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ORIGINAL ARTICLE

Exploring Potentials of Rhizobium Inoculation in Enhancing Soil Fertility and Agro-economic Performance of Cowpeas in Sub-saharan Africa: A Case Study in Semi-arid Mbeere, Eastern Kenya

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ABSTRACT

The potentials of rhizobium inoculation of cowpeas *(Vigna unguiculata (L.) Walp.)* and its contribution to arresting declining soil fertility and improving farm agro-economic performance were investigated in the semi-arid Mbeere District of Eastern Kenya with 30 farmers in a farmer field school. The inoculation of cowpeas with *Rhizobium* and application of triple superphosphate fertiliser, TSP, (T_4) resulted in higher agro-economic performance and positive soil phosphorus balance than planting the same cowpeas variety with either TSP alone (T_3), *Rhizobium* inoculation alone (T_2) or without TSP and rhizobium inoculation (T_1). The grain yields attained in *Rhizobium* + TSP (T_4), TSP (T_3) and *Rhizobium* (T_2) treatments were 54%, 26.1% and 6.8% higher than that of the control (T_1) respectively. The augmentation of *Rhizobia* population through inoculation increased grain yields by 22.5% in treatments with TSP and by 6.8% in non-TSP fertilised plots, demonstrating that *Rhizobium* augmentation had a positive effect above the naturally occurring *Rhizobium* strains. The performance of the treatments in terms of major economic indicators (gross margins, net cash income and return to labour) were in the order *Rhizobium* + TSP > TSP > *Rhizobium* > control further demonstrating the positive effects of augmenting *Rhizobium* population, but with best results from treatments receiving a combination of *Rhizobium* inoculation and phosphorus fertilisers.

Key words: Farmer field school, Participatory experimentation, Rhizobium, Soil fertility

Introduction

The economic growth in sub Saharan Africa (SSA), estimated at 5.7% in 2006, and the quality of life depends on the agricultural sector, which accounts for about 30% of Gross Domestic Product (GDP), 70-80% of employment and is the major source of food, income and raw materials for industries (Commission for Africa, 2005; Economic Commission for Africa, 2007). It is estimated that about 60-75% of SSA population live in the rural areas and rely on land for their livelihoods (The World Bank, 2006). However, given the land's decreasing quality and its central importance to people's livelihoods, there is a growing concern about whether its productivity can be sustained in the future (Hilhorst and Toulmin, 2000). Land degradation in SSA, especially due to declining soil fertility, has been described as the single most important threat to food security and livelihoods (Sanchez *et al*., 1997; Bationo *et al*., 1998).

Addressing declining soil fertility and improving food production in SSA, where the green revolution technologies have had limited impacts, remains an intransigent challenge. Most of the rural poor population who live in SSA are remote from markets, practice subsistence agriculture on marginal soils, do not have access or cannot afford high capital investments in agriculture, lack access to knowledge on how to improve their situation and lacks a well-functioning economic and physical infrastructure (Pretty, 1999). In this situation,

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technologies using low levels of external inputs readily available either on-farm or from nearby off-farm sources are seen by some experts as more appropriate (Pretty, 1995). This approach, often referred to as low external input agriculture (LEIA), emphasises the use of techniques that integrate natural processes such as nutrient cycling, biological nitrogen fixation (BNF), soil regeneration and natural enemies of pests, into food production processes (Pieri, 1995; Snapp *et al*., 1998).

The objective of this study was to explore the potentials of LEIA technology of rhizobium inoculation of cowpeas (*Vigna unguiculata* (L.) Walp.) and its contribution to farm agro-economic performance. The study was carried out in the semi-arid Mbeere District of Eastern Kenya. The value of cowpea, lies in its high protein content (20-25%), making it an important source of protein for resource-poor rural and urban people, and ability to tolerate drought. It also serves as a vegetable (the leaves) and livestock feed (crop residues) and is nitrogen fixing making it a potential plant for improving poor soils, especially in situations where the legume biomass is returned to the soil (Shakoor *et al*. 1984; Bationo *et al*., 2000; IITA, 2007).

The world annual production of cowpeas is estimated at 7.56 million tonnes in about 12.76 million hectares, out of which SSA accounts for about 70% of total world production (IITA, 2007). In Kenya, cowpeas are the second most important grain legume after beans. It is estimated that the area under cowpeas production in Kenya is about 1800 hectares, excluding cowpeas grown in home gardens. The marginal rainfall areas of Eastern Kenya accounts for 85% of total cowpea production in Kenya (Muruli *et al*., 1980). Cowpea grain yield varies between 50 and 300 kg ha^{-1} in farmers' fields in marked contrast to over 2000 kg ha^{-1} obtainable on research stations and by large-scale commercial enterprises in pure cropping systems (Bationo *et al*., 2000). Cowpea yields are low in farmer's fields (mixed cropping systems) due to low soil fertility, low planting densities, shading by other crops, and pests and disease attacks (Ntare, 1989; Reddy *et al.,* 1992; Singh and Tarawali, 1997).

This study was conducted as part of the project, Integrated Nutrient Management to attain Sustainable Productivity Increases in East Africa Farming Systems (INMASP). The INMASP project uses farmer field school (FFS) approach in identifying, testing, monitoring and evaluating Integrated Nutrient Management (INM) technologies. As a holistic approach to soil fertility management, INM embraces responses to the full range of driving factors and consequences, namely biological, physical, chemical, social, economic and political aspects of soil fertility decline (Giller *et al*., 1997; Palm *et al*., 1997). The FFS approach is a group based learning and research-extension methodology (Duveskog, 2006). It is based on the premise that participating farmers can learn (by doing and through discovery) and test various technological options available, during which they are able to decide the best alternatives for their particular circumstances according to their agro-ecological settings, farm size, available capital and access to markets (Matata and Okech, 1998).

Materials and methods

The Study Site

The study was conducted in the semi-arid Mbeere District, Eastern Kenya (Latitude 0º 20' and 0º 50' South and Longitude 37º 16' and 37º 56' East) with a population density of 82 persons km^{-2} (CBS, 2001). The district has an altitude range of 500- 1200 metres above sea level and a mean annual temperature range of 20º to 30º depending on altitude. Rainfall in the district is bimodal, unpredictable and unreliable. Annual average rainfall is 800-1100 mm. The district has two growing periods with a total length of 90-119 days (Kassam *et al*., 1991). Farmers in the district grow mainly subsistence crops and raise indigenous livestock with low genetic potential. Crops grown include maize, beans, millet, cowpeas, sorghum, cassava and sweet potatoes. Livestock found in the district include cattle, goats and poultry.

Farm Characteristics

Following a community meeting held in the study site, 30 volunteer farmers formed an FFS group to participate in the study. The biophysical and socio-economic characteristics of the FFS participants were typical of smallholder farmers in the district (Table 1). The soils in the catchment with the 30 households are well-drained, deep, yellowish brown, loamy sand to sandy loam (Luvic Arenosols) (Muya, 2003). The pH was within tolerance limits for cowpeas, 5.5 to 7.0 (Ball, 2005). However, the soils are low in total nitrogen (N) and extractable phosphorus (P), and are strongly acid to slightly acid.

Farmer Field School Process

Elements of the farmer field school process adopted in this study included, learning through participatory diagnosis of farming system constraints with the 30 FFS members, designing and implementing experiments to address farming system constraints, learning through field observations and data collection (learning by doing and though discovery) and holding discussion sessions (special topics) in bi-weekly meetings with farmers. The FFS process also involved supporting the building of local group structures through group dynamic activities and training FFS members on leadership and team building among others. A farmer field school curriculum, including FFS schedule (timetable), was formulated to guide the FFS process and experimentation throughout the study and learning period. The FFS learning processes, methodological adaptations and institutional experiences have been described in Onduru *et al.* (2003). In this paper, the details of experimentation conducted with FFS members are explored.

Table 1: Farm characteristics of the 30 households studied (mean with standard deviation in parenthesis)

Description	Mean
Socio-economic characteristics	
Number of household members	6.5 (1.8)
Labour units (aeu)[a]	3.2 (1.3)
Family earnings (US$ fam^{-1} half $year^{-1}$)	189 (150)
Households below poverty line (%)[b]	100
Market orientation (% of produce sold)	22
Distance to market (km)	11
Total farm area (ha)	1.4 (1.2)
Average area cultivated (ha)	1.2 (0.8)
TLU[c]	1.1 (1.7)
Soils[d]	
pH-H_20 (1.0 : 2.5 suspension)	5.6 (4.8-6.3)
Total N (g kg^{-1})	0.6 (0.3, 0.9)
Extractable P (Mehlic-1) (mg kg^{-1})	8.8 (2.0, 20)
Exchangeable K (cmol kg^{-1})	0.4 (0.2, 1.0)

[a]Aeu =Adult equivalent units
[b]Poverty line = 1 US $ person day-1
[c]TLU = Tropical Livestock Units (1 TLU = 250 kg live weight)
[d]Soils = Minimum and maximum in parenthesis

Diagnosing of Farming System Constraints and Experimental Design

Farming system constraints were diagnosed through semi-structured interviews, joint transect walks, and plenary discussions and brainstorming sessions with FFS participants. Soil fertility decline, high costs of fertilisers, jointly with high incidences of pests and diseases, low product prices and poor roads were identified as major constraints. An experimental design meeting with farmers prioritised soil fertility decline as the major constrain to be addressed through experimentation.

Farmers proposed technologies for addressing declining soil fertility included farmyard manure, diammonium phosphate, terracing, planting high yielding cowpeas varieties, mulching and Rhizobium inoculation. Proposals from FFS facilitators (researchers and extension staff) were compost, triple superphosphate (TSP) and *Rhizobium* inoculation. A consensus was reached with FFS members to assess the effects of triple super phosphate and *Rhizobium* inoculation on agro-economic performance of cowpeas in an FFS central learning plot (located in the middle of the field to minimise external interference). The treatments agreed upon with farmers were:

T_1: Zero control
T_2: *Rhizobium* inoculation of cowpeas, (0.17 kg ha^{-1});
T_3: Triple superphosphate, TSP (104 kg ha^{-1}); and
T_4: *Rhizobium* inoculated (0.17 kg ha^{-1}) cowpeas + TSP (104 kg ha^{-1}).

Plot sizes measured 10 metres x 5 metres each. The cowpeas variety, Katumani-80 (K80), which matures in 75-85 days was sown in the plots at a rate of 25 kg/ha and at a spacing of 50 cm x 20 cm. The treatments were replicated twice using a pair-wise experimental design. In two of the treatments, T_2 and T_4, the cowpeas were inoculated by *Rhzobium* strains obtained from Microbiology Research Centre (MIRCEN), University of Nairobi, Kenya. Cowpea seeds were inoculated with *Rhizobium* strains at a rate of 15 kg seeds per packet of 100g inoculant and 30g gum Arabic. All inputs used in the trial plots were measured in local units and later calibrated into metric units.

The farmer's criteria and indicators for monitoring the trials were inventoried during the FFS experimental design meeting, and this together with facilitators criteria and indicators, formed the basis for monitoring the trials and data collection during the trial period. Farmers proposed indicators for monitoring the trials included plant height, colour of leaves, grain yields, soil colour, incidence of pests and diseases, soil moisture retention, weed density and labour input. Facilitators' criteria and indicators included monitoring of inputs (labour, fertilizers and related costs) in addition to crop development parameters (stand count, plant height, crop vigour, weed infestation, pest and disease incidence, nutrient deficiencies and crop losses). Other facilitators' criteria were crop output data such as grain yields and quantity of crop residues.

During the experimental design meeting, an action plan was jointly worked out specifying activities and their time frame and roles of the farmers and FFS facilitators. The FFS participants participated in all the activities carried out in the experimental plots from experimental design to harvesting and evaluation of the treatments. For example, they provided the land, participated in plot lay-outs, weeded the plots and made observations and collected data twice a month, jointly with the FFS facilitators. The FFS facilitators provided experimental inputs that required cash purchases e.g. improved cowpea seeds and inorganic fertilisers.

Agro-ecosystem Analysis and Data Collection

Agro-ecosystem analysis (AESA) was the tool used by FFS members to monitor the trials, make observations and collect relevant data. It involved FFS participants, in four sub groups, making observations on the interactions between the planted cowpea, the soil and other biotic and a biotic factors co-existing in the experimental plots based on criteria and indicators agreed upon during the experimental design. AESA was conducted every FFS meeting day (twice every month) for two agricultural seasons under the guidance of the FFS facilitator. The observations were recorded in an AESA chart/record sheet by FFS participants.

Observations made by each FFS sub-group were presented in plenary every FFS meeting day for critique by the rest of the group members and for reaching a consensus on the performance of the various treatments. At the end of each trial season, the cowpeas were harvested per plot, weighed and put in separate labelled bags. Harvesting was done jointly with FFS participants. The harvested cowpeas were sun dried in the home of one of the FFS participants and care taken to avoid mixing harvests from different plots. The sun-dried cowpeas were later re-weighed per plot. In addition to cowpeas grains, the cowpea residues were also harvested per plot and weighed separately.

Evaluation of the Trials

At the end of the trial period (two cropping seasons), a participatory evaluation was conducted to draw farmers' opinions, preferences, criticisms and suggestions about the technologies tested. The evaluation was conducted based on the same performance indicators as given by farmers during the experimental design workshop. It was conducted by the FFS members in four sub-groups using matrix scoring and ranking.

Nutrient Balances

The impacts of different treatments on partial soil nutrient balances were estimated as the difference between nutrient inputs and outputs per treatment plot using nutrient monitoring model (NUTMON) as described in Vlaming *et al* (2001):

Partial nutrient balance = Σ (IN1, IN 2) - Σ (OUT1-OUT 2) where

IN1 = Inorganic fertilizers (TSP)

IN2 = Organic fertilizers (manure)

OUT1 = Harvested product (Cowpea grains)

OUT2 = Crop residue (Cowpea residue)

Nutrient inputs (IN 1 and IN 2) were calculated from the quantity and quality (nutrient contents) of supplied inputs. Similarly, nutrient outputs (uptake) were estimated from the quantity of harvested grains (OUT 1) and cowpea residues (OUT 2) and their respective nutrient contents as described in NUTMON model.

Data Analysis

The data collected during AESA sessions were analyzed by FFS members in sub-groups and shared in plenary each meeting day. This qualitative data analysis was reinforced by quantitative data/statistical data analysis at the end of the study period. Quantitative data analysis included analysis of agronomic parameters, economic indicators of performance and nutrient budgets as well as farmers' evaluation (scoring and ranking). Labour inputs were valued at opportunity costs needed to hire such labour in the site. *Rhizobium* inoculation, cowpeas seeds, TSP and harvested cowpeas grains were valued at prevailing market prices. Data processing and analysis were done using Excel (from Microsoft Cooperation) and Statistical Programme for Social Scientists (SPSS) from SPSS Inc.

Results and discussion

Crop Vigour

Plant height was one of the indicators used in the AESA chart to assess performance of technologies as a proxy indicator for crop vigour. Measurements taken during crop growth showed that treatments involving *Rhizobium* inoculation and TSP (T_4) resulted in vigorous and steady growth of cowpeas throughout the growing period (Figure 1). Cowpea was less vigorous in the zero control treatment (T_1). The treatment T_1 represented normal farmers practice in the study site.

The steady vigorous growth of cowpeas in the treatment, *Rhizobium* + TSP (T_4), could possibly be due to the interactive effects of *Rhizobium* and TSP. TSP (0-46-0) provides phosphorus, which plays an important role in root elongation and thus enables the plant to exploit a greater soil volume (Muriuki and Qureshi, 2001). Also inoculating cowpeas with *Rhzobium* (in soils supplied with phosphorus) could have resulted in increased nitrogen fixation and possibly high vigorous growth.

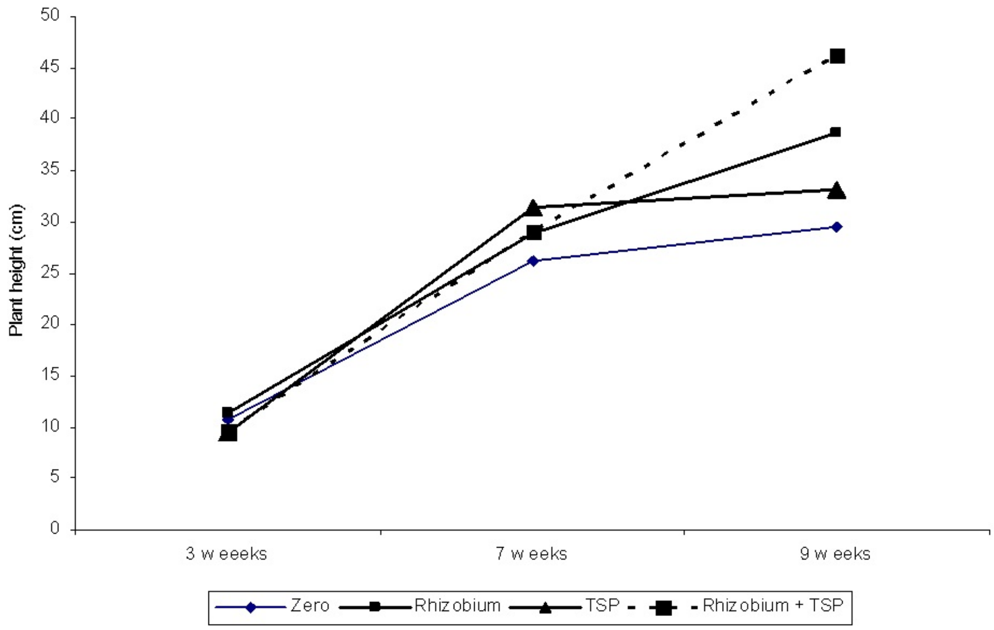

Fig. 1: Height of cowpeas under different treatments over the growing season

Cowpea Grain Yields

The highest grain yields of 1.7 tonnes/ha was obtained in treatment involving the combined use of TSP and *Rhizobium* inoculated cowpeas (Table 2). The grain yields of 1.1 to 1.7 tonnes ha^{-1} obtained in this study were comparable to those reported in other experimental studies in the dryland areas of Eastern Kenya (Shakoor *et al*., 1984). The potential grain yields of Katumani 80 (K-80) cowpeas variety is estimated to be in the range of 1.1 to 1.6 tonnes ha^{-1} (DALEO, 2002).

Table 2: Agro-economic performance of the tested technologies (standard deviation in parenthesis)

Description	T_1	T_2	T_3	T_4
Grain yields (kg/ha)	1,100.0 (115.5)	1,175.0 (206.2)	1,387.5 (322.4)	1,700.0 (216.0)
Gross income (Ksh/ha)	22,059.5 (2329.7)	23,562.3 (4122.7)	27,850.6 (6433.8)	34,117.3 (4349.0)
Non cash variable costs (Ksh/ha)				
Total labour	10,760.0 (230.9)	10,800.0 (196.0)	10,840.0 (138.6)	10,800.0 (196)
Cash variable costs (CVC) in Ksh/ha				
Rhizobium	0.0 (0.0)	117.0 (0.0)	0.0 (0.0)	117.0 (0.0)
TSP	0.0 (0.0)	0.0 (0.0)	2,704.0 (0.0)	2,704.0 (0.0)
Seeds	1,500.0 (0.0)	1,500.0 (0.0)	1,500.0 (0.0)	1,500.0 (0.0)
Sub-total (CVC)	1,500.0 (0.0)	1,617.0 (0.0)	4,204.0 (0.0)	4,321.0 (0.0)
Total variable costs (Ksh/ha)	12,260.0 (230.9)	12,417.0 (196.0)	15,044.0 (138.6)	15,121.0 (196.0)
Gross margins (Ksh/ha)	9,799.5 (2098.7)	11,145.3 (3955.4)	12,806.6 (6478.1)	18,996.3 (4277.8)
Net cash income (Ksh/ha)	20,500.0 (2309.4)	21,883.0 (4123.11)	23,546.0 (6448.5)	29,679.0 (4320.5)
Return to labour (Ksh/day)	72.6 (14.1)	82.2 (28.3)	94.7 (48.1)	140.6 (30.7)
Benefit cost ratio	1.8 (0.2)	1.9 (0.3)	1.9 (0.4)	2.3 (0.3)
Value cost ratio (V/C)		9.6	2.1	4.2

T_1: Zero control; T_2: *Rhizobium* (0.17 kg ha^{-1}); T_3: TSP (104 kg ha^{-1}); T_4: *Rhizobium* (0.17 kg ha^{-1}) + TSP (104 kg ha^{-1}).
V/C= P $(O_{T1}-O_{TC})$ / P $(I_{T1}-I_{TC})$ where P = price; O_{T1} = Output treatment 1; O_{TC} = Output treatment control; I_{T1} = Input treatment 1; I_{TC} = Input treatment control. 1 US \$ = Ksh 75 at time of study.

However, at farm level, the average grain yield of cowpeas is low. In a review of cowpeas production in Mbeere District of Eastern Kenya (1996-1997), Onduru *et al*. (2002) found that the average grain yields of cowpeas was about 0.5 tonnes ha^{-1}. In another study carried out by Muthamia and Kanampiu (1996) in Eastern Kenya, the grain yields of local cowpea variety was low, 0.4 tonnes ha^{-1}. The poor cowpea yield is attributed to many factors including the use of poor yielding varieties, low soil fertility and pest (e.g. *Kiwi* beetle and parasitic weed, *Alectra volgelii)* and disease attacks.

The grain yield performance of the studied treatments were in the order *Rhizobium* + TSP (T_4) > TSP (T_3) > *Rhizobium (*T_2*)* > control (T_1). Inoculated seeds of cowpea planted on plots fertilised with TSP (T_4) attained 54% higher yields than zero control. Similarly, planting cowpeas using TSP alone (T_3) and *Rhizobium* alone (T_2) resulted in 26.1% and 6.8% higher grain yields than the zero control (T_1) respectively. The slightly high grain yields (6.8% more) obtained from *Rhizobium* inoculated seeds compared to control seem to suggest that augmentation of *Rhizobia* population through inoculation results in positive benefits in the study area above the effects of naturally occurring *Rhizobium* strains. This is further corroborated by the observation that T_4 attained 22.5% higher grain yields than T_3. According to Shakoor *et al.* (1984), cowpeas nodulates freely with wild *Rhizobium* strains in the soils.

The potential effect of inoculating cowpeas with *Rhizobium* strains was enhanced with the application of phosphorus. This is probably due to the role that phosphorus plays in enhancing nitrogen fixation in grain legumes. In a study conducted in the Usambara Mountains in northern Tanzania, Amijee and Giller, (1998) reported that nitrogen fixation in grain legumes was inhibited by soil phosphorus deficiency.

Economic Performance

The gross margins, return to labour and benefit cost ratio were all positive for the technologies studied, implying that they were economically viable (Table 2). The *Rhizobium* + TSP treatment (T_4) outperformed the other treatments in gross margins, net cash income, return to labour and benefit cost ratio. The gross margins for *Rhizobium* + TSP (T_4), TSP (T_3) and *Rhizobium* (T_2) treatments were 94%, 31% and 14% higher than that of the control (T^1) respectively. For T_4 and T_3 treatments, the return to labour was 76% and 18% higher than opportunity cost for labour in the study site.

Taking a benefit cost ratio of two, the minimum acceptable for most small scale farming activities (Muyekho and Mose, 2000), it was observed that all the technologies tested (T_2 to T_4) were economically viable in the study site. Similarly, using a value cost ratio of two as a risk factor (Muriuki and Qureshi, 2001), it was observed that all the tested technologies (T_2 to T_4) can be practiced without much risk.

Nutrient Balances and Biological Nitrogen Fixation

Partial nitrogen and potassium balances were negative for studied treatments. However, where phosphorus was supplied (TSP fertiliser), the partial P balances were positive (Table 3). Nitrogen inputs through biological nitrogen fixation were not considered in the calculation of partial nutrient balances, which was restricted to easily quantifiable flows that are "visible" to the farmer.

Table 3: Impacts of tested technologies on nutrient balances

Nutrient balances	T_1	T_2	T_3	T_4
N partial flows (kg ha^{-1})				
In 1 (mineral fertilisers)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
In 2 (organic inputs)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Out 1 (harvested grains)	37.2 (3.9)	39.7 (7.0)	46.9 (10.9)	57.5 (7.3)
Out 2 (crop residues)	0.5 (0.2)	0.5 (0.1)	0.8 (0.2)	0.9 (0.3)
Partial N balance (kg ha^{-1})	-37.7 (4.1)	-40.2 (7.0)	- 47.7 (10.8)	-58.4 (7.5)
BNF (kg N ha^{-1})	19	20	24	29
P partial flows (kg ha^{-1})				
In 1 (mineral fertilisers)	0.0 (0.0)	0.0 (0.0)	20.9 (0.0)	20.9 (0.0)
In 2 (organic inputs)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Out 1 (harvested grains)	3.9 (0.4)	4.2 (0.7)	4.9 (1.2)	6.1 (0.8)
Out 2 (crop residues)	0.1 (0.2)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)
Partial P balance (kg ha^{-1})	-4.0 (0.4)	-4.2 (0.7)	15.9 (1.1)	14.7 (0.8)
K partial flows (kg ha^{-1})				
In 1 (mineral fertilisers)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
In 2 (organic inputs)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Out 1 (harvested grains)	2.2 (0.2)	2.4 (0.4)	2.8 (0.7)	3.4 (0.4)
Out 2 (crop residues)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)
Partial K balance (kg ha^{-1})	-2.3 (0.3)	-2.5 (0.4)	-2.9 (0.6)	-3.5 (0.5)

BNF: Biological Nitrogen Fixation

In this study an attempt has been made to quantify biological nitrogen fixation (BNF), Table 3. The BNF was modelled as comprising symbiotic and non-symbiotic N fixation. The symbiotic N fixation was assumed to be crop-specific percentage (50%) of the total nitrogen uptake of cowpeas (Vlaming *et al.*, 2001). The total nitrogen uptake was defined as the sum of the amounts of nitrogen in the cowpea grains and the cowpea crop residue. Non-symbiotic N fixation was determined using the mean annual precipitation, P, (Smaling, 1993):

IN 4b = $2 + (P - 1\,350) \times 0.005$ where

IN 4b = Biological Nitrogen Fixation (kg N ha^{-1})

P = Mean annual precipitation; mean annual rainfall of 900 mm was used in the calculation

The estimated quantity of nitrogen fixed through BNF was low, 19-29 kg N ha^{-1}. This corroborates other studies, which have indicated that BNF under smallholder conditions in Africa are barely significant as it is limited by soil moisture conditions and phosphorus deficiencies (Wetselarr and Ganry, 1982; Amijee and Giller, 1998). The treatment receiving *Rhizobium* inoculation and phosphorus application, (T_4), fixed 45% higher nitrogen through BNF than where similar inoculated seeds were planted without phosphorus application (T_2). It was further observed that treatments receiving phosphorus alone, (T_3), fixed 26% higher nitrogen through BNF than the zero-control (T_1). These observations seem to indicate that low soil phosphorus could be one of the factors limiting BNF in the study area.

End of Trial Evaluation

Farmer's evaluation of the trials was done in four sub-groups using matrix scoring and ranking, based on 20 scores per criterion. Scores were assigned by farmers according to perceived performance of the treatment with regards to a given criterion, with high scores assigned to treatments with higher performance. The scores were then aggregated for each criterion to determine the outcome of the evaluation (Table 4). Farmers preferred technology was the use of *Rhizobium* + TSP (T_4). This was in agreement with quantitative evaluation, which showed that the treatment exhibited high agro-economic performance and positive partial P balances.

Table 4: Mean scores against the tested technologies as conducted by four sub-groups of farmers (standard deviation in parenthesis)

Treatment	Leaf colour	Plant health	Soil moisture retention	Incidence of weeds	Plant vigour	Overall rank*
T_1	2.8 (1.0)	3.0 (0.8)	3.5 (1.7)	3.5 (1.7)	2.8 (1.0)	4
T_2	4.3 (0.5)	4.8 (1.0)	4.8 (0.5)	5.0 (0.8)	4.0 (0.0)	3
T_3	6.3 (2.1)	5.0 (0.8)	5.0 (0.8)	5.3 (0.5)	5.5 (0.6)	2
T_4	6.8 (1.5)	7.3 (1.3)	6.8 (2.1)	6.3 (1.5)	7.8 (1.3)	1

T_1: Zero control; T_2: *Rhizobium* (0.17 kg ha^{-1}); T_3: TSP (104 kg ha^{-1}); T_4: *Rhizobium* (0.17 kg ha^{-1}) + TSP (104 kg ha^{-1}). *Ranking: 1 = the most preferred technology, 4 = Least preferred based on total scores

When asked about the technology they are going to implement in the immediate subsequent season, *Rhizobium* + TSP (T_4) topped the list of farmers priorities (mean score of 5.8 on the criterion, choice of technology). However, some of the farmers either due to their inadequate cash availability in the immediate post trial period, preferred to start with technologies that they were able to afford at the time (T_1 to T_3 with mean scores of 4.8 each on the criterion, technology choice) with indication that they will eventually implement their most preferred technology of *Rhizobium* + TSP (T_4) in subsequent seasons. This shows that although a technology may be most preferred, its immediate uptake and implementation is dictated by farmer's socio-economic circumstances (cash availability, labour etc.).

Conclusions

This study has demonstrated that cowpeas productivity can be improved through the use of appropriate germplasm and a combination of *Rhizobium* inoculation and inorganic phosphorus application. The inoculation of cowpeas with *Rhizobium* and application of triple superphosphate fertiliser resulted in high agro-economic performance and positive soil phosphorus balance than planting the same cowpeas variety with either TSP alone or *Rhizobium* alone. The performance of the treatments in terms of major economic indicators (gross margins, net cash income and return to labour) were in the order *Rhizobium* + TSP > TSP > *Rhizobium* > control.

The high grain yields obtained through *Rhizobium* inoculation compared to zero control treatment has demonstrated that augmentation of *Rhizobia* population through inoculation results in positive benefits in the study area, above the effects of naturally occurring *Rhizobium* strains. This benefit was enhanced with the application of triple superphosphate fertiliser implying that low soil phosphorus could be one of the factors limiting biological nitrogen fixation in the study area.

Farmers' evaluation of the studied technologies corroborated well with some quantitative analysis demonstrating some degree of congruency between farmers' qualitative analysis and researchers (facilitators) quantitative analysis. The treatment with a combined application of *Rhizobium* and triple superphosphate was rated highly by farmers, despite the fact that it was associated with high total variable costs. Farmers' preference for this technology was attributed to the perception that it resulted in the most vigorous plants and high yields.

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