Nitrogen and phosphorus budgets for sorghum and cowpea production under simulated sole- and intercropping systems in low- and medium-P soils


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A greenhouse study was conducted at Seibersdorf, Austria to simulate sorghum-cowpea cropping systems to quantify biological nitrogen fixation (BNF), estimate the nutrient budgets and yield advantages under low-P (Hungary) and medium-P (Waldviertel) soils. The soils were collected from Kompolt in Hungary and Waldviertel in Austria. ¹⁵N isotope dilution method was used to quantify BNF while a simple input/output model was used for budgeting. Hungarian soil produced significantly (P<0.001) higher biomass than Waldviertel soil for both cowpea and sorghum in all cropping systems. However, crops grown in Waldviertel soil accumulated more N than on Hungarian soil. Despite the apparent variations in total N fixed under the sole cowpea and intercrop cropping systems, cowpea derived 14 to 73% of their N from fixation. Intercropping cowpea with sorghum in both soils significantly (P<0.001) reduced the biomass of cowpea by 30 to 50% and of sorghum by ~70% while increased %N derived from fixation by 20% in Hungarian soil only. Intercropping had > 1.0 land equivalency ratio than sole cropping systems. Exporting crop residues in all cropping systems led to nutrients mining while incorporating cowpea residues gave positive N balance. This study demonstrated the potential of intercropping to produce a sustainable cropping system through BNF and sparing of P within the systems.

Key words: Sorghum, cowpea, nitrogen and phosphorus budgeting, biological nitrogen fixation, land equivalency ratios.

INTRODUCTION

Declining soil fertility has been cited as the major cause of low grain yields in most parts of sub-Saharan Africa (SSA) (Sanchez et al., 1997) where >70% of the rural population rely on rain-fed agriculture for their livelihood and food security. In the wake of climate change and variability, the food crisis issues in SSA are being exacerbated (Fischer et al., 2005). Smallholder farmers may have little capacity to adapt to the impacts of climate change...
change and variability due to their limited resources (Mapfumo and Giller, 2001). Therefore, there is a need to identify sustainable options for farmers that improve soil fertility and ensure food security. Apart from combining inorganic and organic fertilizers for increasing crop yields and reducing the risk of crop failure, legume/cereal intercropping systems is an alternative option where land shortage is of particular concern.

Sorghum is the fifth most important cereal crop after wheat, rice, maize and barley produced in dry areas of the tropics (FAO, 2005). It is mainly used as a source of carbohydrates and is consumed as porridges, pastes, beverages, instant soft porridge, malt extracts and as an additive for brewery (Taylor, 2004). The main strength of sorghum is its ability to produce grain yield under harsh climatic conditions where other grain crops would fail to produce yield (Djurfeldt et al., 2005). Well managed sole sorghum yield ranges from 1.7 to 4.8 t ha$^{-1}$ but yields have remained below 0.8 t ha$^{-1}$ in SSA (FAO, 1998; Rohrbach et al., 2005). There is therefore a need to improve the fertility of the soil to improve sorghum yield by the inclusion of legumes, more so as the latter is a main source of protein which is frequently the limiting component in the people’s diet.

In the semi-arid regions of SSA, farmers plant sorghum as sole stands or under sparse intercropping or irregular crop rotations (Ncube et al., 2007). In the majority of cases, intermediate to resource-constrained household are more risk averse, choose intercropping to achieve some yield of legume without sacrificing the much needed yield of the staple cereal (Mapfumo, 2000). Growing sorghum in mixture with groundnut (Arachis hypogea L.) has been shown to be more productive (as indicated by the land equivalency ratio) than their monoculture combined (Azam-Ali et al., 1990). Despite groundnut showing positive yield benefit in sorghum cropping systems, cowpea has better drought tolerance, wide range of local genetic diversity and fit well in semi-arid areas of SSA (Coetzee, 1995). Cowpea is widely grown in Africa as a food legume, fodder and as a cover crop (Jackai and Adalla, 1997). Nutritionally, cowpea grain is rich in protein (20.5 to 31.7%), carbohydrates (56.0 to 65.7%), fat (1.1 to 3.0%) and fiber (1.7 to 4.5%) (Onwuliri and Obu, 2002).

According to Ncube et al. (2007), sorghum yields following cowpea was 1.6 t ha$^{-1}$, which was more than double the yields attained in the sorghum after sorghum rotation system. Despite the grain increase in rotation systems, intercropping innovation have high potential of being adopted by farmers due to many benefits associated when compared to sole crop stands (Mpairwe et al., 2002; Myaka et al., 2006). Some of the associated benefits include risk aversion, extensive and intensive use of resources, greater return per area, reduction of pest and the possibility of soil fertility management (Alhaji, 2008). Given the high nutrient losses reported in smallholder farming areas of SSA under continuous cropping with low external inputs (Smaling et al., 1993a,b), there is a need to understand the N and P budgeting under sorghum-cowpea cropping systems particularly where fertilizer use and soil fertility are low.

Adu-Gyamfi et al. (2007) investigated the N and P budget in farmer-managed plots of intercropped maize-pigeonpea in Tanzania and Malawi and reported negative budgets when all the above-ground materials were removed. In a scenario where the entire shoot (except the edible parts) were returned to the soil, positive balance was recorded. There is however, very little information on the N and P budget for sorghum/cowpea cropping systems. The main objective of this study was to quantify the amount of atmospheric N fixed in the soil by cowpea in sole and intercropping with sorghum, estimate the nutrient (N and P) flow and yield advantages as estimated by the land equivalency ratio (LER).

**MATERIALS AND METHODS**

**Study site**

Seibersdorf which is about 40 km south-east of Vienna has a long-term average rainfall of 607 mm; with June and July having the highest rainfall (74 and 63 mm, respectively). The air temperature ranges from -1.5°C in January to 20°C in July. Table 1 show the weather conditions at Seibersdorf during the study period. Seibersdorf received more than the average rainfall in 2010 with August receiving the highest (Table 1).

**Greenhouse establishment**

A greenhouse pot experiment was established in the 2010 summer season at the International Atomic Energy Agency (IAEA) laboratory at Seibersdorf (47°56′0″N 16°31′0″E), Austria. A low-P soil from Hungary classified as a Dystric Eutrocrept, and a medium-P soil from Waldviertel Austria classified as a Dystric Cambisol was used (Table 2). Plastic trays (0.6 m × 0.3 m × 0.2 m) filled with 25 kg of soil composed of sieved airdried soil (< 2 mm) and sand mixture in the ratio 1: 1 were used to grow the crops. At planting, P in the form of triple super phosphate (TSP) and N as labelled $[^{15}\text{N}]\left(\text{NH}_4\text{SO}_4\right)$ with 1.991% atom excess were applied each at 30 kg ha$^{-1}$ (3 g m$^{-2}$) to all the trays. Rhizobia inoculant solution (Strain MAR 1510) was also applied to all trays to ensure similar conditions. Sorghum (ICSV 111 IN) and cowpea (IT87S-1462) seed were then planted per hill at 0.02 m depth with spacing of 0.6 × 0.1 m in the trays simulating three different cropping systems (sole sorghum, sole cowpea and sorghum cowpea intercropping) on 16th of June 2010. The spacing arrangement gave a plant population of 30 plants per tray for both sole and intercropping systems. The treatments were arranged in randomized complete block design (RCBD) with two soils (Hungarian and Waldviertel), three cropping systems and each treatment replicated three times. Adequate water was applied each morning to all trays to avoid water loss through the drains below the trays and as the plant developed the amount of water was adjusted to avoid moisture stress. Weeds were controlled by hand picking while pest and disease control was done using appropriate pesticides.

**Plant sampling and analysis**

Plant samples were collected two months after establishment of the
experiment. The plant samples were cut from the soil surface and oven dried to a constant at 70°C and their dry mass measured. After cutting the above ground biomass the root systems were carefully removed, washed with water, dried to a constant at 70°C and weighed. The biomass (shoots and roots) samples were ground in a Wiley Mill to pass through a 1 mm sieve and analysed for total carbon and total N using the same method.

### Table 1. Selected weather characteristics outside the greenhouse from 16 June to 16 August at Seibersdorf, Austria 2010.

<table>
<thead>
<tr>
<th>Month</th>
<th>Monthly Averages of Solar Radiation Dgt (mJ/m²)</th>
<th>Precipitation (mm)</th>
<th>Average Wind Speed (m/s)</th>
<th>Average Air Temperature (°C)</th>
<th>Average Relative Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>15.31</td>
<td>90.8</td>
<td>3.26</td>
<td>18.01</td>
<td>73.40</td>
</tr>
<tr>
<td>July</td>
<td>17.36</td>
<td>109.2</td>
<td>3.00</td>
<td>22.13</td>
<td>67.19</td>
</tr>
<tr>
<td>August</td>
<td>14.17</td>
<td>164.2</td>
<td>3.10</td>
<td>20.22</td>
<td>77.81</td>
</tr>
</tbody>
</table>

### Table 2. Selected physical and chemical characteristics of soils in which sorghum and cowpea were planted, under greenhouse conditions at Seibersdorf, Austria.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Sand (g kg⁻¹)</th>
<th>Clay (g kg⁻¹)</th>
<th>Silt (g kg⁻¹)</th>
<th>pH Organic carbon (g kg⁻¹)</th>
<th>Total N (mg kg⁻¹)</th>
<th>Total P (mg kg⁻¹)</th>
<th>Inorganic P (mg kg⁻¹)</th>
<th>Available P (mg kg⁻¹)</th>
<th>Exchangeable cation (cobalthexamine) (cMol. kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H₂O KCl</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ca *</td>
</tr>
<tr>
<td>Waldviertel</td>
<td>145</td>
<td>273</td>
<td>582</td>
<td>6.5 6.0</td>
<td>20.00</td>
<td>1.21</td>
<td>502</td>
<td>56</td>
<td>144</td>
</tr>
<tr>
<td>Hungarian</td>
<td>82</td>
<td>830</td>
<td>88</td>
<td>5.5 4.6</td>
<td>7.91</td>
<td>0.83</td>
<td>302</td>
<td>36</td>
<td>85</td>
</tr>
</tbody>
</table>

Adapted from Adu-Gyamfi et al. (2009); * phosphate fractions.

### Assessment of land equivalency value

As yields of different crops cannot be compared directly with each other, mixed culture advantage (or intercropping productivity) is commonly assessed by land equivalency ratio (LER) (Dariush et al., 2006). It is defined as the relative land area under monoculture that is required to produce the yields achieved under mixed culture (Goodie, 2001). Total land equivalency ratio (LERs) is obtained by the summation of LER values for the sole crops (i.e. partial LER) in the mixture.

\[
\text{LER}_s = \frac{\text{Intercrop}_s}{\text{Soil}_s} + \frac{\text{Intercrop}_c}{\text{Soil}_c} \tag{1}
\]

#### Estimation of biological nitrogen fixation in cropping systems

Total labelled N (¹⁵N) in plant biomass were analysed using Isotope Ratio Mass Spectrometer (Isoprime GV Instruments) and according to Peoples et al. (1989), the percentage N derived from the atmosphere (%Ndat) in cowpea was calculated as:

\[
\%\text{Ndat} = \left(1 - \frac{\text{Atom}\%\text{excess}^{15}\text{N in cowpea}}{\text{Atom}\%\text{excess}^{15}\text{N in sorghum}}} \right) \times 100 \tag{2}
\]

The proportion of N fixed was calculated for all cropping systems. The amount of N symbiotically fixed by cowpea (Ndat, g m⁻²) was calculated by multiplying the total N in cowpea samples by the Ndat. The proportions of N derived from fertilizer (%Nff) were calculated as:

\[
\%\text{Nff} = \frac{(\text{Atom}\%\text{excess of plant biomass}} - \text{Atom}\%\text{excess of fertilizer})}{\times 100} \tag{3}
\]

### Nitrogen and P budgets

A simple input/output model was used to calculate the N and P budgets (Adu-Gyamfi et al., 2007). The inputs were soil stocks, fertilizer and non-fertilizer (BNF) while excluding atmospheric deposition. The outputs were represented as nutrients removed in harvested biomass while such losses out of the cropping systems as leaching, erosion, overland and lateral transport were assumed as negligible. Nutrient budgeting for this study was simulated basing on how farmers manage their harvest and residues in smallholder farming systems of SSA (Mapfumo and Giller, 2001). In the first management scenario, all the aboveground biomass are grazed or exported from the...
Figure 1. Aboveground biomass productivity (g m$^{-2}$) of sorghum and cowpea under three different cropping systems established on Waldviertel and Hungarian soils at Seibersdorf, Austria, 2010.

Field due to strong crop–livestock interdependence, while the roots and the fallen leaves are incorporated into the soil (Adu-Gyamfi et al., 2007; Vesterager et al., 2007). In the second management scenario where farmers do winter ploughing, all the biomass (except grain) of the sorghum and cowpea are returned to the soil. The aboveground and belowground biomass from this study was used to do nutrient budgeting simulating the different management scenario in farming systems.

Data analysis

Data were analyzed by analysis of variance and mean comparisons for biomass productivity, amount of N fixed, P budgets and N budgets were done using GENSTAT for Windows Discovery Edition 2 (2005). All mean comparisons for the individual treatments were made at 95% confidence interval.

RESULTS

Biomass productivity of cowpea and sorghum

Cowpea and sorghum grown in Hungarian soil produced significantly (P < 0.001) higher biomass than in Waldviertel soil irrespective of cropping systems (Figure 1). Aboveground cowpea biomass from Hungarian soil was 5.2 g m$^{-2}$ whilst that from Waldviertel was 4.5 g m$^{-2}$. Visual observation showed that crops grown in Waldviertel soil had a steady growth rate compared to the fast growth on Hungarian soil which was later reduced when sorghum started showing severe nitrogen deficiency within two month growth period. Intercropping cowpea with sorghum significantly (P < 0.001) reduced the cowpea biomass from 4.55 to 1.32 g m$^{-2}$ under Waldviertel soil and from 5.20 to 2.64 g m$^{-2}$ in Hungarian soil. On Hungarian soil, intercropping significantly (P < 0.001) reduced sorghum biomass by 29% (Figure 1). A similar trend was observed for sorghum under Waldviertel soil though this was not significant.

Land equivalency ratio for intercropping cropping systems (Biomass and N uptake)

Sorghum/cowpea intercropping showed an advantage over sole crop sorghum and cowpea alone. On the low-P Hungarian soil intercropping had an advantage over sole crops as indicated by LER$_{t}$ of 1.09 for biomass productivity and by LER$_{t}$ of 1.31 for N uptake. However, there was little advantage of intercropping over sole cropping in the Waldviertel soil as its LER$_{t}$ was 1.01 for biomass productivity and 1.22 for N uptake.

Shoot root ratio

Sole cowpea and intercropped cowpea/sorghum had a higher shoot to root (S: R) when grown in the Waldviertel soil than the Hungarian soil; the reverse was the case for the sole sorghum. The S: R was 1.73 for sole sorghum grown on Hungarian soil and 1.41 when grown on Waldviertel (Table 3). For both sorghum and cowpea, intercropping resulted in higher S: R than sole-cropping in the Waldviertel soil while the reverse was the case in the Hungarian soil (Table 3).

Nitrogen fixation by cowpea

Cowpea grown in Hungarian soil fixed more nitrogen (0.068 g N m$^{-2}$) and derived more nitrogen from fixation (49.2%) than those grown in Waldviertel soil. Intercropping cowpea with sorghum significantly reduced the amount of N fixed and the %N$_{dfa}$ (23.8 to 14.2%) in Waldviertel soil (Table 4). However, intercropping cowpea with sorghum on Hungarian soil significantly increased %N$_{dfa}$ by 20% while the amount of N fixed was reduced (Table 4). Although the relative values of %N$_{dfa}$ in sole and intercropping depended on the soil considered, the cowpea variety can potentially derive 14 to 73% of their N from fixation.

Nitrogen budgeting under the three cropping systems

Shoot N uptake was higher under all cropping systems in
Nitrogen budgeting in simulated sole- and intercropping systems under Waldviertel and Hungarian soils under greenhouse condition at Seibersdorf, Austria.

Table 3. Shoot to root ratio of cowpea and sorghum under Waldviertel and Hungarian soil following establishment under three different cropping systems at Seibersdorf in Austria.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Cropping system and treatment</th>
<th>Shoot:Root ratio</th>
<th>Soil</th>
<th>Cropping system and treatment</th>
<th>Shoot: Root ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waldviertel</td>
<td>Cowpea</td>
<td>2.88</td>
<td>Hungarian</td>
<td>Cowpea</td>
<td>1.83</td>
</tr>
<tr>
<td>Waldviertel</td>
<td>*Cowpea</td>
<td>2.93</td>
<td>Hungarian</td>
<td>*Cowpea</td>
<td>1.68</td>
</tr>
<tr>
<td>Waldviertel</td>
<td>*Sorghum</td>
<td>1.56</td>
<td>Hungarian</td>
<td>*Sorghum</td>
<td>1.51</td>
</tr>
<tr>
<td>Waldviertel</td>
<td>Sorghum</td>
<td>1.41</td>
<td>Hungarian</td>
<td>Sorghum</td>
<td>1.73</td>
</tr>
</tbody>
</table>

*Crop under intercropping system.

Table 4. Total amount of N2-fixed (g N m⁻²), %Ndfa (as determined by the dilution method) and %Neff in cowpea under two different soils and cropping systems two months after establishment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nitrogen yield (g m⁻²)</th>
<th>%Ndfa</th>
<th>Ndfa (g m⁻²)</th>
<th>%Neff</th>
<th>Neff (g m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>H</td>
<td>W</td>
<td>H</td>
<td>W</td>
</tr>
<tr>
<td>Sole cowpea</td>
<td>0.16</td>
<td>0.14</td>
<td>23.8</td>
<td>49.2</td>
<td>0.039</td>
</tr>
<tr>
<td>*Intercropped</td>
<td>0.04</td>
<td>0.07</td>
<td>14.2</td>
<td>73.3</td>
<td>0.005</td>
</tr>
<tr>
<td>LSD</td>
<td>0.03</td>
<td>0.03</td>
<td>6.64</td>
<td>6.64</td>
<td>0.016</td>
</tr>
</tbody>
</table>

*Sorghum cowpea intercropping; W, Waldviertel soil; H, Hungarian soil.

Table 5. Nitrogen budgeting in simulated sole- and intercropping systems under Waldviertel and Hungarian soils under greenhouse condition at Seibersdorf, Austria.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Cropping system</th>
<th>Initial soil N (g N)</th>
<th>N imports (g m⁻²)</th>
<th>N exports (g m⁻²)</th>
<th>N balance (g m⁻²)</th>
<th>C: N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waldviertel</td>
<td>Cowpea</td>
<td>0.030</td>
<td>0.225</td>
<td>0.345</td>
<td>0.10 (-0.12)</td>
<td>17</td>
</tr>
<tr>
<td>Waldviertel</td>
<td>*Sorghum/Cowpea</td>
<td>0.030</td>
<td>0.186</td>
<td>0.294</td>
<td>0.0 (-0.004)</td>
<td>19</td>
</tr>
<tr>
<td>Waldviertel</td>
<td>Sorghum</td>
<td>0.030</td>
<td>0.18</td>
<td>0.34</td>
<td>0.0 (-0.24)</td>
<td>17</td>
</tr>
<tr>
<td>Hungarian</td>
<td>Cowpea</td>
<td>0.020</td>
<td>0.258</td>
<td>0.075</td>
<td>0.14 (-0.06)</td>
<td>23</td>
</tr>
<tr>
<td>Hungarian</td>
<td>*Sorghum/Cowpea</td>
<td>0.020</td>
<td>0.241</td>
<td>0.189</td>
<td>0.09 (-0.01)</td>
<td>27</td>
</tr>
<tr>
<td>Hungarian</td>
<td>Sorghum</td>
<td>0.020</td>
<td>0.18</td>
<td>0.20</td>
<td>0.07 (-0.13)</td>
<td>37</td>
</tr>
</tbody>
</table>

*Sorghum or cowpea under intercropping. Figures in parentheses denote the N balance of the system.

Hungarian soil than Waldviertel soil. Exporting all the aboveground biomass (Budget 1) depleted the soil N, regardless of cropping system and soil. In Hungarian soil, exporting all shoot biomass under sole cowpea, sole sorghum and intercropping gave 0.14, 0.07 and 0.09 g N m⁻², respectively. When all the aboveground biomass were incorporated into the soil (Budget 2), the mean N budget for sole cowpea and intercropped systems improved (Table 5).

Exporting shoot biomass resulted in a negative N balance (-0.004 to -0.24) in all treatments. Exporting the shoots from Waldviertel cropping systems resulted in low C: N values (< 20) while in Hungarian system the corresponding values were >20. Incorporation of both shoots and root resulted in the positive N balance (+0.01 to +0.08) and lowered the C: N, except for sole sorghum and intercrop in Hungarian soil (Table 5). In Hungarian soil, intercropping increased the N budget to 0.26 g N m⁻² (+0.06 N balance) compared to sole sorghum (0.20 g N m⁻² which was 0.00 N balance). Similar trends were observed under Waldviertel soil with sole cowpea having higher N balance than the intercrop and sole sorghum (Table 5).

Phosphorus uptake under the three cropping systems

Sole cropping of sorghum in Waldviertel accumulated 0.023 g P m⁻² while intercropping with cowpea significantly reduced sorghum P uptake by 48% (Figure 2). A similar trend was observed for sorghum grown in Hungarian soil which showed the highest P uptake of 0.056 g P m⁻² under sole cropping. In both soils, sole
cowpea accumulated low P uptake compared to intercropped sorghum (Figure 2). Intercropping cowpea with sorghum further reduced the amount of P accumulated in the cowpea biomass in both soils. Overall, P uptake under intercropping was significantly lower than that under sole sorghum for both soils (Figure 2).

**DISCUSSION**

**Productivity of the cropping systems in low- and medium-P soils**

The higher biomass observed in Hungarian soil than Waldviertel soil might be associated with readily available mineral nitrogen (N) in the soil. Hungarian soil had low organic carbon indicating that most of the total N was available rather than being locked up in the carbon (C). The visible N deficiency symptoms in the sorghum might be attributed to dilution of the plant N as the crop developed without adequate supply of N from the soil (Janssen et al., 1990). The low biomass and steady growth of plants grown in Waldviertel could be attributed to the soil characteristics. The reduction of crop biomass under intercropping systems was due to reduction in the plant density for both crops (from 30 to 15 plants per tray) and interspecific competition for nutrients given differences in nutrient requirements of the two crops. Similar reduction in biomass yields were observed when legumes were intercropped with cereals (Kimaro et al., 2009).

The data for LER showed that intercropping was more beneficial than sole cropping of each crop. When the LERt > 1, intercropping is advantageous because environmental resources are used more efficiently for plants growth and LERt < 1, there is disadvantage as environmental resources utilised less efficiently. According to Van der Meer (1989), an indicator of intercropping advantage is when LERt > 1 where complementary facilitation will be contributing to the interaction than the competitive interference. Similar benefit has been reported for pigeonpea/cereal mixed cropping systems than legume/legume cropping system in term of LERt and grain yield (Katayama et al., 1995). Thus, in low nutrient environments of the SSA cereal/legume intercropping will be more beneficial to improve soil-crop productivity than sole cropping of legumes and cereals. Low-P Hungarian soil proved to be suitable for intercropping with all residues incorporated into the soil. However, intercropping on Waldviertel soil is likely to be N-sustainable system which promotes N release for the subsequent crop due to its lower C:N ratio than for Hungarian.

The low shoot/root ratio (S:R ratio) for crops grown in Hungarian soil indicates that under low P conditions root development was more prolific than the shoot growth. Given that Hungarian soil was a low-nutrient soil, crops would need to develop more prolific root systems to get sufficient nutrients. Intercropping increased the root abundance for both cowpea and sorghum in response to the belowground competition to get nutrients for crop growth. For the medium-P Waldviertel, intercropping resulted in a reduced competition for nutrients to the crops as more nutrients were available for uptake. The high S:R under sole cowpea and intercropped in Waldviertel indicated that a less prolific rooting system was developed. Although sorghum has a good rooting system to acquire nutrients (Katayama et al., 1995), there was no compensatory root growth under favourable soil conditions (readily availability of nutrients) as observed in Waldviertel under intercropping relative to sole cropping.

**Nitrogen accumulation and biological fixation in the cropping system**

The high N uptake of crop under Waldviertel soil is related to the medium available P which confirms that cereals respond to N fertilization only when P deficiencies have been addressed (Bationo et al., 1990). In addition, the high total nitrogen and organic carbon in the soil might have supplied adequate nitrogen for the crops than on Hungarian soil. The fact that sole sorghum crop under Waldviertel showed N deficiency faster than that under sorghum-cowpea intercrop could be attributed to high N demand of sorghum under sole stand (high population) than under intercropping. According to Katayama et al. (1995), cereals have an advantage in the below-ground N competition due to their extensive root proliferation in the surface soil. Sorghum under intercrop showed the N deficiency later than that in sole cropping due to reduced competition for N within the system because of reduced...
sorghum density. Despite the reduction of the total amount of N fixed in the intercrop relative to sole cowpea, the results support the fact that intercropping enhances biological nitrogen fixation. Similar results have been obtained when legumes were intercropped with cereals (Danso et al., 1987; Adu-Gyamfi et al., 2007; Eskandari and Ghanbani, 2009). Hungarian soil was low in N compared to Waldviertel and intercropping cowpea with sorghum was likely to deplete the soil N further thus forcing cowpea to entirely depend on fixation (Jensen, 1996; Hauggaard-Nielsen et al., 2001), which could explain the 20% increase in fixation by cowpea. Similar results have been obtained when maize was intercropped with cowpea and this is termed a facilitative effect of intercrop components (Eskandari and Ghanbani, 2009). According to Giller (2001), P application is a major requirement for N₂-fixation in both cropping and natural systems. A low P soil (Hungarian) attained the highest %N₀a and N₀a under both cropping systems suggesting that the P requirement of this cowpea variety for N fixation was low. Limitation to fixation under Waldviertel might be nutrients other than P since it was a medium soil P. Similar challenges have been cited in efforts to enhance productivity of legumes under severely depleted soils following P application in sub-Saharan Africa (Zingore et al., 2007; Tauro et al., 2010). Overall the inoculant (Strain MAR 1510) was an effective cowpea strain considering cowpea was a new legume on both soils.

Nitrogen and phosphorus budgeting under the three cropping systems

According to Vesterager et al. (2007), a cropping system is only N-sustainable when the N balance exceeds N outputs. Exporting the above ground biomass under intercropping had a negative N balance as a result of the nutrient mining by the crops particularly sorghum. Similarly, Wani et al. (1994b) showed that negative net N balances (kg ha⁻¹) from -27 to -95 for groundnut, -25 to -65 for cowpea and -28 to -104 for soybean when crop residues were removed from the field. Despite the reduction in sorghum density, sorghum attained higher P uptake under intercropping system than sole cowpea confirming the high nutrients mining capability of sorghum. Therefore exporting the biomass from the system will also have negative balance which would reduce soil fertility status given that P is only supplied from the soil and fertilizers. The improvement of the N balance across all cropping system by incorporating all the above ground is due to high shoot biomass with high N content being added to the system. Our results showed that incorporation of the shoot and root gave a positive N balance in all the cropping systems for both soils and thus being N sustainable. Positive net N-balance of up to 136 kg ha⁻¹ has been report for several legumes following seed harvest (Kumar and Rao, 1987). Thus in terms of P, incorporation of the biomass will make the system sustainable due to recycling back the P into the soil.

Implication of intercropping on soil and crop production in low nutrient conditions

The high nitrogen content in cowpea or sorghum roots under Waldviertel led to a lower C:N ratio when aboveground biomass was exported. This might be associated with the better soil condition (high available P and total N) to supply nitrogen to sorghum and cowpea. Despite the good C:N ratios for mineralization following exportation of aboveground biomass (Frankenberger and Abdelmagid, 1985), crops grown in the medium-P Waldviertel soil had negative N balance which is not sustainable. According to Seneviratne (2000), the high C: N ratios existing in both intercropping systems following exporting aboveground biomass are likely to cause net immobilization. Incorporating all biomass under across Waldviertel soil treatments and Hungarian cowpea crop lowered C:N ratio due to the increase in the N contribution from the aboveground biomass. Such C: N ratio would promote mineralization (Palm et al., 2001) which confirms the systems as being N-sustainable. High C: N ratio following incorporation of all biomass under Hungarian intercropping and sole sorghum cropping systems may be attributed to high plant C and low N in the sorghum biomass. The high C: N ratio (58) under sole sorghum stands on Hungarian soil is likely to cause immobilization for a long time and the subsequent crop might suffer from N deficiency. The evidence suggests that sole cropping sorghum without P application or legume intercropping might deplete soil P leading to severe nutrient depletion and soil degradation. Similarly, depletion of P has also been cited as a reason for field abandonment in smallholder areas of SSA (Chuma et al., 2000; Mapfumo et al., 2005) which might subsequently affect household food security.

Conclusion

Hungarian soil produced high biomass across all treatments than Waldviertel. However, crop grown on Waldviertel soil had a higher N uptake than that grown on Hungarian soil. Despite the apparent variations in total N fixed under the two cropping systems, cowpea derived 14 to 73% of their N from fixation. Intercropping reduced crops biomass productivity and the amount of N fixed by cowpea while increased the percentage of N derived from air (%N₀a) on Hungarian soil by 20%. Exporting crop residues promoted nutrients (N and P) mining with sorghum and continuous monocropping of sorghum may cause severe soil mining as a result of its highly adaptive rooting system. Incorporating all aboveground biomass increased the N balance across all cropping system except for sole sorghum stand and reduced the C:N to
benefit the subsequent crop. The LERt (>1.0) indicated intercropping was a more advantageous on Hungarian than Waldviertel soil. This study demonstrated the potential of biological nitrogen fixation to improve the N balance in cropping system particularly in where soil are low in N and crop residues are incorporated. Given that most smallholder farming systems have strong crop-livestock linkages there is need for a further study to understand the influence of the returned livestock manure to such cropping systems. Continuous sole sorghum cropping without adequate P application or legume intercropping has serious implication on soil health leading to field abandonment. This study demonstrated a potential of intercropping to produce a sustainable cropping system through biological nitrogen fixation and sparing of P within the system particularly when crop residues are incorporated.

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