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Causes of legume-rotation effects in increasing cereal yields across the Sudanian, Sahelian and Guinean zone of West Africa

A. Bürkert[1)], M. Bagayoko[2)], S. Alvey[3)] and A. Bationo[4)]

[1)] *Institute of Crop Science, University of Kassel, Steinstr. 19, D-37213 Witzenhausen, Germany, buerkert@wiz.uni-kassel.de*

[2)] *Institut d'Economie Rurale (IER), B.P. 258, Bamako, Mali, Minamba.Bagayoko@ier.ml*

[3)] *Department of Environmental Sciences, University of California Riverside, Riverside, CA 92521, USA, smalv@mail.ucr.edu*

[4)] *TSBF-UNESCO, United Nations Complex, Gigiri, P.O. Box 30592, Nairobi, Kenya, a.bationo@cgiar.org*

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Abstract

On-farm experiments and pot trials were conducted on eight West African soils to explore the mechanisms governing the often reported legume rotation-induced cereal growth increases in this region. Crops comprised pearl millet (*Pennisetum glaucum* L.), sorghum *(Sorghum bicolor* Moench), maize (*Zea mays* L.), cowpea (*Vigna unguiculata* Walp.) and groundnut (*Arachis hypogaea* L.). In groundnut trials the observed 26 to 85% increases in total dry matter (TDM) of rotation cereals (RC) compared with continuous cereals (CC) in the 4th year appeared to be triggered by site- and crop-specific early season differences in nematode infestation (up to 6-fold lower in RC than in CC), enhanced Nmin and a 7% increase in mycorrhizal (AM) infection. In cowpea trials yield effects on millet and differences in nematode numbers, N_{min} and AM were much smaller. Rhizosphere studies indicated effects on pH and acid phosphatase activity as secondary causes for the observed growth differences between RC and CC. In the study region legume-rotation effects on cereals seemed to depend on the capability of the legume to suppress nematodes and to enhance early N and P availability for the subsequent cereal.

Introduction

Legume rotations have been advocated as a low input strategy to increase cereal yields on acid sandy soils of sub-Saharan West Africa that are notoriously low in phosphorus (P) and nitrogen (N). However, this view is based on a very limited number of comparative yield trials providing site-specific results (Bationo *et al.*, 1998; Nicou, 1978; Stoop and van Stavern, 1981). To critically assess the merits of legume rotations for different soils and crops of the region, information is needed about the mechanisms governing cereal yield increases.

Materials and methods

Field experiments with pearl millet, sorghum, maize, cowpea and groundnut were conducted from 1995 to 1999 under rainfed conditions at eight sites in Niger, Burkina Faso and Togo (Bagayoko *et al.*, 2000b). The sites provided a gradient of annual rainfall from 510 to 1300 mm with a corresponding range in topsoil (0-0.2m) pH from 4.1 to 5.6, in cation exchange capacity (CEC) from 0.8 to 3.3 $cmol_c$ kg^{-1}, in mineral N (Nmin) from 5 to 18 mg kg^{-1}, in organic carbon from 1.5 to 6.5 g kg^{-1} and in clay content from 20 to 160 g kg^{-1}. The field experiments were used to record data of crop yields, root infection with arbuscular mycorrhizae (AM) and nematode infestation. Additionally, pot and root box experiments with CC and RC soil from two of the sites (Fada and Gaya) were set up to investigate soil-root interactions under controlled conditions.

Results and discussion

Legume-induced increases in cereal total dry matter (TDM) as recorded in the field experiments were site- and crop-specific, relatively consistent over years, but tended to grow over time. In the 4th trial year groundnut rotations led to average TDM increases in RC between 26 and 85% compared with CC. Respective increases in cowpea systems varied between –3 and 26% (Table 1).

Early season N_{min} levels in RC of cowpea sites tended to be higher than in CC but such differences with up to 114% at Fada (Bagayoko *et al.*, 2000b) and 89% at Koukombo (Alvey at al., unpublished) were only significant at groundnut sites. AM infection of millet roots was significantly higher in RC than in CC (Table 2) but differences declined over the growing season. The same was found for sorghum (data not shown). Regardless of the amount of applied P in the multi-factorial field experiment, nematode numbers were up to six-times lower in RC than in CC at Fada but no rotation effects on nematode infestation were noted at Gaya (Figure 1).

Under controlled conditions legume-rotation effects on cereal growth were even larger than in the field and similar effects on nematodes and AM infection were found (data not shown). Bagayoko *et al.* (2000a) reported from the field trials at Goberi that the pH at the rhizoplane of millet was 1.9 units higher than in the bulk soil at 45 days after sowing (DAS) and 1.2 units at 75 DAS. Respective differences were 0.6 units at 50 DAS and 0.4 units at 80 DAS at Gaya. At all sites, pH levels followed the pattern rhizoplane>rhizosphere>bulk soil. For sorghum at Kouaré, pH increases at the rhizoplane reached a maximum of 0.3

units, much smaller than in millet, and were not statistically significant (data not shown). Rotation-induced pH increases in the respective bulk soils were noted under controlled conditions at Fada (Figure 2) and to a lesser degree also at Koukombo and Kaboli (data not shown). These differences are still poorly understood, as are those in the rhizosphere, and may be due to particular properties of decomposing groundnut crop residues (Yan and Schubert, 2000).

Table 1. Legume-rotation effects on cereal total dry matter (TDM) in sub-Saharan West Africa. Data are means across P and N levels after three cropping cycles.

Site	Rain mm yr^{-1}	System	TDM kg ha^{-1}
Bani	510	Continuous millet	3080
		Millet after cowpea	3420 **
Sadoré	560	Continuous millet	3500
		Millet after cowpea	4310 ***
Kara	590	Continuous millet	4430
		Millet after cowpea	5580 ***
Goberi	600	Continuous millet	4220
		Millet after cowpea	4800 ***
Gaya	800	Continuous millet	2600
		Millet after cowpea	2510 ns
Fada	850	Continuous sorghum	2680
		Sorghum after cowpea	3630 ***
Kouk.	1100	Continuous maize	4990
		Maize after groundnut	6280 ***
Kaboli	1300	Continuous maize	3440
		Maize after groundnut	6350 ***

, * significant at P<0.01 and P<0.001; ns=not significant

Table 2. Root infection by mycorrhizae (AM) in millet (0-0.3m soil depth) as affected by cropping systems in a field experiment at Sadoré, Goberi and Gaya in 1997.

Cropping system	Sadoré 35 DAS[a]	Goberi 45 DAS	Gaya 50 DAS
	AM infection (% of roots)		
Continuous millet	23a[b]	27a	11a
Millet after cowpea	32b	48b	31b

[a] days after sowing; [b] significantly different at P < 0.001

Acid phosphatase activity at the root surface of sorghum was lower in rotation soil indicating improved P nutrition of seedlings and a subsequently smaller exudation of phosphatase from the root. In the rhizosphere, of rotation sorghum, however, an up to 74% higher phosphatase activity was noted (Figure 2). This was most likely the consequence of microorganisms that may have substantially contributed to the consistent increase of the measured P fractions in rotation soil compared with continuous soil (Alvey *et al.*, 2001).

The combination of (i) improved P availability through changes in soil pH, earlier AM infection, increased rhizosphere phosphatase activity and decreased parasitic nematode populations and (ii) higher levels of early season N_{min} likely explain the observed growth differences between RC and CC on the acid nutrient poor soils of sub-Saharan West Africa. Site-specific differences of such rotation effects likely depend on the legume component used (groundnut effects>cowpea effects), the ability of the cereal crop to cope with low nutrient availability (millet>sorghum>maize) and nematode infestation levels.

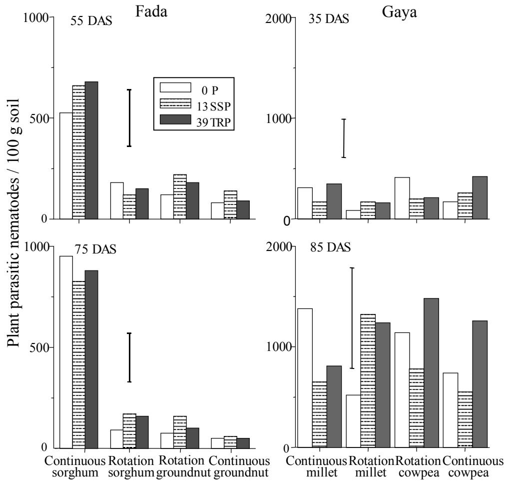

Figure 1. Effects of cropping system on nematodes without P, with annually 13 kg P ha^{-1} SSP and with 39 kg P once as Tahoua rockphosphate (TRP) at Fada and Gaya in 1998.

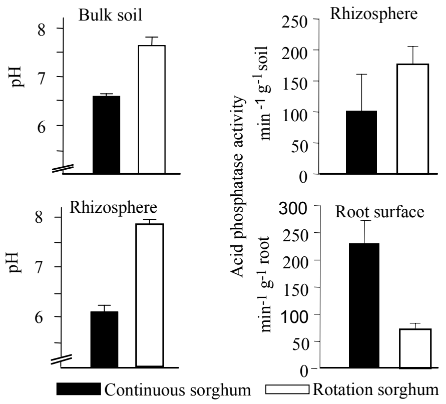

Figure 2. Effects of cropping system on pH and on acid phosphatase activity at the root of sorghum at Fada 37 days after sowing (after Alvey *et al.*, 2001).

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