-products and processing methods across villages

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INTRODUCTION

Low crop yields in the semi-arid region of Senegal are attributed primarily to increasing drought frequency and low soil fertility (Pieri, 1986). In the past, farmers counted on prolonged fallow periods to build soil nutrient reserves and organic matter. Today, this is not feasible in the arable areas of Senegal because of an increase in both human and animal populations. Farmers know about the benefits of mineral fertilizers but the majority of Senegalese farmers have small land holdings and are unable to purchase adequate levels of mineral fertilizers.

Traditionally, for economic and logistic reasons, African farmers rarely use inorganic fertilizer; instead, they apply organic methods such as animal manure, green manure, and agroforestry-related practices to restore fertility of their farmlands (Gillier, 1960; Lemoine, 1967; Pieri, 1986). Although, farmers recognize that crop yields are sub-optimal when fertilized solely with organic amendments, they continue to use them because sources of organic inputs are sustainable locally. Furthermore, several studies have documented positive results with the use of organic amendments in cropping systems, both in the temperate and tropical environments (Gillier, 1960; Hamon, 1967; Lemoine, 1967; Pieri, 1986).

Generally, fish meal in various forms is traded internationally. In Senegal, however, parts of the fish like the intestines, bones, scales, fins and gills are not eaten and are discarded after processing. The present study is to determine the effect of these fish by-products on yields of millet and groundnut. Prior to the agronomic field work, socioeconomic surveys were condacted KO ascertain adequacy, availability and farmers' perception of the fish by-product for farming (Ndiaye et *al.*, 1994). This study was the first attempt to evaluate the use of fish by-products in cropping systems in Senegal (Anonymous, 1993).

MATERIALS AND METHODS

Site characteristics and fish processing

The study was conducted in two villages, Gandigal and Ndianda, in the semi-arid zone of Senegal. Reasons for the: choice of these villages were (1) proximity to the ocean where the fish are processed and (2) experience of the farmers in organic farming. Rainfall for the study period ranged from 300 to 620 mm yr^{-1} which was recorded at both villages. Mean annual temperature is 27.6°C. Soil and plant analyses were determined using standard laboratory techniques developed at IITA (1977). The soils are Alfisols with the following pre-plant chemical properties: cation exchange capacity 1.2–2.8 cmol kg^{-1}; organic carbon 0.23–0.35%; pH 5.8-6.5; exchangeable calcium + magnesium 0.76 cmol kg-'; and sand 93.5%. The vegetation is wooded Guinea savanna comprising predominantly *Combretum* sp.

The fish *(Sardinella orita)* by-products were obtained from the fishing villages of Joal and Mbour. The fish were first smoked and then processed by cleaning and removing the by-products which were made up of intestines, bonrs, scales, fins and gills. The by-products were then placed into compost pits for 4–6 weeks depending on location and farmer. Prior to planting, the contents of the pits were removed, broadcast, and applied to the field, usually by incorporation. Table 1 gives chemical content of the fish by-product at the time of field application as determined by standard analytical procedures (IITA, 1977).

There were three field experiments from 1994 to 1996; two on the direct effects of fish by-product on yields of millet and the third on the residual effects. Fertilizer rates commonly recommended by ISRA (21 N, 4 P and 9 K kg ha^{-1} as NPK + 46 N kg ha-’ as urea) were used (M. Ndiaye, persona1 communication, 1999).

Experiment I

The first experiment was designed to test the effect of 0, 2, 4 or 6 Mg ha^{-1} fish remains on the millet variety Souna 3 at Gandigal. Plot size was 4.5 by 9.0 rn with six rows of millet spaced 0.9 m between rows and 0.9 m (thinned to three plants per hill) within rows. Also, the effect of 0, 0.5, 1 .0, 1.5 or 2 Mg ha^{-1} fish by-product on the groundnut variety 55437 at Ndianda was tested. Smaller plots, 2.0 by 5.0 m, consisting of six groundnut rows were used; spacing was 0.4 m between rows and 0.2 within rows. Both millet and groundnut had a 90 day growth cycle.

Seed bed preparation was done with a no-till method in conformity with prevailing farmers’ practices in the Sahelian region of West Africa (Lal, 1987). Fish by-product was incorporated followed by seeding with a local disk planter; the disk of thc planter was adjusted to deliver seeds at recommended plant

TABLE 1

Chemical analysis of processed fish by-product.

	pH		C	N	P	K	Ca	Mg	Na	SiO_2	Cl	S
	water	KCl	(%)									
Mean	6.6	6.5	27.3	5.35	4.17	0.92	9.77	0.36	7.99	19.2	2 87	0.37
s.e	0.10	0.10	0.10	0.80	0.90	0.10	1.20	0.10	0.30	0.80	0.30	0.10

	Al	Mn	Fe	Zn	Cu
	(mg kg^{-1})				
Mean	tr	35	1493	84	30
s.e.		0.01	262	8.5	3.5

populations of 38,000 plants ha-' for millet and 125.000 plants ha^{-1} for groundnut. Two central rows were harvested for biomass and yield analysis. Experimental design was a randomized complete block with four replications.

Experiment II

The second study compared the effect of minera1 fertilizer and fish by-product on millet and groundnut yields. Treatments for millet were (1) control; (2) 21 kg N, 4 kg P, and 9 K kg h^{-1} (14-7-7 NPK fertilizer) followed by 46 kg N ha^{-1} (urea) as top dressing; and (3) 4 Mg ha^{-1} fish by-product. The NPK fertilizer was broadcast at planting and the urea was split in equal proportions, one half at 25 days after planting and the rest 20 days later. The treatments for groundnut were: (1) control; (2) 21 N, 4 P and 9 K kg ha^{-1} as NPK fertilizer alone; or (3) 2 Mg ha^{-1} fish by-product at planting. The design was a randomized complete block with four replications. Planting arrangement and other cultural practices were the same as Experiment I.

Experiment III

Experiment 3 was a millet (variety Souna3)-groundnut (variety 55-437) rotation conducted on 13 farmers' fields at Lagnaer and Mbotile villages from 1995 to 1997. There were three treatments; (1) control; (2) 4 Mg ha-' fish by-product; or (3) 21 N, 4 P and 9 K kg ha^{-1} as NPK fertilizer followed by 46 kg N ha-' urea as top dressing. Half of the urea was applied 25 days after planting and the remaining 20 days later. Groundnut received 12 N, 12 P and 34 kg ha^{-1} as NPK (8-18-27) and 2 Mg ha^{-1} fish by-product. Each farmers' field was split in half for planting millet or groundnut in each half of the field. The two crops and fertilization treatments are presented sequentially in Table 2. Within each split treatments were superimposed with plot sizes of 4.5 m by 9.0 m. The experimental design was a randomized complete block with four replications.

TABLE 2

Crops and fertilization treatments scheme in Experiment III

Year	Plot	Crop	Fertilization treatments
1995	1	Millet	Control, fertilizer. fish by-product
1995	2	Groundnut	Control, fertilizer. fish by-product
1996	1	Groundnut	Control, no fertilizer, no fish by-product
1996	2	Millet	Control, fertilizer, no fish by-product
1997	1	Millet	Control, fertilizer, no fish by-product
1997	2	Groundnut	Control, no fertilizer, no fish by-product

Data was analysed hy standard ANOVA procedures with mean separation ($p = 0.05$) and second order regression, $Y = a+bX+cX^2$ (where Y = yield and X = fish by-product are in Mg ha-') to estimate optimum level of fish residue for millet and groundnut yields. Fish by-product N-use efficiency (FNU) was calculated as the ratio: (yield in Mg ha-' N)/(Mg ha-' N in fish by-product) *100 SPSS (Norusis, 1997) and MSTAT-C software was used for the statistical analysis.

RESULTS AND DISCUSSION

Nutrient contents of the fish by-product before field application are shown in Table 1. According to the data, nutrient values for N = 5.35% and P = 4.17% were relatively high, compared to the NPK fertilizer formula used in this study. In the course of the study, it was noticed that rainfall was lower and more erratic at Gandigal than Ndianda. Thus, under normal conditions, yields would be expected to be higher at Ndianda than Gandigal.

Experiment I

Manuring with processed fish by-product significantly ($p < 0.05$) increased millet yield (Table 3). The lowest rate of 2 Mg ha-' by-product increased yield

TABLE 3

Effect of fish by-product on yields of millet and groundnut in Experiment I.

Crop	By-product rate (Mg ha-')	Yield (Mg ha^{-1})
Millet	0	0.29
	2	1.40
	4	2.44
	6	2.50
Standard error (s.e.)		0.15
Linear effect		0.05
Quadratic effect		0.10
Groundnut	0	0.23
	0.5	0.57
	1	0.81
	1.5	0.93
	2	0.95
Standard error (s.e.)		0.056
Linear effect		$p < 0.0001$
Quadratic effect		$p < 0.0001$

of millet by over 350% (from 0.292 kg ha-' to 1. 392 Mg ha-') at Gandigal. The highest yield of 2.50 Mg ha^{-1} with 6 Mg fish by-product ha^{-1} did not differ from that of 4 Mg ha^{-1}. The second order regression, $Y = 0.24 + 0.78 - 0.07X^2$ indicated that 4 Mg ha^{-1} fish by-product is the optimum rate. The equation attributcd 98% of the variability of millet yield to fish by-product.

Similarly, fish by-product used as manure increased groundnut yield (Table 3). The lowesr rate of 0.5 Mg ha^{-1} resulted in an increase of 150% (from 0.23 Mg ha^{-1} to 0.57 Mg ha^{-1}) at Ndianda. Groundnut yield did not increase significantly beyond the use of 1.0 Mg ha-' manure. The yield data were hest described by the second order regression function: $Y = 0.23 + 0.80 - 0.22X^2$, which also explained 99% of the variability of groundnut yield.

In general, FNU decreases with increasing rates of N. Fish by-product N-use efficiency was 10%, and the by-product rate was optimum between 2 and 4 Mg ha^{-1} in the millet; FNU in the groundnut system was 4.5% and the rate was optimum between 0.5 and 1.0 Mg ha^{-1}. Groundnut crop meets part of its N requirement through atmospheric N fixation and therefore it is less dependent on N from an external source.

Experiment II

Experiment II assessed the potential value of fish by-product as a fertilizer amendment (Table 4). Millet grain and residue yields with the application of 4 Mg ha^{-1} fish hy-product significantly out-performed the use of the recommended dose of minera1 fertilizer for two consecutive years. Total N applied as minerai fertilizer in the recommended dose was 67 kg ha^{-1} giving N efficiencies of 11% and 4% respectively in 1995 and 1996 at Ndianda. The same minerai lèrtilizcr had a N effïciency of 5% at Gandigal in 1996. Generally, N from

TABLE 4

Effects of fish by-product and inorganic fertilizer on millet (Souna 3) yields at Ndianda and Gandigal in 1995–1996 in Experiment II.

	Yield (Mg ha-')					
	Ndianda			Gandigal		
	1995		1996	1995		1996
Treatments	Grain	Stover	Grain	Grain	Stover	Grain
Control	0.23	1.06	0.5 1	1.52	3.31	0.93
Fertilizer	1.44	3.47	0.91	2.23	4.33	1.50
Fish by-product	2.23	6.15	1.48	2.31	5.38	1.89
Standard error	0.12	0.19	0.92	0.07	0.14	0.06

inorganic sources is more readily available to crops than N from organic sources such as green manure and compost (Palm & Sanchez, 1990).

Mean yields of groundnut from fish by-product treated plots and plots fertilized with NPK were comparable (Table 5). Yields from the two above treatments were significantly ($p < 0.05$) better than the control. Fertilizer N use efficiencies were 4% in 1995 and 6% in 1996. Yields of millet and groundnut did not differ ($p > 0.05$) between sites.

Experiment III

Direct and residual effects of fish by-product on millet and groundnut yields are presented in Table 6. Years, fertilization and years by fertilization interaction were significantly different ($p < 0.0001$). Yields of both crops in the control plots decreased slightly with years of cultivation due to decline in native soil fertility. Millet yields fertilized with fish by-product were much higher in 1995 and 1996 than yields in the fertilizer treated and control plots, even though millet was fertilized with inorganic fertilizer every year. This suggests that fish by-product may have an added effect on millet yield that goes beyond its nutrient contribution, because the inorganic fertilizer treatment is high enough to maximize yields. Perhaps, increased crop biomass after harvest in addition to the remaining fish by-product improved the soil structure to enhance root activity. Organîc additions provide the important substrates for microbial activity that stimulates physical enmeshment of soil particles and the organic compounds that bind particles together (Tate, 1987). Although the amount of C added by organic amendments is low relative to the total organic matter, recent additions can significantly affect aggregation and aggregate stability. As an example, Martin (1942) showed that various compost amendments increased water stable aggregates from 26 to 49% over the control even after 200 days on soil that was 82% sand. Subsequent studies have found that organic inputs can affect

TABLE 5

Effects of fish by-product and inorganic fertilizer on groundnut yields at Ndianda and Gandigal in 1995-1996 in Experiment II.

	Yield (Mg ha^{-1})					
	Ndianda (1995)			Gandigal (1996)		
Treatments	Stover	Pods	Grain	Stover	Pods	Grain
Control	1.62	1.11	0.69	1.10	0.88	0.46
Fertilizer	2.88	1.50	0.90	2.45	1.15	0.88
Fish by-product	2.95	1.22	0.94	2.27	1.10	0.75
Standard error	0.10	0.06	0.04	0.08	0.02	0.03

TABLE 6

Effect of direct and residual affects of fish by-products and inorganic fertilizer on yields of millet and groundnut in Experimem III.

Year	Treatment	Yield (Mg ha-') Millet	Groundnut
199.5 (direct effect)	Control	0.61	0.46
	Fertilizer	0.90	0.79
	Fish by-product	1.13	0.17
1996 (first year effect)	Control	0.59	0.43
	Fertilizer	0.80	0.66
	Fish by-product	1.77	0.71
1997 (second year effect)	Control	0.57	0.38
	Fertilizer	0.83	0.43
	Fish by-product	0.82	0.57
Level of significance			
Year (Y„		$p < 0.0001$	$p < 0.0001$
Treatment (T)		$p < 0.0001$	$p < 0.0001$
Y x T		$p < 0.0001$	$p < 0.0001$

aggregation within a growing season (Gilmour *et al.*, 1948; Griffiths & Jones, 196.5; Oades, 1984). More recent studies have shown that recently deposited organic matter (l-4 years, Buyanovsky *et ai., 1994; < 6* years, Puget et *al.,* 1995) is important in macroaggregate stabilization. Recent organic matter additions can also increase a light fraction organic matter, also known as particulate organic matter which is undecomposed plant and microbial debris (Cambardella & Elliot, 1992) which can also provide structure to soils.

Millet yields in 1997 were about half the harvest of 1996, and this may suggest that positive effect of fish by-product on yield lasts only one year and has to be renewed thereafter. But, even in 1997, the yields were comparable with inorganic fertilized millet and better than the control.

Groundnut yields in 1995 were higher in the fish by-product and inorganic fertilized plots. Groundnut yields with fertilizer and manure were about equal. In 1996, fish by-product out yielded inorganic fertilizer by 7% and the control by 62%. Groundnut yield dropped by 20% from 1996 to 1997 with fish by-product but it still remained superior to inorganic fertilizer and the control. Yields in the third year (i.e. second year effect) were 0.43 Mg ha^{-1} for inorganic fertiiizer as opposed to 0.57 Mg ha^{-1} with fish by-product, a difference of 34% with respect to inorganic fertilizer.

Figure 1 presents information on adaptability and stability of millet yields as affected by fish by-product, inorganic fertilizer and the control across all 13 farms in the three experiments. The treatments responded positively and significantly ($p < 0.01$) across farms. Clearly, fish by-product produced hrgher

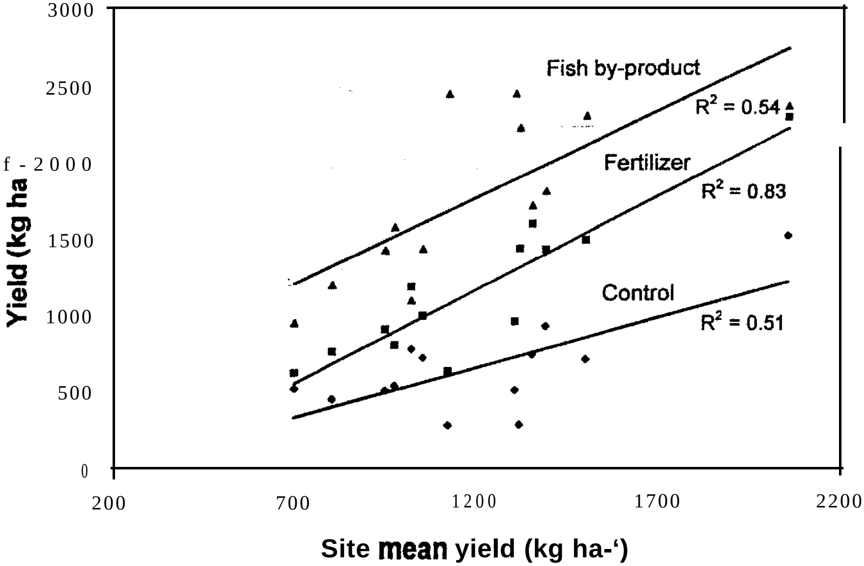

FIGURE 1. Stability analysis of millet yields as affected by fish by-producr and inorganic fertilizer treatments.

yields than the inorganic fertilizer and the control treatments, but the yields were more variable across farms as indicated by large standard error (s.e. = 0.31). Although inorganic fertîlizer was not as high-yielding as fish by-product, yields were more responsive to fertilizer as shown in Figure 1 with the steepest positive slope of the three treatments ($p < 0.0001$) and stable from farm-to-farm (s.e. = 0.16).

The conclusion from this study is that fish by-product has potential to increase crop yields but its effect on yields is more variable across farms reflecting the numerous ways farmers process their fish by-products. There was indirect evidence that the increase in yield due to fish by-products was not solely due to the nutrient addition because even with adequate applications of inorganic fertiizer, the fish by-product caused an additional yield response. The by-products are currently causing an environmental problem in the community because of the bad odour and are free of cost. Storing them in compost pits is a means to improve the environment and soil fertility. By-product is available in sufficient quantities now to be agronomically important (Ndiaye *et al.*, 1994) and likely to increase in availability as the population grows and demand for fish consumption increases. Mixing the fish by-product with crop residues will result in improved compost that could fertilize a greater number of farms or to fertilize specialized high value crops.

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