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Comparative assessment of maize, finger millet and sorghum for household food security in the face of increasing climatic risk

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ABSTRACT

Questions as to which crop to grow, where, when and with what management, will be increasingly challenging for farmers in the face of a changing climate. The objective of this study was to evaluate emergence, yield and financial benefits of maize, finger millet and sorghum, planted at different dates and managed with variable soil nutrient inputs in order to develop adaptation options for stabilizing food production and income for smallholder households in the face of climate change and variability. Field experiments with maize, finger millet and sorghum were conducted in farmers' fields in Makoni and Hwedza districts in eastern Zimbabwe for three seasons: 2009/10, 2010/11 and 2011/12. Three fertilization rates: high (90 kg N ha^{-1}, 26 kg P ha^{-1}, 7 t ha^{-1} manure), low (35 kg N ha^{-1}, 14 kg P ha^{-1}, 3 t ha^{-1} manure) and a control (zero fertilization); and three planting dates: early, normal and late, were compared. Crop emergence for the unfertilized finger millet and sorghum was <15% compared with >70% for the fertilized treatments. In contrast, the emergence for maize (a medium-maturity hybrid cultivar, SC635), was >80% regardless of the amount of fertilizer applied. Maize yield was greater than that of finger millet and sorghum, also in the season (2010/11) which had poor rainfall distribution. Maize yielded 5.4 t ha^{-1} compared with 3.1 t ha^{-1} for finger millet and 3.3 t ha^{-1} for sorghum for the early plantings in the 2009/10 rainfall season in Makoni, a site with relatively fertile soils. In the poorer 2010/11 season, early planted maize yielded 2.4 t ha^{-1}, against 1.6 t ha^{-1} for finger millet and 0.4 t ha^{-1} for sorghum in Makoni. Similar yield trends were observed on the nutrient-depleted soils in Hwedza, although yields were less than those observed in Makoni. All crops yielded significantly more with increasing rates of fertilization when planting was done early or in what farmers considered the 'normal window'. Crops planted early or during the normal planting window gave comparable yields that were greater than yields of late-planted crops. Water productivity for each crop planted early or during the normal window increased with increase in the amount of fertilizer applied, but differed between crop type. Maize had the highest water productivity (8.0 kg dry matter mm^{-1} ha^{-1}) followed by sorghum (4.9 kg mm^{-1} ha^{-1}) and then finger millet (4.6 kg mm^{-1} ha^{-1}) when a high fertilizer rate was applied to the early-planted crop. Marginal rates of return for maize production were greater for the high fertilization rate (>50%) than for the low rate (<50%). However, the financial returns for finger millet were more attractive for the low fertilization rate (>100%) than for the high rate (<100%). Although maize yield was greater compared with finger millet, the latter had a higher content of calcium and can be stored for up to five years. The superiority of maize, in terms of yields, over finger millet and sorghum, suggests that the recommendation to substitute maize with small grains may not be a robust option for adaptation to increased temperatures and more frequent droughts likely to be experienced in Zimbabwe and other parts of southern Africa.

1. Introduction

Since its widespread promotion in southern Africa from the 1920s, smallholder farmers have progressively shifted to maize (*Zea mays* L.) as the main cereal crop for household food and income, superseding traditional small grains such as finger millet

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(*Eleusine coracana* Gaertn.) and sorghum (*Sorghum bicolor* L. Moench) (Byth, 1993; Chidhuza, 1993). Thus, maize has become the most important staple food in the region, even in dry areas (Eicher, 1995). Maize is perceived to have a number of advantages by smallholder farmers. On average, the yields of maize are greater than those of small grains, particularly when the rainfall conditions are favourable (Alumira and Rusike, 2005). The produce market and the low labour demands for weeding, harvesting and processing for maize have been attractive to farmers (Easterling et al., 1992). Maize has also received more attention from breeders than small grains (Alumira and Rusike, 2005; Bänziger et al., 2006).

However, with the projected negative impacts of increasing temperatures combined with more frequent droughts, on crop production in the region (IPCC, 2013), the fundamental question is whether maize production alone will be enough to provide sufficient and stable production to meet food security of many southern African smallholder households. In Zimbabwe, mean daily maximum temperature has increased by about 0.1 °C per decade in the last 40 years, and is projected to further increase by between 2 °C and 4 °C by 2100 (Unganai, 1996). Although rainfall patterns are likely to vary widely from location to location, southern Africa is generally projected to become drier (Shongwe et al., 2009). Unganai (1996) reported that the national average precipitation in Zimbabwe decreased by between 10% and 16% in the crop growing period between 1900 and 1993, and a further decrease in rainfall by similar magnitude is predicted for the year 2100. The frequency of dry spells has also increased in some parts of Zimbabwe particularly in eastern Zimbabwe (Rurinda et al., 2013).

Several modelling studies suggest that maize production is more sensitive to rainfall and temperature changes than other staple cereals such as sorghum and finger millet (Makadho, 1996; Fischer et al., 2005; Knox et al., 2012). Maize yield is projected to decline by about 30% compared with a decrease of only 2% for sorghum by 2030 in southern Africa (Lobell et al., 2008). Sorghum and millets are known to perform better in dry areas than maize (Frere, 1984). Consequently, substitution of small grains for maize has been suggested as a viable adaptation option in the face of climate variability and change (Makadho, 1996; Lobell et al., 2008). The majority of these studies focused on effects of water limitation and did not consider the impact or interaction of nutrients limitations. By contrast, Chipanshi et al. (2003) assessed the impacts of reduced rainfall and increased temperatures on crop production taking into account the effects of soil fertility. They found that yields of both maize and sorghum will decrease by about 33% in the poor soils of southern Africa. This suggests that the extent of the impacts of the changing climate on crop production will vary with location depending on other factors particularly soil fertility. Given this lack of consensus on the magnitude of climate impacts on crop production (Knox et al., 2012), and the variation in predicted rainfall amounts and distributions in most parts of the region (Sivakumar et al., 2005), the recommendation that farmers should replace maize with small grains remains controversial.

A further reason to expand the cropping areas of millet and sorghum is to diversify production. Diversifying production on farms can be a strategy not only to increase production, but also to increase resilience of agro-ecosystems (Van Staveren and Stoop, 1985; Lin, 2011). Current global debates on climate change adaptation options for smallholders need also to consider benefits for human nutrition. Fageria et al. (2008) reported that production of traditional crops such as small grains could be a strategy for reducing micronutrient deficiencies in humans. Finger millet and sorghum contain high content of minerals and vitamins (Hulse et al., 1980). Further, in smallholder communities, small grains are valued for other uses. Malted millet and sorghum have been used to brew local beverages such as opaque beer and *mahewu*, refreshments commonly used during community ceremonies and when farmers are working in the field (Zvauya et al., 1997).

The potential of different cereal crops as options for adaptation to the changing climate has been evaluated mainly through modelling studies (Chipanshi et al., 2003; Lobell et al., 2008), but there is paucity of information on field-based empirical evidence coupled with local farmers' knowledge. Field-based experiments not only increase the relevance of research findings to farmers, but also support modelling studies particularly in Africa where data is scarce (Knox et al., 2012). In this paper we assess whether small grains (finger millet and sorghum) perform as well as maize under variable rainfall and soil conditions. Our objectives were to: (i) evaluate crop emergence and yield performance of maize, finger millet and sorghum for different planting dates and fertilization rates, (ii) analyse nutrient use efficiency and water productivity for the three crop types, (iii) evaluate economic benefits and nutritional value of maize, finger millet and sorghum under smallholder management conditions.

2. Material and methods

2.1. Study sites

The study was carried out in the Nyahava smallholder resettlement area in Makoni district (18°12′S 32°24′E; 1400 m a.s.l; mean annual rainfall of 800 mm) and the Ushe communal area in the Hwedza district (18°37′S 31°34′E; 1100 m a.s.l; mean annual rainfall 750 mm), in Zimbabwe. Both areas experience a unimodal rainfall pattern extending from October to April. Granitic sandy soils prevail in both study sites with low organic carbon and low nutrients contents (Table 1), and poor water holding capacity (Nyamapfene, 1989). Maize (*Z. mays* L.) is the dominant crop occupying >80% of the total area under cultivation in both sites in the 2009/10 season. In addition to maize, groundnuts (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* [L.] Walp.) and tobacco (*Nicotiana tabacum* L.) are widespread in Makoni, where maize and tobacco are the main cash crops. In Hwedza, maize, groundnuts and cowpea predominate. Maize is grown for both consumption and income at both sites. A few farmers, notably the older household heads still grow small grains mainly finger millet, but they hardly apply fertilizers.

2.1.1. Testing farmer identified adaptation options

Two researcher-managed experiments were conducted in farmers' fields in each site over three seasons: 2009/10, 2010/11 and 2011/12, to assess crop emergence and yield of maize, finger millet and sorghum as affected by different planting dates and fertilization. The core of the experiment was based on two seasons: 2009/10 and 2010/11. An extra experiment was conducted in the third season; 2011/12, to understand more about the emergence of sorghum and finger millet, as described subsequently. One experiment was conducted with maize, which is reported in detail by Rurinda et al. (2013) while the experiments reported in this article comprised similar treatments with finger millet and sorghum.

Before the establishment of the experiments, several farmers' fields were surveyed to carefully select fields for experimentation. Criteria for selection were (i) fields had to have sandy soils, which are representative for a larger area of smallholder farming systems (Mtambanengwe and Mapfumo, 2005); (ii) fields had to have a gentle slope and similar management given that these two factors are the main causes of soil fertility gradients in the case study farming systems (Carter and Murwira, 1995); (iii) fields had to be large enough to randomize all the experiments. In Hwedza, both experiments were conducted side-by-side in one field. In Makoni, the two experiments were conducted in nearby fields (about 200 m apart)