Field Crops Research 164 (2014) 136–147

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Maize productivity and nutrient and water use efficiencies across soil fertility domains on smallholder farms in Zimbabwe

Natasha Kurwakumire[a], Regis Chikowo[b,c,*], Florence Mtambanengwe[a], Paul Mapfumo[a], Sieglinde Snapp[c], Adrian Johnston[d], Shamie Zingore[e]

[a] Soil Science and Agricultural Engineering Department, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, Harare, Zimbabwe
[b] Crop Science Department, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, Harare, Zimbabwe
[c] Plant, Soil and Microbial Sciences Department, Michigan State University, East Lansing, MI 48824, USA
[d] International Plant Nutrition Institute, 102-411 Downey Road, Saskatoon, Saskatchewan, Canada
[e] International Plant Nutrition Institute, ICIPE Compound, Box 30772, Nairobi, Kenya

ARTICLE INFO

Article history:
Received 22 February 2014
Received in revised form 21 May 2014
Accepted 22 May 2014
Available online 12 June 2014

Keywords:
Maize
Nutrient use efficiency
Sandy soils
Soil carbon
Soil variability

ABSTRACT

Strategic targeting of scarce nutrient resources by smallholder farmers on different field types has remained poor partly due to knowledge limitations, resulting in inefficient use of the resources. We sought to establish efficient strategies for use of nutrient resources so as to narrow the yield gap in maize production on heterogeneous light-textured soils under rain-fed conditions in Eastern Zimbabwe. A nutrient omission study was implemented during two cropping seasons, across six on-farm sites with soil organic carbon (SOC) ranging from 3.5 to 8.9 g kg^{-1}, and clay content between 4 and 19%. Treatments used were: (i) a zero fertilizer control, (ii) NK, (iii) NPS, (iv) PKS, and (v) NPKS. Rainfall water productivity, RWP, (kg grain mm^{-1}) was used as a proxy for water use efficiency for the different nutrient combinations. During both seasons, only 70 kg ha^{-1} N could be applied across all sites as prolonged mid-season droughts forced withholding of the second N topdressing targeted at maize anthesis. Maize productivity was influenced by both nutrient management and initial soil fertility. During the first season, maize yields across sites ranged from 0.25 to 0.84 t ha^{-1} for the control and 2.05–3.75 t ha^{-1} for the NPKS treatment that represented attainable yields. The corresponding RWP were 0.38–1.13 kg grain mm^{-1} for the control and 3.15–7.66 kg grain mm^{-1} for the NPKS treatment. For the second season, maize yields for the control ranged from 0.2 to 1.2 t ha^{-1}, while those for the NPKS treatments ranged from 2.4 to 3.60 t ha^{-1}. Across sites, response to N ranged 1.2–2.35 t ha^{-1}, response to P ranged 0.71–2.10 t ha^{-1} and response to K ranged 0.08–0.30 t ha^{-1}, indicating little response to K. Overall, balanced nutrient management has an overriding effect on maize grain and water productivity, but only for soils with SOC > 4 g kg^{-1} soil. Nitrogen and P remain the most limiting nutrients, in contrast, addition of K did not enhance grain yield, nor did it influence response to N or P. Variable N application strategies must be an integral component of farmer management if losses related to fertilizer investment are to be minimised under the risky rain-fed crop production systems.

1. Introduction

Smallholder farmers in sub-Saharan Africa (SSA) face challenges that include inherently poor soil fertility, limited access to external inputs and recurrent droughts. Crop production is largely dependent on natural rainfall that is characterized by poor distribution, with flooding and drought episodes occasionally occurring within a cropping season (Mtambanengwe et al., 2012). Consequently, a paltry 20–40% of the seasonal rainfall is used productively due to the mismatch between soil water availability and crop demand, compounded by high runoff and evaporation losses (Falkenmark and Rockstrom, 2005; Nyagumbo and Rurinda, 2007). A combination of poor nutrient and soil water availability has resulted in maize productivity rarely exceeding 1.5 t ha^{-1} on the majority of the smallholder farms. The green revolutions in Asia and Latin America were underpinned by high rates of mineral fertilizer application and improved seed varieties (e.g. FAO, 1996). However, in SSA, fertilizer use is still less than 10 kg ha^{-1} largely due to prohibitive prices (Camara and Heinemann, 2006), and

* Corresponding author at: Crop Science Department, University of Zimbabwe, P. O. Box MP 167, Mount Pleasant, Harare, Zimbabwe. Tel.: +263 772455838.
E-mail addresses: regischikowo@yahoo.co.uk, chikowor@msu.edu (R. Chikowo).

http://dx.doi.org/10.1016/j.fcr.2014.05.013
0378-4290/

general inaccessibility. This falls well below the fertilizer use target of 50 kg ha^{-1}, deemed a prerequisite for an African Green Revolution by the Abuja Declaration (Africa Fertilizer Summit, 2007).

Many smallholder farms are known to be spatially heterogeneous in terms of soil quality, mainly due to differences in management of fields within or across farms (Prudencio, 1993; Manlay et al., 2002; Masvaya et al., 2010). Differences in nutrient resource management by farmers, which is usually a function of resource endowment and preferential application of nutrient inputs to fields close to the homesteads, has often accentuated variability in soil fertility, creating gradients of fertility across fields and farms (Mtambanengwe and Mapfumo, 2005; Zingore et al., 2007). Short range spatial variability in soils also exists within and across farms due to inherent properties of soils. It has also been established that nutrient use efficiencies and crop yields vary strongly along gradients of soil fertility within smallholder farms (Vanlauwe et al., 2006, 2011). Thus, targeting nutrient resources tactfully to enhance nutrient use efficiencies are basic principles that should be used by resource-constrained farmers. Some soils have complex chemical imbalances and poor physical structure that inhibit crop production even if adequate fertilizers are used, a phenomenon that is now referred to as 'poorly or non-responsive' soils (Vanlauwe et al., 2002, 2011; Tittonell et al., 2007; Zingore et al., 2007). Despite the highly variable soil fertility conditions, fertilizer recommendations currently available to smallholder farmers rarely reflect these circumstances and are based on an assumption of soil resource base homogeneity (Snapp et al., 2003). For example, in Zimbabwe fertilizer recommendations are linked to agro-ecological zones that are principally delineated based on rainfall, despite well established variability in soils over short distances within the agro-ecological zones (Ncube et al., 2007; Zingore et al., 2007).

Spatial variability in soils on smallholder farms has largely been trivialized when designing technological interventions, yet it is widely asserted that variability of soil fertility within farms poses a major challenge for efficient use of resources for increased crop productivity (Tittonell et al., 2007; Wopereis et al., 2006; Zingore et al., 2007). Explicitly recognizing that farmers deal with a variable soil resource base is important for the formulation of nutrient management strategies that enhance efficient use of nutrient resources on farms (Janssen et al., 1990). Considering that fertilizer resources are scarce, it is critical that fertilization regimes be tailored to both the site specific biophysical environments and socioeconomic status of farmers. When robust soil fertility indicators are known, it is possible to use them to tailor fertilizer application strategies for an informed approach that could lead to improved farming system functioning (Janssen et al., 1990; Zingore et al., 2007; Nandwa, 2001). In this paper, we hypothesize that soil organic carbon (SOC) is one such robust indicator for soil fertility status that can be used to predict resource use efficiencies under a range of management regimes. Soil organic carbon and pH have already been integrated in the model Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) as useful parameters for informing soil productivity (Janssen et al., 1990).

One of the strategies that farmers employ in maintaining or improving SOC is the application of organic materials, such as livestock manure and composted organic materials from diverse sources including crop residues, household waste and woodland litter. However, use of livestock manure in crop fields is largely a preserve of farmers who own cattle, as farmers who only have small ruminants such as goats, do not get sufficient manure to fertilize both crops fields and vegetable gardens, for which the latter is prioritized. Appropriate use of mineral fertilizers is a potential alternative strategy to enhance primary crop productivity, fixing atmospheric carbon and generating organic residues that when incorporated into the soil can increase soil SOC inputs, and support sustainable crop production intensification. However, most of these residues are eaten by livestock during the dry season, save for the below-ground root biomass inputs, making this pathway ineffective in communities with high livestock populations. The specific objectives of this study were (i) to define soil fertility domains relevant for the development of nutrient management recommendations according to SOC levels, (ii) to determine attainable yields and indigenous nutrient (N, P and K) supply for soil fertility domains and (iii) to establish the N, P and K and water use efficiencies across soil fertility domains within a landscape.

2. Materials and methods

2.1. The study site

The study was carried out in Dendenyore ward, a smallholder farming community in Wedza District (18°41S′, 31°42E′), Eastern Zimbabwe during the 2011/12 (Year 1) and 2012/13 (Year 2) cropping seasons. The research site lies in Natural Region (NR) II receiving >800 mm annual precipitation between November and March. Zimbabwe is delineated into five agro-ecological regions with NR I having the most reliable rainfall of >1000 mm per cropping season while NR V is semi-arid with long-term average annual rainfall of <500 mm. Wedza is known to have a high inter-annual rainfall variability with a coefficient of variation of between 23% and 40% (Mazvimavi, 2010). Rainfall amounts for the two seasons as well as the average long-term rainfall data for Dendenyore ward are shown in Fig. 1. The area has a mean temperature of 24 °C during the cropping season, between November and April. Soils are predominantly sandy Lixisols with low SOC and inherently poor nutrient supply potential.

2.2. Field sites selection procedure

An exploratory survey was carried out by sampling soils from 60 fields from farming households in the study area, within a radius of 5 km. Soil samples were collected from a depth of 0–20 cm, considered as the plough depth achieved by farmers using ox-drawn ploughs. The soil samples were analysed for SOC using the modified Walkley–Black method. This preliminary analysis established that 95% of the fields in the area had SOC contents ranging between 3 and 10 g C kg^{-1} soil that was strongly linked to clay

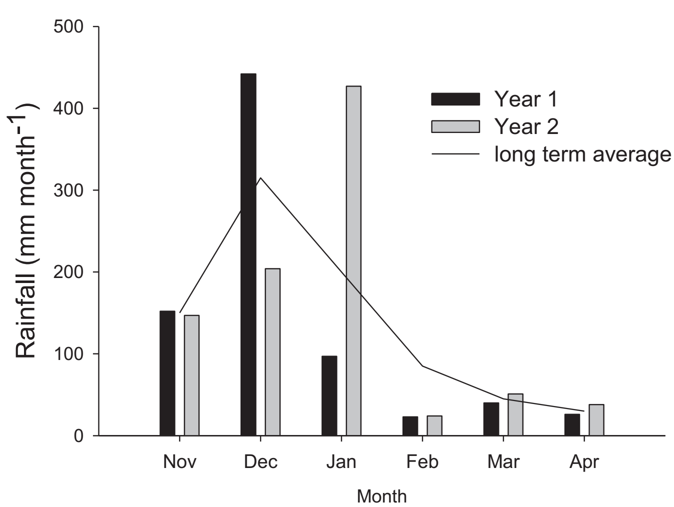

Fig. 1. Monthly rainfall distribution for 2011/12 and 2012/13 cropping seasons, with the long term average rainfall in Dendenyore ward, Hwedza District, Zimbabwe.