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Planting date and yield benefits from conservation agriculture practices across Southern Africa

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ABSTRACT

Managing production risks under high rainfall variability remains a research priority in Southern Africa. In this region, conservation agriculture (CA) has been promoted as useful set of principles that could improve farmers' resilience to climate variability and change. However, matching practices to agro-ecological and farmers' socio-economic conditions remain contentious. Here we combine empirical data and results from a cropping system model to quantify benefits and trade-offs, in terms of sowing opportunity, yield, and yield variability, from adopting CA practices. We hypothesized that CA practices would require less labour, allow farmers to plant earlier, at times closer to optimum planting times and consequently result in higher maize yields.

We tested the hypothesis using available household labour and the outputs from a cropping systems model (DSSAT) run for six locations in Malawi, Mozambique and Zimbabwe. Thirty years of climate records and soil characterisations were available for each site. Modelled CA practices included, a basin planting system prepared early during winter (CA-Basins early); a basin planting system prepared late and at the onset of the rains (CA-basins late); an animal draught direct seeder e.g. using a Fitarelli animal traction planter (CA-Direct seed); an animal traction ripper (CA-Ripper); and a dibble stick manual planting system (CA-Dibble). Check conventional cropping systems included conventional mouldboard ploughing prepared early (CMP-early), and late (CMP-late), which mimicked farmers having early or late access to draft power, respectively.

Simulated results showed that CA-Ripper, CA-Direct seeding and CA-Basins improved timeliness of operations and enabled earlier planting across all locations compared to conventional systems. Mechanized CA systems potentially offered farmers flexibility on when to plant. However, timely planting of CA systems did not translate into higher yields when carried out during periods of high rainfall variability. Yield benefits of early plantings in CA were only apparent in Zimbabwe. Rainfall patterns showed a shift of 0.28 and 0.39 days yr^{-1} in planting dates at Chitala and Chitedze, over the simulated 30 years. However, this was not evident at the other four locations. Optimum planting dates established for the six locations were 5th to 27th December for Malawi; 26th December to 7th January for Mozambique; and 4th to 7th December for Zimbabwe. For each location, planting maize close to the optimum period resulted in higher yields, irrespective of cropping system. Significantly ($P < 0.05$) lower yield variability values i.e. 25% compared to 32 and 36%, were observed for optimum date plantings. Model generated optimum planting dates could be used to provide farmers with site-specific planting date recommendations.

1. Introduction

Highly variable rainfall (Fauchereau et al., 2003; Rurinda et al., 2014), the cost and availability of agricultural inputs (Anseeuw et al., 2012), lack of draught power (Francis et al., 1999), and labour (Munhande et al., 2013), are some of the key constraints faced by smallholder farmers in Southern Africa. These are also the leading causes of delayed and failed planting or lower than achievable plant populations and crop yields (Collinson, 1987; Rurinda et al., 2014; Roxburgh and Rodriguez, 2016). These challenges contribute to protracted food shortages and malnutrition among smallholder farmers in Zimbabwe (FEWSNET, 2014; Makuvaro et al., 2014) and elsewhere.

In semi-arid areas of Zimbabwe, late plantings as a result of missed planting opportunities can lead to complete yield losses (Makuvaro et al., 2014; Twomlow et al., 2008). For sub-humid regions in Zimbabwe, previous findings suggest maize yield reductions of at least 5% per week's delay in planting (Nyagumbo, 2008; Shumba et al., 1992, 1989); reaching as high as 32% (Shumba et al., 1992). Factors influencing planting time are the onset of rainfall and soil temperature (Savin et al., 2007), though operationally, socio-economic factors will finally determine when crops are sown. Key socio-economic factors affecting

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farmers' decision to plant include available power sources (draught power, labour (Houmy et al., 2013)), extent of mechanisation for land preparation and planting, inputs availability (Rurinda et al., 2014), availability of manual labour, and choice of crop. The reduced need for land preparation associated with no till practices in CA systems (FAO, 2001) has the potential to enable early planting, while saving labour and conserving soil moisture (Kucharik, 2006; Marongwe et al., 2012; Nyamangara et al., 2013). Furthermore, CA has the capacity to reduce soil loss and run-off (Nyagumbo, 2008); increase soil moisture conservation (Thierfelder and Wall, 2009); reduce weeding labour when herbicides are available and used (Muoni et al., 2013); and reduce the impact of dry spells (Mkoga et al., 2010). The type of CA system used depends on the availability of draught power, with manual CA-Basins being more dominant among non-draft power users in Zimbabwe (ZCATF, 2009) and in central Mozambique. Manual ridge and furrow conventional systems are also commonly used in central Mozambique and Malawi (Ngwira et al., 2012). CA systems in this region use manual, dibble stick based CA planting (Ngwira and Aune, 2011). In contrast, animal traction in conventional mouldboard ploughing is more common in Zimbabwe (ZCATF, 2009) and western parts of Mozambique.

Draught powered mechanized CA systems, have the potential to further reduce labour demands associated with land preparation, though they are still uncommon in Southern Africa (ACIAR, 2013; Jaleta et al., 2014). Furthermore, the poor livestock condition after the long dry season, potentially delays planting in conventional mouldboard plough based systems even when farmers have access to some draught power. Thus in animal traction cropping systems, greater availability of household labour and timely land preparation activities are likely to increase the chances of early planting and higher crop yields.

Farmers in drier or semi-arid parts of Southern Africa tend to use multiple staggered opportunistic planting to spread the risk associated with dry spells (Milgroom and Giller, 2013). However, the merits of such practices have not been quantified. Previous studies in Zimbabwe suggest that the time of planting is more important than the type of tillage system employed (Nyagumbo, 2008). In Zimbabwe the start of the season for different agro-ecologies is defined based on the time of the year when precipitation (P) exceeded half the potential evapotranspiration (PET) i.e. P > 0.5PET (Hussein and Johnson, 1987). Further studies by Raes et al. (2004) defined best planting times based on depth of a wetting front in the soil, so that planting was recommended whenever 40 mm of rainfall is received within 4 consecutive days. Such a rule can reduce the risk of a “false season starts” from 2 in every 5 years to 1 in every 4 years. Other studies in semi-arid Zimbabwe defined the start of the rainfall season as the first day after 1 October when the rainfall accumulated over 1 or 2 days is at least 20 mm and followed by a period of not > 10 consecutive dry days in the following 30 days (Mupangwa et al., 2011). However, none of these criteria takes into account farm labour availability (Mhizha et al., 2014). In Zimbabwe farmers practising CA are recommended to plant with the first rains in order to fully utilize the season's rainfall (ZCATF, 2009). Unfortunately, farmers practising CA may plant during the ‘*false start*’ periods of the season with serious yield penalties or complete crop failure.

Despite the benefits of early planting (Abdallah, 2012; Gaile, 2012; Amjadian et al., 2013), field observations in Malawi and Mozambique show that farmers rarely plant early in the season. Furthermore, the advantages of timely planting are hardly tested in agronomic experiments comparing farmer's practice and the different CA cropping systems, as these are usually planted at the same time.

Thus the perceived advantage of timely planting can be evaluated in essence in farm scale studies, which take into account labour, land size and other resources impacting farmers' ability to plant their crop. Such field experiments to study early planting are complex and resource intensive as they require many years of research and get confounded by other seasonal factors hence a crop modelling approach is warranted. This study therefore investigated the value of planting time for different CA and non-CA based cropping systems using previous weather records and the consequent maize yields and their variability across six contrasting agro-ecologies of Southern Africa using model simulations.

2. Materials and methods

The study used 30-years of climate records (from 1966 to 2001) and soil characterisations from six contrasting agro-ecologies across Southern Africa (Supplementary Fig. 1). The data generated emerged from three major steps or procedures (Fig. 1), which involved (i) the quantification of household labour availability; (ii) DSSAT model parameterization and validation; and (iii) analysis of simulated results (Fig. 1). The procedures used at each step are described below.

Two sites representing wet and dry agro-ecologies were selected from each of the three countries; Malawi: (Chitedze and Chitala), Mozambique (Angonia and Chimoio), and Zimbabwe (Marondera and Matopos), Fig. 2.

2.1. Malawi

Chitedze (13.97°S; 33.65°E and 1150 m.a.s.l.) is a sub-humid region receiving a mean of 900 mm of rainfall per annum, predominant soils are Ferruginous Alfisols. Chitala is a semi-arid region in Malawi's lowlands (13.25°S; 34.30°E and 606 m.a.s.l.). Chitala receives a mean of 1170 mm of rainfall per annum with the majority falling between November and May. The site experiences high rainfall variability as well as high temperatures (Fig. 2). Predominant soils are sandy clay-loam soils (Young and Brown, 1962). Manually prepared ridges and furrows and the use of the dibble stick are the most common crop establishment techniques in Malawi (Ngwira and Aune, 2011).

2.2. Mozambique

Chimoio (19.12°S; 33.47°E and 750 m.a.s.l.) in Manica Province, receives a mean of 1035 mm total rainfall per year (Harrison et al., 2011). Typical soils are fine textured, well drained, red in colour and originate from acidic metamorphic weathering rocks (Famba et al., 2011). Angonia (14.545°S; 34.185°E and 1220 m.a.s.l.) in Tete Province, receives 947 mm mean annual rainfall, and the most common soils are Lixisols and Luvisols (Geurts, 1997; Amane and Mlay, 2002). Like Malawi, farmers here also commonly use manually prepared ridges and furrows for planting.

2.3. Zimbabwe

Marondera is located in agro-ecological region IIa in Zimbabwe's Mashonaland East province (18.18°S and 31.55°E and 1689 m.a.s.l.). The site receives a mean of 813 mm of rainfall per annum and is dominated by light textured sands classified as Ferric Acrisols (Nyamapfene, 1991). Matopos, (20.378°S; 28.509°E and 1365 m.a.s.l.), is a semi-arid area in Zimbabwe's agro-ecological region IV in Matabeleland South Province and receives a mean of 557 mm of rainfall per annum (Vincent and Thomas, 1961). Predominant soils are Chromic-Leptic Cambisols (Mashingaidze et al., 2012). The most common cropping system across Zimbabwe is animal traction powered maize production under conventional mouldboard ploughing (ZCATF, 2009).

2.4. Cropping systems

The modelled cropping systems included manual and animal traction CA systems. As a control, the conventional mouldboard ploughing early (CMP-early) system mimicked a farmer with full access to draught oxen, i.e. with the capacity to start land preparation at the onset of the cropping season. Also a control without access to draught power in a late cropping system (CMP-late) was included. The latter farmer relies on hired or borrowed animals only accessible when owners of draught animals have finished their own land preparation and planting. Although the ridge and furrow system is commonly used in Malawi and