GLOBAL SYMPOSIUM ON SOIL ORGANIC CARBON, Rome, Italy, 21-23 March 2017

Rehabilitating degraded croplands for improved crop productivity and soil carbon sequestration on smallholder farms in Zimbabwe

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Introduction, scope and objectives

Most croplands in smallholder farming systems in Southern Africa are degraded, as evidenced by severe nutrient deficiencies, critically low SOM levels and a general low response of the soils to mineral fertilizer addition (Mapfumo et al., 2005; Nezomba et al., 2010). Against this background, the region is facing increased demands for food due to population rise (FAO, IFAD and WFP, 2014), and unfavourable changes in climatic patterns (IPCC, 2013). Rehabilitating the degraded croplands is therefore key not only to increasing farm-level crop production, but also for sequestering soil carbon to reduce greenhouse gas emissions. Nitrogen (N)-fixing indigenous herbaceous legumes, commonly referred to as weeds by farmers, were found to establish well on degraded sandy soils on smallholder farms in Zimbabwe when sown at high seed rates (Mapfumo et al., 2005; Nezomba et al., 2010). Because of their ability to fix N, we envisaged that the establishment of these legumes on degraded soils could enable crops to respond better to subsequent applications of the small amounts of organic and inorganic nutrient resources commonly available to farmers. The inclusion of legumes in cropping sequences as well as combined application of organic and inorganic fertilizers form the core of integrated soil fertility management (ISFM); an approach designed to increase soil productivity in resource-limited environments (Vanlauwe et al., 2010). Conducted on degraded sandy soils on smallholder farms in eastern Zimbabwe, the specific objectives of this study were therefore to (i) assess the effect of indigenous herbaceous legume fallows (indifallows) on above-ground C and N productivity on degraded soils, (ii) determine maize grain yield responses to mineral N fertilizer under indigenous legume-based ISFM sequences and (iii) determine the influence of indigenous legume-based ISFM sequences on soil carbon dynamics.

Methodology

This paper reports findings of a 3-year study conducted on degraded sandy soils (< 10% clay, < 0.3% organic carbon, < 4 ppm available P) on smallholder farms in Zimbabwe. First, non-cultivated N_2-fixing indigenous legumes, mostly of the genera *Crotalaria*, *Indigofera* and *Tephrosia*, were planted at 120 seeds m^{-2} $species^{-1}$ on ploughed fields. In the second year, the legumes biomass was incorporated into soil together with an equivalent of 7 t ha^{-1} of cattle manure. A maize crop was then planted. In the third year, a second maize test crop was planted. Natural fallow and continuous maize were used as controls. The experimental treatments are described in detail in Table 1. Data were collected on legume biomass productivity (Year 1), changes in soil microbial biomass (Year 3), changes in total carbon and maize grain yield responses (Year 3).

Table 1. Sequencing framework of ISFM options on degraded sandy soils on smallholder farms in Zimbabwe. Adapted from Nezomba et al. (2015)

Sequencing option	**Year 1**	**Year 2**	**Year 3**
'Indifallow-start '	Indifallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
'Sunnhemp-start'	Sunnhemp fallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
'Natural fallow-start'	Natural fallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
Fertilized maize	Fertilized maize	Fertilized maize	Fertilized maize
Unfertilized maize	Unfertilized maize	Unfertilized maize	Unfertilized maize

Results

Initial biomass productivity on degraded soils: Above-ground biomass carbon (C) and nitrogen (N) accumulation were 3038 kg ha^{-1} and 203 kg ha^{-1}, respectively, under 1-year indigenous legume fallow (indifallow) against 518 kg C ha^{-1} and 14 kg N ha^{-1} under 1-year natural fallow. Indigenous legumes contributed > 80% of the biomass produced under indifallows.

Maize yield response under herbaceous legume-based ISFM sequences: When all the treatments were planted with a maize test crop in the third year, herbaceous legume-based sequences showed the highest response to mineral fertilizer N compared with natural fallow-based sequences and continuous fertilized maize. Maize grain yields averaged 2.5 t ha^{-1} under herbaceous legume-based ISFM sequences compared with a maximum of 1.1 t ha^{-1} under mineral fertilizer alone and < 0.4 t ha^{-1} with no fertilizer (Figure 1).

Effects of ISFM sequences on soil C sequestration: Herbaceous legume-based ISFM sequences gave the highest microbial biomass C (MBC) of 243 mg kg^{-1} soil compared with 187 mg kg^{-1} soil under continuous maize. Also, MBC to organic C ratio averaged 7; about 1.5 times more than under the natural fallow-based sequence. Continuous maize treatments gave higher metabolic quotients (qCO_2) than legume-based sequences indicating a lower microbial efficiency under the former. However, soil organic C in the 0-20 cm depth averaged 5.5 t C ha^{-1} under natural fallow-based ISFM sequence compared with less than 5.1 t C ha^{-1} for the herbaceous legume-based treatments.

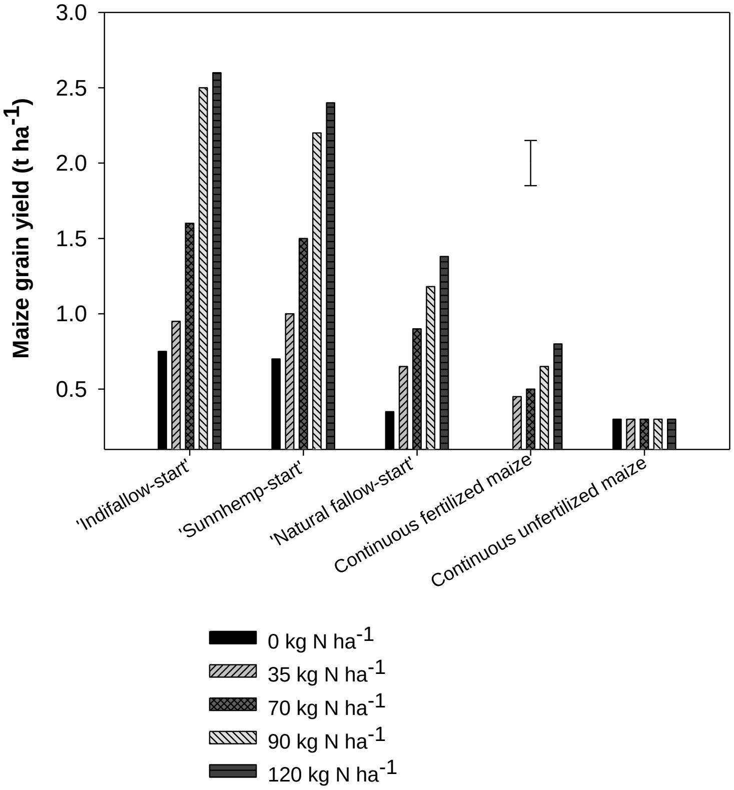

Figure 1. Maize grain yields (t ha-1) and responses to mineral N fertilizer different ISFM sequences on degraded soils in Hwedza farming communities in Zimbabwe. Vertical bars represent standard error of the difference of means (SEDs)

Discussion

Degraded soils are typified by low net primary productivity, which leads to low soil organic matter content and physico-chemical fertility. However, in this study, 1-year indifallow yielded > 3 t C ha^{-1} of above-ground biomass on nutrient-depleted soils, while 1-year natural fallow accumulated < 1 t C ha^{-1}. The high amounts of C and N measured under 1-year indifallow and 1-year sunnhemp fallow was due to the biomass contributed by legume species. Herbaceous N_2-fixing legumes, such as naturally-adapted indigenous legumes, therefore offer prospects for generating high initial biomass on sandy degraded soils. Microbial biomass was highest under herbaceous legume-based ISFM sequences suggesting that the legumes biomass generated in the first year and cattle manure applied in the second year provided labile C and N to stimulate soil microbial activity. Inclusion of legumes in cereal-based cropping systems has been shown to increase microbial biomass (Silva et al., 2010). The ratio of microbial biomass carbon to total soil organic C was highest under herbaceous legume-based ISFM sequences indicating greater biological activity that would suggest a faster soil rehabilitation potential as compared to the other treatments. The higher soil C sequestration under the natural fallow-based ISFM sequence compared with the herbaceous legume-based ISFM sequences could be explained by the more recalcitrant biomass generated under the former compared with the easily decomposable N-rich biomass under the latter. The higher maize response to mineral N fertilizer under the legume-based ISFM sequences could be explained by increased soil N availability through addition of legume biomass and cattle manure.

Conclusions

Seeding of indigenous legumes on degraded sandy soils led to more biomass C and N production than leaving the fields to natural fallow. The predominantly legume biomass produced under indifallow in combination with cattle manure increased soil biological activity (microbial biomass) and the responsiveness of the degraded soils to mineral N fertilizer. On the other hand, natural fallow-based ISFM sequences are a potential pathway for increasing C sequestration on sandy soils.

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