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Unpacking the push-pull system: Assessing the contribution of companion crops along a gradient of landscape complexity

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ABSTRACT

The push-pull system, a stimulo-deterrent cropping strategy consisting of intercropping cereals with herbaceous legumes and surrounded by fodder grasses, is presented as a promising crop diversification strategy for smallholder farmers in Africa as it may contribute to maize stemborer *Busseola fusca* (Fuller) suppression, while improving soil fertility and providing feed for livestock. The push-pull system has often been assessed at plot level and as a package (e.g., Maize + *Desmodium* + Napier grass). However, it is unclear how the system performs in different landscape settings or when companion crops are changed to better meet household needs. Here we evaluate the potential of the push-pull system to suppress maize stemborer infestations in three landscapes in the Rift Valley region of Ethiopia along a gradient of landscape complexity. Within each landscape, experimental plots were established on four representative smallholder farms. At each farm we used a split-plot factorial design with main plots surrounded or not by Napier grass, and subplots consisting of sole maize, maize-bean or maize-*Desmodium*. We assessed stemborer infestation level and maize grain and stover yields during two years, as well as natural enemies abundance and egg predation at two maize development stages in the second year. In the simple landscape, which was dominated by maize, all treatments had high stemborer infestation levels, irrespective of within-field crop diversity; the presence of Napier grass was associated with higher predator abundance, while egg predation rates were the highest in the maize-bean intercrop. In the intermediate complexity landscape, subplots with sole maize had higher stemborer infestation levels compared to maize-bean or maize-*Desmodium*. In the complex landscape, infestation levels were low in all treatments. However, none of these effects led to significant differences in maize grain and stover yields among treatments in any of the landscapes. The benefits of the push-pull system accrued from the companion crops (bean, *Desmodium* and Napier), rather than from stemborer suppression *per se*. Our findings highlight the importance of the surrounding landscape in mediating the performance of the push-pull system, provide new insights on the contribution of the different components of push-pull system and can guide the design of ecologically intensive agroecosystems.

1. Introduction

There is increasing interest in multipurpose cropping systems able to deliver a range of products and services to meet the multiple needs of rural smallholder families and that capitalize on ecological processes rather than external inputs. In large parts of Africa, maize (*Zea mays* L.) is an important staple crop providing food, feed and fuel (Shiferaw et al., 2011). However, maize production can be severely compromised by pests, diseases and parasitic weeds in many parts of the region (Reynolds et al., 2015). Maize stemborers *Busseola fusca* and *Chilo partellus* are considered to be the most damaging insect pests, causing variable but sometimes devastating yield losses. Stemborer infestation is severe in Southern Ethiopia, where maize production is further limited by declining soil fertility (Corral-Nuñez et al., 2014) and unpredictable rainfall (Muluneh et al., 2015). These factors, in combination with decreasing farm size, threaten food security, as well as household incomes (Mellisse et al., 2018). There is a need for affordable strategies that can reduce pest incidence below economic thresholds, while improving soil fertility and fodder production.

Crop diversification strategies may offer scope for enhancing natural suppression of stemborers (Chabi-Olaye et al., 2008). While the use of chemical pesticides is a common control method across the world, it is not effective for stemborer control because of the cryptic behavior of the larvae in the stems. Moreover, chemical insecticides are often too

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expensive for smallholder farmers and often have adverse effects on non-target biota (including natural enemies), the environment and human health (Rusch et al., 2010). Crop diversification strategies may contribute to reducing crop losses by pests by limiting the pests' ability to locate host plants (Poveda et al., 2008), by repelling pests via plant-mediated semiochemicals (Bakthavatsalam, 2016), or by stimulating the abundance and diversity of natural enemies that may provide top-down control of pests (Mailafiya et al., 2011; Pickett et al., 2014). However, the effectiveness of pest suppression potential depends critically on the composition – in terms of species and cultivars – of the cropping system (Zhang et al., 2013), while the crop assemblage should meet the requirements of the household in terms of food, feed and/or cash.

The push-pull system is a crop diversification strategy based on intercropping maize with a legume species such as *Desmodium* spp., whose semiochemicals repel stemborers (´push´ effect), bordered by a trap crop (e.g., *Pennisetum purpureum* or *Brachiaria* spp.), which attracts stemborers (´pull´ effect) (Cook et al., 2007; Khan et al., 2010; Zhang et al., 2013). This system is also associated with enhanced suppression of the parasitic weed *Striga*, enhanced soil fertility through N-fixation by the legume *Desmodium* spp., and increased food and feed production (Cook et al., 2007; Belay and Foster, 2010). Perennial fodder crops alter the attractiveness of the crop habitat for potential natural enemies of stem borers in maize fields. For instance, Khan et al (2001) demonstrated that the parasitism of stemborers in push-pull systems is enhanced through attraction of parasitoids to molasses grass. Similarly, Mammo (2012) found that Napier and Sudan grass attractd predators of stemborers, such as ants, earwigs and spiders. The adoption of the push-pull system may be further stimulated by replacing the *Desmodium* spp., which can only be used for feed, by a multipurpose grain legume such as common bean, which is an important source of protein in local diets (Fischler, 2010). Beyond their ability to fix nitrogen, legume crops produce secondary metabolites as defense compounds against herbivores (Wink, 2013). Indeed, traditional maize/bean or maize/cowpea intercropping systems are less prone to stemborer infestations (Chabi-Olaye et al., 2002; Belay and Foster, 2010), and tend to provide higher maize yield than sole maize (Songa et al., 2007; Seran and Brintha, 2010). However, the push-pull system has often been assessed as a package and the contribution of each component is not clear. In addition, the performance of the push-pull system based on *Desmodium* spp. and other legume crops in different landscape contexts is not well known.

Despite the considerable research effort on push-pull systems, most studies have focused on assessing the effectiveness of this system at the field scale, often in research stations, without considering the effect of the surrounding landscape (Midega et al., 2014; Eigenbrode et al., 2016). Landscape context can influence the pest and natural enemy interactions by providing resources and shelter (Eigenbrode et al., 2016). For instance, while maize fields function as reproduction habitats for stemborers, perennial crops may support natural enemies in maize-based cropping systems (Kebede et al., 2018). Landscape factors that drive stemborer and natural enemy population dynamics at relatively large spatial scales may interact with within-field crop diversity factors that moderate stemborer repelling and attracting effects at smaller spatial scales. It is yet unclear how such interactions unfold in African smallholder landscape settings. Moreover, the push-pull system based on Napier-*Desmodium* may not fulfil the needs of smallholder farmers without livestock. In these cases, replacing the feed crop *Desmodium* by common bean may be beneficial, and Napier, which is also used for feed, may be less desired by farmers. There is a need to assess the performance of the different crop combinations and system components in the push-pull cropping system to meet the needs of different production situations of smallholders while considering the landscape context (Eigenbrode et al., 2016).

This paper has two objectives. The first objective is to assess the agronomic and pest suppression potential of push-pull systems in landscapes of increasing complexity, from landscapes dominated by maize to landscapes dominated by perennial crops and semi-natural vegetation. For this, we assessed the stemborer infestation levels in maize, the abundance of generalist predators, the associated predation rates, and maize grain and stover yields. Based on previous studies (Cook et al., 2007; Khan et al., 2008b; Pickett et al., 2014), we hypothesized that the push-pull system would suppress stemborers and result in higher maize yield, irrespective of the landscape setting. The second objective is to assess the performance of the alternative push-pull systems by varying or omitting one of the companion crops. We compared the performance of the traditional push-pull system based on Napier-maize-*Desmodium* (*Desmodium uncinatum* jacq) to the performance of Napier-maize-common bean (*Phaseolus vulgaris L.*) and Napier-maize, and also assessed the performance of these three cropping systems without Napier. We expected that replacing *Desmodium* with common bean and omitting the Napier trap crop would result in higher stemborer infestation levels and lower maize yields.

2. Materials and methods

2.1. Study area

The study area is located in the Hawassa region in the Ethiopian Rift Valley between 7°03′11″ to 7°08′4″ N latitude and 38°15′17″ to 38°38′47″E longitude (Fig. 1). The area is characterized by moist to sub-humid warm subtropical climate. Annual precipitation ranges from 750 to 1200 mm in a bimodal distribution pattern, expected in March to April and June to August (Dessie and Kleman, 2007). *Busseola fusca* is the major maize stemborer species found in the area. The average land holding per household is below one hectare of arable land (Dessie and Kleman, 2007; Dessie and Kinlund, 2016). We selected representative landscapes in three districts: Hawassa Zuria, Tula and Wondo Genet along a gradient of decreasing annual/perennial crops ratio. We refer to these three landscapes as simple, intermediate and complex landscapes, respectively. Hawassa Zuria is dominated by maize, while Wondo Genet contains a substantial proportion of woody semi-natural habitat and the perennial crops khat (*Catha edulis*) and enset (*Ensete ventricosum*). Tula has an intermediate proportion of maize and semi-natural habitat. Data on landscape composition and configuration were obtained by combining Landsat satellite images and focus group discussions with farmers (Kebede et al., 2018).

2.2. Experimental design and plot management

Prior to the installation of the experimental plots we evaluated the performance of five Napier grass genotypes (4 genotypes of *Pennisetum purpureum*: 16 803, 16 786, 16 837 and 14 984, and one of *Pennisetum riparium*: Sodo 88) obtained from the International Livestock Research Institute (ILRI) in Ethiopia. In the simple landscape we planted three rows of each genotype and replicated the experiment in three sites (Kebede, unpublished data). Based on the performance in terms of stemborer larvae density, leaf eating by stemborer and biomass productivity we selected the genotype 16 803 for the push-pull experiment (Appendix A). In each landscape, experimental fields were established on four farms, for a total of twelve fields. Each field was divided in two blocks separated by 5 m and surrounded by Napier grass or not (Fig. 2). Napier was planted a month prior to maize planting in 2014 at inter and intra-row spacing of 75 cm and 50 cm, respectively, using stem cuttings of *Pennisetum purpureum* (Genotype 16 803). Each block was divided in three plots (10 by 7.5 m) with an inter plot distance of two meters, the maximum distance possible given the small size of farmer's fields in the area. Three cropping systems were randomly assigned to each plot: sole maize, maize-silverleaf *Desmodium uncinatum* and maize-common bean (Fig. 2). The commonly used maize variety in the study area BH540 was planted at inter and intra-row spacing of 75 cm and 30 cm, respectively. We applied 100 kg ha^{-1} diammonium phosphate (DAP) at planting and