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Tillage, mulch and fertiliser impacts on soil nitrogen availability and maize production in semi-arid Zimbabwe

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ABSTRACT

Conservation agriculture has been promoted widely in sub-Saharan African to cushion smallholder farmers against the adverse effects of soil fertility decline, stabilize crop yields and increase resilience to climate change and variability. Our study aimed to determine if aspects of CA, namely tillage and mulching with manure and fertiliser application, improved soil mineral N release, plant N uptake and maize yields in cropping systems on poor soils in semi-arid Matobo, Zimbabwe. The experiment, run for three seasons (2012/13–2014/15), was a split-split plot design with three replicates. Tillage (animal-drawn ploughing and ripping) was the main plot treatment and residue application was the sub plot treatment with two levels (100% residues removed or retained after harvest). Five fertility amendments (mineral fertiliser at 0, 20 and 40 kg N ha-1, 5 t ha-1 manure only and 5 t ha-1 manure + 20 kg N ha-1) were sub-sub plot treatments. Plough tillage stimulated N mineralisation by 4–19 kg N ha-1 and maize N uptake 13–23% more than the ripper tillage. When mulch was added to the plough tillage, mineralisation was slowed resulting in less crop N uptake (by 5–19%) compared with no mulch application. N uptake was highest in the manure treatments. N recovery and agronomic N efficiency by maize were highly variable over the three seasons, reflecting the uncertainty complicating farmers' decision making. Nitrogen recovery in the manure treatments was generally poor in the first season resulting in low grain yields in the range 100–260 kg ha-1 regardless of tillage, though higher in subsequent seasons. In the second season manure application gave the largest grain yields under the ripper tillage, both with and without mulch averaging 1850 and 2228 kg ha-1 respectively. Under the plough tillage, the 40 kg N ha-1 treatment gave the highest grain yields of 1985 kg ha-1. In the third season yields were generally poor under all treatments due to low and poorly-distributed rainfall. The CA principles of minimum soil disturbance and maintenance of a permanent mulch cover resulted in reduced soil mineral N availability for crop uptake and poor maize yields. Nutrient inputs through mineral fertilisers and manure are key to ensuring production in such infertile, sandy soils which predominate in semi-arid regions of southern Africa.

1. Introduction

Smallholder farmers practicing rainfed agriculture in sub-Saharan Africa (SSA) face a myriad of challenges; these include poor soil fertility, low incomes, labour and land constraints, and are further exacerbated by climate variability (Mupangwa et al., 2012; Ngoma et al., 2015; Rurinda et al., 2013). Different approaches to improve soil fertility have been proposed including biological nitrogen fixation, soil surface residue management, fertiliser use, enhanced recycling of animal manure and conservation agriculture (Hobbs, 2007; Mupangwa et al., 2012; Ncube et al., 2009; Nyamangara et al., 2005).

Conservation agriculture (CA) has been promoted throughout sub-humid and semi-arid areas of SSA to cushion smallholder farmers against the adverse effects of soil fertility decline, crop yield decline, and climate change and variability (Hobbs et al., 2008; Ngoma et al., 2015). CA is based on three principles: (i) minimum or no tillage to minimise soil disturbance, (ii) diversification of crop species (often with legumes) grown in rotation and/or association, and (iii) maintaining semi-permanent or permanent soil cover, for example by leaving at least 30% of crop residues (FAO, 2011; Stevenson et al., 2014). This three-pronged approach is reported to

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have the potential to improve farm resource use efficiency and crop yields especially where moisture is limiting (Hobbs et al., 2008).

Although CA is promoted as a soil-fertility enhancing technology, application of crop residues poor in N, such as cereal stover, may result in prolonged immobilisation of mineral N (Giller et al., 1997). In CA systems, reduced N availability has been attributed to slow residue decomposition and N losses from leaching and denitrification (Angás et al., 2006; Verachtert et al., 2009). Nyamangara et al. (2014) proposed that larger N inputs may be required under CA to offset the N immobilisation caused by cereal stover. A combination of high quality manure combined with low quality crop residue may reduce N leakage and increase nutrient use efficiency (Kihara et al., 2011). Qin et al. (2015) found that larger N inputs resulted in a positive effect of straw mulch on maize yields. In sub-humid west Africa, maize grain yield in a no-till system was only increased by mulch when fertiliser was also applied (Lal, 1995). However, smallholder farmers in SSA typically apply only small amounts of N which may not be adequate. (Vanlauwe et al., 2014) argue that appropriate fertiliser use should be considered a fourth principle of CA as fertiliser is required to enhance both crop productivity and produce sufficient crop residues to ensure soil cover.

In the current smallholder farming system, the perturbation by tillage stimulates a flush of mineral N (the "Birch effect") with the start of the rains (Chikowo et al., 2004; Giller et al., 2011), whereas soil organic matter may have otherwise been protected from degradation. This "Birch effect" is reported to be short-lived and the decomposition rates may fall back to rates similar to that of an undisturbed soil (Andersson and Giller, 2012). Minimum tillage promoted in smallholder areas in SSA under CA is mainly focused on the hand hoe planting basins (Giller et al., 2011; Nyakudya and Stroosnijder, 2015). Farmers with limited access to draught power and using hand hoes prepare their fields in the dry season in order to spread labour requirements for land preparation, allowing for early planting (Nyamadzawo et al., 2012). However, the use of animal drawn conservation tillage methods such as the ripper and direct seeder provides an opportunity to reduce the labour demand associated with land preparation using hand hoes. Mechanisation can increase productivity per unit area by improving timeliness of farm operations including planting. Early planting may coincide with the "Birch effect" which is beneficial to the crop (Chikowo et al., 2004). Minimum soil disturbance in CA systems, however, results in slower mineralisation compared with conventional tillage because of the minimum disturbance (Chivenge et al., 2007) leading to preservation of soil organic matter from decomposition. Due to this slow mineralisation, (Lal, 2007) suggested that resource poor farmers would be better off ploughing their sandy soils to enhance mineralisation of whatever soil organic matter present to enhance nutrient supply in the short term. There are, however, no detailed studies on seasonal mineral N availability in the semi-arid areas under CA practices such as minimum tillage and crop residue retention particularly on soils of poor fertility that are typical in smallholder agriculture in SSA.

We hypothesise that for cropping systems in semi-arid climates and on poor fertility soils, the benefits of CA and added mulch are in immobilising N so that it is not lost from the system and becomes available later for crop growth. The study specifically aimed at determining if and how tillage, mulching, manure and fertiliser application and their interactions improved soil mineral N release, plant N uptake and ultimately maize yields.

2. Materials and methods

2.1. Site description

The study was carried out in Nqindi ward, Matobo district, Matabeleland South, Zimbabwe (20 39.58′S, 28 15.58′ E; 900 masl). Matobo district lies in Agroecological Zone IV, characterised by semi-arid climate typical of south west Zimbabwe. Rainfall is unimodal with a distinct wet (November–March) and dry (April–October) season. The wet season receives 450–650 mm annual rainfall with a long term average annual rainfall of 580 mm. Droughts are frequent as are severe dry spells during the wet season. There is only a 45–65% probability of rainfall between October and April exceeding 500 mm (Vincent et al., 1960). The dominant soils are Eutric Arenosols derived from granite (WRB, 2006). These sandy soils constitute >15% of the total land area in Zimbabwe (Hartemink and Huting, 2008). The smallholder farming system in Matabeleland is characterised by privately managed arable fields and communally-managed grazing lands. The arable fields are also communally grazed during the dry season unless if securely fenced off. Matobo district is largely rural (99.4%) with Nqindi ward having a total population of 3507 persons (ZIMSTAT, 2012).

2.2. Trial layout and treatments

A field experiment was set up in December 2012 on a slightly sloping (<2%) farmer's field and run for three seasons. The experiment was set up as a split-split plot with plots arranged in a randomised complete block design with three replicates. The tillage system was the main plot treatment with two levels (ox-drawn ploughing and animal drawn ripping) and the mulch management was the sub plot treatment with two levels (100% residue removed and 100% residues retained after harvest). The mulch sub-treatment was not applied in the 2012/13 season as this was the first season. Five fertility amendments (mineral fertiliser at 0, 20 and 40 kg N ha^{-1}, 5 t ha^{-1} manure only and 5 t ha^{-1} manure + 20 kg N ha^{-1}) were randomised as the sub-sub plot treatment. Plots measured 35 m × 12 m with borders measuring 5 m × 15 m. The third CA principle, crop rotation, was not included in the study because of the short duration of the experiment.

2.3. Trial management

A basal application of compound D fertiliser (14 kg N ha^{-1}, 12 kg P ha^{-1} and 12 kg K ha^{-1}) or manure was applied in planting furrows. The 0N fertility treatment received a basal application of single super phosphate (12 kg P ha^{-1}) and muriate of potash (12 kg K ha^{-1}). All plots were planted to a short season maize variety (SC403) at 0.9 m × 0.3 m spacing to achieve a plant population of 37 000 plants ha^{-1}. The remainder of the N requirement (6, 20, 26 kg N ha^{-1} for the 20 kg N ha^{-1}, manure + 20 kg N ha^{-1} and 40 kg N ha^{-1} treatments respectively) was applied as a top dressing, using ammonium nitrate (which contained 34.5% N) at six weeks after planting and when there was enough soil moisture for top dressing. In the second season incessant rains caused waterlogging such that top dressing application was delayed until nine weeks after planting which coincided with the crop flowering stage. The plots were kept weed free by an initial application of glyphosate [N-(phosphono-methyl) glycine] herbicide soon after planting and thereafter by hand hoeing when required. At harvest, in plots where mulch was to be applied, the stover was left on the soil surface. The amount of mulch retained on the surface was dependent on the biomass produced in the previous seasons and ranged from 1 to 2 t ha^{-1} after the 2012/13 season and 2–4 t ha^{-1} after the 2013/14 season which translated to approximately 10–20% and 20–30% surface cover at planting respectively (based on visual assessment of ground cover). In the plough tillage treatment, the mulch was ploughed in at land preparation. The plots were located in a fenced off section of the farm and thus no livestock could feed on crop residues during the dry months.