EFFECT OF LEGUME-WHEAT CROPPING SEQUENCES ON SOIL MICROBIAL BIOMASS, SOIL MINERAL N AND PERCENT TOTAL N IN WHEAT AT RONGAI - NJORO, KENYA

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ABSTRACT

The objective of this study was to evaluate the effect of cropping sequences on soil microbial biomass (SMB), soil mineral N (N) and its uptake by wheat at different stages of growth. A one year crop sequence study involving chickpea (*Cicer arietinum*) followed by wheat (C-W); beans (*Phaseolus vulgaris*) followed by wheat (B-W); and fallow followed by wheat (F-W) was conducted at Egerton University agronomy farm between 1995 and 1996. N levels were highest in F-W at planting compared to C-W and beans-wheat B-W but shot up in C-W and B-W after 30 DAS in the 0-30 cm depth. However, from 30 DAS till harvest, the 0-30 cm depth showed a gradual decline in levels of N while the 30-60 cm depth had a gradual increase in N levels throughout the study period. The % total N content in wheat declined from seedling to harvest (straw) for all the cropping sequences and had significant effect at $P \leq 0.05$ between seedling and heading stages for the F-W and C-W cropping sequences. SMB on the other hand varied across the cropping sequences and from one growth period to another, increasing from planting to seedling stage (30 days after planting [DAS]) and thereafter declining up to heading of wheat (70 DAS) followed by a steady increase up to wheat harvest (127 DAS). In the pre-wheat season therefore, the amounts of N fixed by the legumes were inadequate to offset the amount of N used for growth and that removed by seeds. Either mineralization of immobilized N in the legume rhizosphere, N contribution through the mineralization of leaf litter and the roots or the “Birch effect” restored the depressed N levels by wheat seedling stage in the C-W and B-W sequences. The variations in SMB during the wheat growing season imply that SMB may be regarded as a nutrient reservoir for the respective cropping sequences in the agro-ecosystem under study.

Keywords: cropping sequence, legumes, Nitrogen, soil microbial biomass, wheat

INTRODUCTION

Non-legume crops influence N levels in the soil (Ondenge, 1980) through N uptake that varies with either type of crop or stage of growth (Guindo et al., 1995; Norman et al., 1992). Legume crops on the other hand fix nitrogen and spare N (Herridge et al., 1995) though the amounts of N fixed in some pulses maybe inadequate to offset the amount of N used for growth and that removed by seeds leading to depressed N levels (Peoples et al., 1995).
A fertile soil can have either a pool of plant nutrients that can sustain crops throughout the growing season or SMB that can continually release the nutrients from organic substrates for crop uptake (Roder et al., 1988). In addition, soils managed with organic amendments have been found to have a higher and more active microbial populations than those managed with inorganic fertilizer (Alef et al., 1988). There are indications that seasonal fluctuations in SMB may provide more N for crop uptake (Franzluebbers and Stuedemann, 2008) though Nieder et al. (2008) have disputed the proposition.

N dynamics, percent (%) N in Wheat and SMB have received minimal attention in the wheat belt and the objective of this study was to assess the effect of cropping sequences on SMB, N, N uptake and its subsequent accumulation in wheat. The results reported in this paper are part of a larger study to assess the N dynamics in a legume-wheat cropping sequence in an agro-ecosystem of the Kenyan Rift Valley (Guto, 1997).

MATERIALS AND METHODS

Site Description
The study was conducted at Egerton University Agronomy farm at a mean altitude of 2200 m above sea level at the edge of Rongai Njoro plain with gentle undulating slope. The average annual rainfall ranges from 800 to 1000 mm, with a bimodal distribution whereas the average annual temperature is 16°C. The soils of the study site are classified as Mollic phaeozem (FAO-UNESCO, 1988) and Mollisols (Soil Survey Staff, 1982). Table 1 shows the physical and chemical properties of the soil whereas Table 2 shows the rainfall amounts during the experimental period.

(Insert Table 1 and 2 around here)

Experimental Design
Wheat was drilled onto plots previously grown with either chickpea, beans or left fallow. The experiment evaluated the effect of the cropping sequences on SMB, N and % total wheat N. There were three levels of cropping sequences (fallow, chickpea and beans) that were replicated three times in a randomized complete block design.

The experimental area was initially cleared, tilled by hand hoe and raked to obtain a fine tilth seedbed. In the pre-wheat season (December 1995-April 1996), chickpea and beans were planted in December 1995 to give a total plant population of $2.2 \times 10^5$ plants/ha while fallow plots were demarcated and left fallow. At the end of the season, the legumes were harvested and all above ground plant material was removed except the plant litter.

Wheat was planted in the second season (June 1996) at a seed rate of 100 kg/ha and a uniform application of 30 kg P hectare$^{-1}$. Recommended wheat weed, pest and disease control measures for the area were enforced.

Soil/plant sampling and analysis
Prior to the beginning of the experiment, soil samples were randomly collected across the field at 0-15, 15-30 and 30-60 cm depths and bulked to obtain composite samples that were analyzed for initial soil fertility. To determine N levels in the soil during wheat growth, composite soil samples were collected randomly from in between rows from three spots per plot at three stages of wheat growth [Planting (0 DAS), seedling (30 DAS), heading (70 DAS) and harvest stage (127 DAS)]. The soil samples were analyzed for NH$_4^+$ and NO$_3$ following procedures outlined by Keeney and Nelson (1982) and adapted by Odhiambo (1989). The SMB N and Carbon were determined by the chloroform fumigation following methods described by Nelson and Sommers (1982) and relevant correction factors applied as recommended by Vance et al. (1987) and Brookes et al. (1985). For determination of % total wheat N in wheat, plant samples were collected at seedling and heading stages of growth (20 to 30 plants per plot) and harvest (sub samples of grain and straw from two middle rows per plot) were used for analysis. All plant samples were oven dried at 60°C and then analyzed for % total wheat N by the procedure described by Bremner and Mulvaney (1982).

RESULTS AND DISCUSSION

Effect of cropping sequences on N levels in the soil at different stages of wheat growth. N varied with depth and for the different stages of wheat growth at P ≤0.05 (Figure 1).

Insert Fig. 1.

At planting, the legume based cropping sequences had the lowest amounts of N in the 0-15 cm depth compared to F-W cropping sequence with the mean amounts showing. This was attributed to higher uptake of N and subsequent accumulation by legumes compared to weeds during the pre-wheat season. The amounts of N fixed in some pulses are sometimes inadequate to offset the amount of N used for growth and that removed by seeds (Peoples et al., 1995). Besides that, removal of all aboveground legume biomass from the field at legume harvest and immobilization of N by SMB (Collins et al., 1992; Reddy and Reddy, 1993) also could have depressed the amounts of N even further resulting to negative N balances (Peoples and Craswell, 1995) for the legume based cropping systems.

At the 30 DAS of wheat, N amounts in the C-W and B-W treatments had increased in the 0-15 cm depth due to either mineralization of immobilized N in the legume rhizosphere or N contribution through the mineralization of leaf litter and the roots and were significantly different at P ≤ 0.05 compared to those at planting. Ismaili and Weaver (1986) made similar observations, though birch effect (Birch, 1958) would have also contributed to the elevation of N levels over this period.

Between 70 and 127 DAS of wheat growth, N amounts decreased steadily in the 0-15 cm depth for all the treatments. The average decreases were 524, 377 and 181% for F-W, B-W and C-W cropping sequences, respectively. The 15-30 cm depth showed similar trends though the magnitudes were lower. This presumably reflected the uptake and assimilation of N by growing wheat as well as N losses through various transformation processes such
as leaching, volatilization and denitrification. Ladha et al. (1996) observed similar trends in the N level for rice fields and Odhiambo (1989) in maize.

The 30-60 cm depth exhibited a different trend from the other two depths with N levels showing a steady increase from the 30 DAS stage till harvest for the cropping sequences. The average increments were 17, 0.7 and 14.3% for F-W, B-W and C-W cropping sequences respectively. This was probably because most of the wheat root biomass was found within the upper soil depths (0-30 cm) hence limiting N uptake from the 30-60 cm depth. Also, N additions through leaching from upper soil layers (0-30 cm) would have contributed to N build up in the 30-60 cm layer since this coincided with the long rain season. Odhiambo (1989) also observed heavy leaching of N from the 0-30 cm soil layer to the lower 30-60 cm soil horizon.

Effect of cropping sequences on percent total N in wheat at different stages of growth

The % total N content in wheat varied for the different cropping sequences and growth stages at P≤0.05 (Figure 2).

(Insert Figure 2)

The cropping sequences had significant (P≤0.05) treatment effects on % total wheat N between seedling and heading stages of growth. This was probably because high N uptake by crops mainly took place during early stages of growth and was then re-distributed within the plants at latter stages (Norman et al., 1992). N is also lost from the soil with time through processes such as leaching, volatilization, denitrification and immobilization (Tisdale et al., 1990) hence decreasing progressively from the soil nutrient pool.

The % total N in wheat plants was highest at seedling stage and this could be attributed to the low plant biomass with small fibre content at seedling stage leading to high N content in the plant tissues. Harper et al. (1987) noted that a high proportion of young and succulent tissues in seedlings would contribute to the elevated total N levels.

The wheat head appeared to have accumulated N at the expense of the other plant parts such that by harvest, the kernels had greatest levels of % wheat total N that were significantly higher compared to those at all the other growth stages at P≤0.05 within the respective cropping sequences. Norman et al. (1992) found that the total plant N in rice panicle continued to accumulate at the expense of the other plant parts such that by maturity, it had two thirds of the total plant N.

Effect of cropping sequences on soil microbial biomass at different stages of wheat growth

In the course of wheat growth, soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) varied for the different cropping sequences and from one stage of wheat growth to another at P≤0.05 (Figure 3).

Insert figure 3
The legume based cropping sequences had higher SMB compared to F-W across the different depths probably due to provision of additional substrate in the form of sloughed root cells, root exudates and leaf fall from the legume crops for microbial proliferation. Holmes and Zak (1994) made similar observations while Collins et al. (1992) observed that substrate quality and quantity could influence the size of SMB.

The levels of SMB increased from planting (0 DAS) to seedling stage (30 DAS) and thereafter declined up to heading of wheat (70 DAS) followed by a steady increase towards harvest (127 DAS). The increase in SMB from planting to seedling stage was attributed to root growth as the wheat crop established such that sloughed root cells and root exudates provided substrates for microbial proliferation. Carter (1986) found that ryegrass (Lolium multiflorum) increased SMB in the same manner. The increase in SMB towards harvest stage would be due to elevated soil water content caused by reduced rates of evapo-transpiration owing to crop senescence and decomposing root tissue that provided ready substrate for microbial proliferation.

Wardle and Parkinson (1990) largely attributed within season variations in SMB levels to soil moisture content whereas and Fisk and Schimdt (1995) ascribed it to nutrient availability with SMB acting as a nutrient reservoir. For the particular cropping sequences studied, nutrient availability may have played a major role on the SMB levels and consequently, SMB maybe proposed as a nutrient reservoir.

CONCLUSIONS

At wheat planting the legume based cropping sequences had lower amounts of N compared to F-W cropping sequence in the top-soil (0-15 cm) indicating higher uptake of N and subsequent accumulation by legumes compared to weeds during the pre-wheat season. The amounts of N fixed by the legumes were therefore inadequate to offset the amount of N used for growth and that removed by seeds. Patterns in % total N in wheat and SMB mirrored those of N except between heading stage and harvest whereby, SMB increased whereas N and % total wheat N declined. The period between heading and harvest coincided with a period of low nutrient demand by the wheat crop and immobilization of nutrients as SMB especially N would curb its loss by leaching. SMB can therefore be proposed as a nutrient reservoir for the cropping sequences in the agro-ecosystem under study.

REFERENCES


Table 1: Some physical and chemical soil properties of the experimental site at Egerton University, Agronomy Farm.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>0-15</th>
<th>15-30</th>
<th>30-60</th>
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<tr>
<td>Texture:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sand (%)</td>
<td>26</td>
<td>29</td>
<td>27</td>
</tr>
<tr>
<td>silt (%)</td>
<td>24</td>
<td>30</td>
<td>46</td>
</tr>
<tr>
<td>clay (%)</td>
<td>27</td>
<td>28</td>
<td>45</td>
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<tr>
<td>class</td>
<td>clay</td>
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<td>Organic C (%) – wet oxidation</td>
<td>2.83</td>
<td>2.79</td>
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<tr>
<td>Total N (%)</td>
<td>0.33</td>
<td>0.31</td>
<td>0.28</td>
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<tr>
<td>C/N ratio</td>
<td>8.60</td>
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<td>Ca (Cmol/Kg)</td>
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<td>Mg (Cmol/Kg)</td>
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<tr>
<td>K (Cmol/Kg)</td>
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<td>pH\textsubscript{KCl}</td>
<td>5.38</td>
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<td>5.10</td>
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</tbody>
</table>

Table 2: Rainfall amounts at the Egerton University, Agronomy Farm during the experimental period (December 1995 to November 1996).

<table>
<thead>
<tr>
<th>Month</th>
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<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
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<tr>
<td>Rainfall (mm)</td>
<td>48</td>
<td>90</td>
<td>52</td>
<td>85</td>
<td>30</td>
<td>38</td>
<td>158</td>
<td>145</td>
<td>166</td>
<td>83</td>
<td>90</td>
<td>112</td>
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</table>
Fig. 1. Mean amounts of soil mineral N (Kg/ha) with SE bars at P ≤ 0.05 for the cropping sequences at different stages of wheat growth during the wheat growing season.
Fig. 2. Mean amounts of Percent total N with SE bars at P ≤ 0.05 in wheat for the cropping sequences at different stages of wheat growth during the wheat growing season.
Fig. 3. Mean amounts of soil microbial biomass carbon and nitrogen with SE bars at $P \leq 0.05$ for the cropping sequences at different stages of growth during the wheat growing season.