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N_2-fixation and N contribution by grain legumes under different soil fertility status and cropping systems in the Guinea savanna of northern Ghana

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ABSTRACT

Continuous cereal-based cropping has led to a rapid decline in soil fertility in the Guinea savanna agro-ecological zone of northern Ghana with corresponding low crop yields. We evaluated the effects of cropping system and soil fertility status on grain yields and N_2-fixation by grain legumes and net N contribution to soil fertility improvement in contrasting sites in this agro-ecological zone. Maize was intercropped with cowpea, soybean and groundnut within a row, with a maize stand alternated with two equally spaced cowpea or groundnut stands and in the maize-soybean system, four equally spaced soybean stands. These intercrops were compared with sole crops of maize, cowpea, soybean and groundnut in fertile and poorly fertile fields at sites in the southern (SGS) and the northern (NGS) Guinea savanna. The proportion of N derived from N_2-fixation (%Ndfa) was comparable between intercrops and sole crops. However, the amount of N_2-fixed was significantly larger in sole crops due to a greater biomass accumulation. Legumes in poorly fertile fields had significantly smaller shoot $\delta^{15}N$ enrichment (−2.8 to +0.7‰) and a larger %Ndfa (55–94%) than those in fertile fields (−0.8 to +2.2‰; 23–85%). The N_2-fixed however was larger in fertile fields (16–145 kg N ha^{-1}) than in poorly fertile fields (15–123 kg N ha^{-1}) due to greater shoot dry matter and N yields. The legumes grown in the NGS obtained more of their N requirements from atmospheric N_2-fixation (73–88%) than legumes grown in the SGS (41–69%). The partial soil N balance (in kg ha^{-1}) was comparable between intercrops (−14 to 21) and sole legumes (−8 to 23) but smaller than that of sole maize receiving N fertiliser (+7 to +34). With other N inputs (aerial deposition) and outputs (leaching and gaseous losses) unaccounted for, there is uncertainty surrounding the actual amount of soil N balances of the cropping systems, indicating that partial N balances are not reliable indicators of the sustainability of cropping systems. Nevertheless, the systems with legumes seem more attractive due to several non-N benefits. Our results suggest that soybean could be targeted in the SGS and cowpea in the NGS for greater productivity while groundnut is suited to both environments. Grain legumes grown in poorly fertile fields contributed more net N to the soil but growing legumes in fertile fields seems more lucrative due to greater grain and stover yields and non-N benefits.

1. Introduction

The Guinea savanna agro-ecological zone of northern Ghana is characterised by a single cropping season (with 180–200 growing days), a unimodal rainfall pattern and an annual mean precipitation of 1100 mm (SRID, 2016). The soils in many parts of the region are poor in fertility, particularly N (Dakora et al., 1987). Shortened fallow periods have exerted pressure on the already fragile soils (Dakora et al., 1987; Franke et al., 2004). These issues, compounded by continuous cereal-based systems without sufficient nutrient inputs to the soil, have led to wide scale declines in soil fertility and persistently poor crop yields on smallholder farms (Sanginga, 2003).

The incorporation of grain legumes into cereal-based cropping systems can contribute to the replenishment of soil fertility through the fixation of atmospheric nitrogen (N_2), while supplying protein-rich grains for household food and nutrition (Giller, 2001). In the West African Guinea savanna, grain legumes fix between 15 and 201 kg N ha^{-1} per season (Dakora et al., 1987; Sanginga et al., 1997; Belane and Dakora, 2010; Yusuf et al., 2014). A net N contribution of up to 48 kg ha^{-1} by groundnut (Yusuf et al., 2014) and 125 kg N ha^{-1} by

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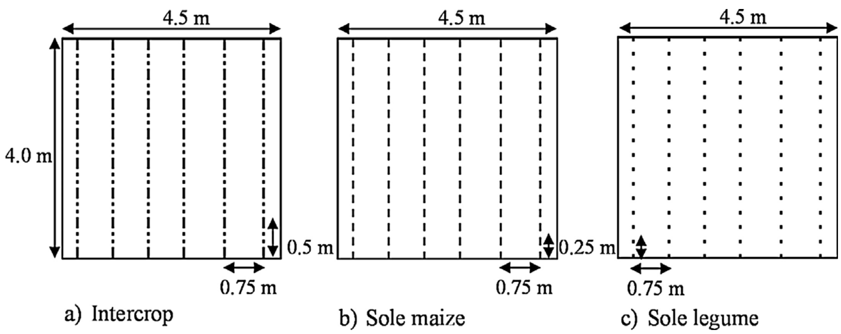

Fig. 1. Schematic overview of cropping patterns: a) maize-legume within-row intercrop treatment, b) sole maize treatment and c) sole legume treatment. The intercrop scheme shown is for maize-cowpea and maize-groundnut systems. For the maize-soybean intercrop, a maize stand was alternated with four soybean stands within a row. Sole legume scheme (Fig. 1c) is for sole crops of cowpea and groundnut (16 plant stands per row). Sole soybean treatment had 32 plant stands per row (0.125 m intra-row spacing).

cowpea (Dakora et al., 1987) with the grain exported from the field has been documented. Consequently, incorporation of grain legumes into cereal-based cropping systems represents an opportunity to address these soil fertility concerns. Legumes can be incorporated through sole-cropped legume-cereal rotations as predominantly practised by farmers in the region. However, the increased risk of crop failure in sole cropping due to an unpredictable rainfall regime in the single cropping season threatens household food security. Accordingly, intercropping the main cereals (especially maize which is the dominant crop in the area) with grain legumes can alleviate such risks to safeguard household food and income security (Giller, 2001).

The high labour requirements and the general yield reduction of the main crop in cereal-legume intercropping compared with sole cropping are a concern for farmers. Nevertheless, cereal-legume intercropping may improve diversification in nutrient uptake by the component crops, environmental resources use efficiencies and increased yield per unit area relative to sole cropping (Willey, 1990). Cereal-legume intercropping thus presents an alternative to sole cropping. The diverse biophysical environments and variable crop management strategies lead to a large variability in benefits from N_2-fixation and net N contribution of legumes to the soil (Giller, 2001). Also, grain legume species and varieties differ in their contribution to soil N fertility enhancement (Giller, 2001). This suggests a need for targeting different legume species to different agro-ecological zones or contrasting environments within an agro-ecological zone for increased yields and soil fertility improvement.

Several studies have quantified N_2-fixation and net N contribution to the soil in the Guinea savanna of West Africa (e.g. Eaglesham et al., 1981; Sanginga et al., 1997; Ogoke et al., 2003; Yusuf et al., 2008) and northern Ghana (e.g.Dakora et al., 1987; Naab et al., 2009; Belane and Dakora, 2010; Konlan et al., 2015). Only few studies (e.g. Eaglesham et al., 1981; Konlan et al., 2015) assessed the effect of maize-grain legume intercropping on N_2-fixation. Even so, the net N contributions to the soil from the intercrop systems were not measured. In addition, the wide variability in soil fertility across the different fields in the West African Guinea savanna agro-ecological zone was not considered. The objectives of this study were to determine the effects of: (i) intercropping, (ii) soil fertility status and (iii) grain legume species on grain yield, N_2-fixation and net N contribution to soil fertility improvement in the southern and northern Guinea savanna agro-ecological zones of northern Ghana.

2. Materials and methods

2.1. On-farm trials and trial management

The field trials were conducted on-farm in the 2013 cropping season at Kpataribogu {9°58′ N, 0°40′ W; 172 m above sea level (masl)} in the Karaga District (southern Guinea savanna, SGS) and at Bundunia (10°51′ N, 1°04′ W; 185 masl) in the Kassena-Nankana East Municipal (northern Guinea savanna, NGS) of northern Ghana. Rainfall was recorded with rain gauges at both trial sites. A total of 598 mm in the SGS and 532 mm rainfall in the NGS were received during the growing season. The soils at both sites are classified as Savanna Ochrosol and Groundwater Laterites in the interim Ghana soil classification system (Adjei-Gyapong and Asiamah, 2002) and as Plinthosols in the World Reference Base for soil resources (WRB, 2015). Two field types representing fertile and poorly fertile soil conditions were selected at each site, using farmers' knowledge and the help of agricultural extension officers. Fields selected were under mono-cropped maize, grain legume or cotton in the three preceding seasons. Soils of each field were sampled at 0–15 cm depth prior to land preparation, thoroughly mixed and about 1 kg sub-sample was air-dried, sieved through a 2 mm-mesh sieve and analysed for pH (1:2.5 soil:water suspension), organic C (Walkley and Black), total N (Kjeldahl), available P (Olsen), exchangeable K, Mg, and Ca (in 1 M ammonium acetate extracts) and texture (hydrometer method).

Treatments consisted of cowpea – *Vigna unguiculata* (L.) Walp; soybean – *Glycine max* (L.) Merr. and groundnut – *Arachis hypogaea* L. intercropped with maize (*Zea mays* L.) or grown as sole crops. In the intercrop treatments, maize and legumes were grown within the same row. A maize stand was alternated with two equally spaced cowpea or groundnut stands within a row. In the maize-soybean system, a maize stand was alternated with four soybean stands within a row. Maize and all intercropped legumes were sown at one seed per hill, while sole legumes were sown at two seeds per hill. Inter-row spacing was 75 cm in all treatments. Intercropped maize was spaced at 50 cm within a row while intra-row spacing for sole maize was 25 cm. Sole cowpea and groundnut had an intra-row spacing of 25 cm and that of sole soybean was 12.5 cm. These resulted in plant populations (plants ha^{-1}) of 26,667 and 53,333 for maize, 53,333 and 106,666 for cowpea and groundnut, and 106,666 and 213,334 for soybean, respectively for intercrops and sole crops. The spatial planting arrangements of the different cropping patterns are shown in Fig. 1. The experimental design was a randomised complete block design. Blocks of treatments were replicated four times per fertility level at each site and treatments were randomised within blocks. A single plot measured 4.5 × 4.0 m.

The land was tractor-ploughed, ridged and sowing done on the apex of the ridges. The varieties used were Padi-tuya: SARC 3-122-2 (cowpea), Jenguma: Tgx 1448-2E (soybean), Samnut 22 (groundnut) in SGS and Chinese variety (groundnut) in NGS, and Obatanpa: GH83-63SR (maize). All crops were sown on July 1–2 in the SGS and July 16–17 in the NGS. Sowing was relatively late due to a late onset of rains. Soybean seeds were inoculated with the commercial inoculant Legumefix (Legume Technology, UK) containing *Bradyrhizobium japonicum* strain 532c (re-isolated in Brazil from strain USDA 442 Wisconsin, USA) at sowing at the rate of 5 g of inoculant per kg of seed. At sowing, 25 kg P ha^{-1} and 30 kg K ha^{-1} as TSP and MoP were uniformly applied to all treatments. Urea was spot-applied to only maize stands at a rate of 25 kg N ha^{-1} for intercropped maize and 50 kg N ha^{-1} for sole maize. Half of the N was applied at three weeks after sowing (WAS) and the other half at six WAS. All fertilisers were band-applied at 3 cm depth and 5 cm from the plants. No N fertiliser was applied to sole legumes. Plots were weeded twice with hoe at 3 and 6 WAS.