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Courting the rain: Rethinking seasonality and adaptation to recurrent drought in semi-arid southern Africa

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ABSTRACT

Increasingly erratic rainfall and unreliable cropping seasons in southern Africa, combined with high food prices, heighten vulnerability of rural people to food insecurity. To understand what actions are needed to expand adaptive capacity to climate change and its consequences for food security, it is useful to learn from existing agricultural practices in semi-arid areas that exploit positive opportunities of rainfall variability. To determine how residents attain food self-sufficiency based on rain-fed maize farming in a semi-arid region that receives an average annual precipitation of 400 mm, we carried out a detailed, interdisciplinary study of the agricultural system in Massingir, Mozambique from 2006 to 2010. We found that some people produced enough maize when rainfall conditions were favorable to sustain the staple food needs of a household for 2–3 years, buffering the negative effects of subsequent poor cropping seasons and avoiding seasonal hunger periods. To maximize production people employed a variety of practices including: planting after every rainfall event throughout the rainy season, up to six times in one season on as large an area as possible, as much as 18 ha per household, and employing labor/oxen exchange arrangements. We explored the role of these practices as key factors that determined total food production and variability among households. Although only 35% of planting events were successful, total seed sown represented only 8.5% of harvest over 15 years. Labor/oxen exchange arrangements allowed disadvantaged households to produce twice as much as without collaboration. Recent invasion of the large grain borer (*Prostephanus truncatus*), a devastating post-harvest storage insect pest, represents a major new threat to the sustainability of the agricultural system and to food security that could worsen with climate change. Our results suggest that policies aimed at reducing vulnerability to climate change could be improved through a deeper understanding of existing practices.

1. Introduction

Sub-Saharan Africa is expected to be one of the regions of the world most severely affected by climate change (Hahn et al., 2009; Kotir, 2011). Climate change projections for southern Africa suggest that dry areas will become even drier and rainfall more erratic (Lobell et al., 2008). Most studies paint a dismal picture for food production in semi-arid environments in the face of climate change, especially for maize (Jones and Thornton, 2003; Lobell et al., 2008; Parry et al., 1999). Maize is the staple crop in the region, despite its relatively high and regular water requirement, and is increasingly replacing sorghum and millet that are better adapted to the conditions of southern Africa. Increased variability of rainfall will not only decrease overall food production, but is likely to exacerbate negative effects of seasonal patterns of food-insecurity (Ahmed et al., 2011). Much of southern Africa already suffers from food scarcity between the end of the food stocks from the previous year's harvest and the next harvest (Devereux, 2009; Handa and Mlay, 2006). The pattern of seasonal hunger periods, known as 'seasonality', has been recognized as one of the major determinants of poverty because it limits choices about education and work, forces the sale of assets to buy food, and has severe consequences for health and nutrition (Devereux, 2009; Vaitla et al., 2009). Hunger periods tend to coincide with peaks in food prices, and with high prevalence of diseases such as malaria and diarrhea in the rainy season before harvest (Chambers et al., 1981). The combination of the recent global food crisis and effects of climate change on agricultural production makes understanding the dynamics of seasonality, and how food production can be improved, doubly important (Swan et al., 2010).

Studies to assess potential impacts of climate change tend to be carried out on a global or regional scale and focus on changes in agricultural production based on risk of drought and changes

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in the length of the growing period. Such studies often assume generalized cropping practices, such as a single planting date per season, a fixed area for production per household, and do not consider the effects of climate change on post-harvest grain storage. Scaling down from national or regional-scale studies is complex and creates challenges for assessing possible future scenarios and designing policy interventions (Hahn et al., 2009; Thornton et al., 2009). Studies based on actual cropping practices, that look beyond production and that account for heterogeneity between households in terms of yield and households' responses to climate variation can lead to different conclusions about food security (Moore et al., 2011; Thornton et al., 2010).

People constantly adapt to environmental and social changes (Aase et al., 2010; Barbier et al., 2009). Expanding adaptive capacity is key to reducing vulnerability to the negative effects of climate variability (Engle, 2011; Smit and Wandel, 2006). However, policy makers and researchers alike struggle to ground the concept of expanding adaptive capacity in actual practices and potential actions (Berrang-Ford et al., 2011). A plethora of practices have been documented across the world that are employed to mitigate negative effects of an environmental or political change (Jarvis et al., 2011). By contrast, few studies document cases of people exploiting positive opportunities (Berrang-Ford et al., 2011; Cooper et al., 2008). Adaptive capacity and adaptive practices are context-specific and best understood through in-depth studies of existing practices (Slegers, 2008). The area of the world with arid and semi-arid conditions is expected to increase significantly (Fischer et al., 2005). By understanding existing agricultural systems in semi-arid areas, and how they respond to their natural and social environments, insights from farmers' current practices can shed light on the complex challenge of food production in the face of increasing rainfall variability (Mortimore and Adams, 2001; Osbahr et al., 2008). Interdisciplinary studies at household and village scale are therefore needed to gain a realistic vision of adaptive capacity and of interventions that are likely to be effective (Thornton et al., 2009, 2010).

The case study presented in this paper provides an example of an agricultural system that exploits positive opportunities of climate variability. The Massingir district in Southern Mozambique, our study site, was deemed unsuitable for cropping due to low and erratic rainfall and frequent drought (Kassam et al., 1982; Reddy, 1986; Westerink, 1995), yet we describe how people achieve food self-sufficiency over multiple years after sporadic favorable rainfall events through a mixed crop-livestock farming system based on maize production. This interdisciplinary study brings together and explains the agronomic and socio-economic components of this agricultural system to understand how people manage to attain food self-sufficiency in this marginal environment. Our specific objectives were to: (1) understand the contribution of maize production and livestock to food security, (2) determine which farming practices were key to achieving food self-sufficiency and maximizing maize production, (3) explain variability in maize production among households, and (4) explore the role of post-harvest storage of maize in determining the household food supply and food security.

2. Methods

We carried out this study in a series of steps described in detail below. We first documented livelihood activities and cropping practices, including patterns of household food self-sufficiency (Section 2.2). To understand how much maize households were able to produce from a favorable rainfall event, we quantified maize production, based on recall data from interviews, over 12 years (Section 2.3.1). Then, we simulated harvest success/failure and relative yield for each planting event over 15 years using daily rainfall data, taking local cropping practices and heterogeneity among households into account (Section 2.3.2). We investigated the specific characteristics of the local maize, selection practices and local preferences to understand the role of the landrace itself in food production under marginal conditions (Section 2.4). Finally we examined post-harvest storage conditions (Section 2.5).

2.1. The study area

The study was carried out in the district of Massingir, Gaza Province in southern Mozambique (coordinates of the district capital: 23°55′S, 32°09′E). We collected data in six villages between 2006 and 2010: Massingir Velho, Macavene, Zulo, Manhica, Nanguene and Chinhangane. Households were defined as all people who share the same granary on a regular basis.

The rains fall mainly between November and March with a long-term average of 399 mm per year (INGC et al., 2003), but large variability between years (200–900 mm) (Rainfall data, Massingir station, IIAM 1986–2005 and Ara-Sul, Massingir, 1995–2010). Temperatures range between an average minimum of 11 °C in the cold and dry season to an average maximum of 34 °C in the hot and wet season with average daily temperatures that range from 19 and 27 °C, respectively. Soils are mainly eutric fluvisols and mollic fluvisols along the rivers, and haplic luvisols and arenosols outside the river valleys (INIA/DTA, 1994).

2.2. Cropping patterns and food self-sufficiency

To understand the contribution of maize-cropping practices and livestock to food security, we interviewed members of 141 households in a total of six villages between 2007 and 2009. Interview topics included: family demography, sources of income, responses to lack of food, number of livestock, source of oxen for plowing, planting patterns in recent years, yield (measured in local units), number and location of fields, access to land, seed security, and maize consumption rates. Data on livestock keeping was validated through direct observations on a subset of households, but we recognize the difficulty in attaining accurate livestock counts. Data on livestock-keeping and sales was complemented by data in two other neighboring villages (Leonardo, 2007). We observed and documented cropping practices in the village of Nanguene over a 4-year period from October 2006 to June 2010 including: where and when crops were planted, source of the seed, animal traction, labor, planting density and intercropping, weeding, crop protection, and production recorded in local units. We asked nine children between 8 and 12 years of age to draw all the food items they ate in the rainy season, and in the dry season.

Seven households from Nanguene constructed food self-sufficiency calendars specifying sources of food from 1999 to 2010. Household heads indicated when the household was food self-sufficient, eating from their own harvest, and when food was obtained from other sources. We validated these calendars by comparing with our own observations from 2006 to 2010, rainfall records of all years and with independent recollections of other household members. Pictorial representations of the calendars were used to improve accuracy of the data collected in three iterations of interviews and calendar revisions with each household head.

2.3. Maize production

2.3.1. Household maize yields over 12 years

To quantify patterns of household maize production, we constructed a time series of yields for each of 22 households (HH) from 1999 to 2010. We used yield figures attained through the food self-sufficiency calendar exercise with seven households in Nanguene (Section 2.2) and interviewed 15 households from Chinhangane using similar methods. We calculated yield (kg/HH) from recall figures based on the local units of bag, sleigh (*xilei* in shangaan), cart and granary. A sleigh or *xilei* is a cart that is dragged behind cattle; because of the sandy soils of the area, the cart does not have wheels, but two wooden rails, like a sled. Calculations to convert local units to kg were based on interviews and corroborated by two independent sources (Leonardo, 2007; Trabalho de Inquerito Agricola, 2008). One standard "50-kg" bag of ears of maize, including husks, weighed 20 kg; six bags fit in a sleigh, and four sleigh loads fit in a cart. The number of cartloads that fit in a granary varied between 6 and 31 depending on the size of the granary; therefore we measured the size of the granary for each household. When the size of an individual granary could not be measured, we used the average size for the village. To calibrate conversions of recall harvest to yield in kg/ha, we measured yield in 4 m × 4 m plots in maize fields in the village of Chinhangane between March and May of 2009 ($n = 24$) and in April of 2010 ($n = 5$), a year in which very few farmers harvested any grain.

2.3.2. Using daily rainfall data to estimate maize production

To explain the trends in the recall exercise (Section 2.3.1), we simulated harvest success/failure and relative yield based on daily rainfall records and crop water requirements. Through this exercise we explored how local cropping practices contributed to maximizing yield. Daily rainfall and temperature data over 15 years (1995–2010) from the ARA-SUL station in Massingir (23°53′S, 32°09′E) were used as input; Nanguene and Chinhangane are 14 and 12 km from Massingir, respectively. Decision rules for planting, based on our field observations and interviews, were a function of rainfall, as follows: The first planting event occurred when at least 20 mm of rain fell over 5 days, regardless of the date; subsequent planting events started when more than 10 mm of rain fell over 5 days. The number of days spent planting per planting event was determined by the number of consecutive days where more than 10 mm of rain fell over the previous 5 days. The maximum number of consecutive dry days was calculated for each period in the growing cycle of each planting event using INSTAT (Stern et al., 2006). Crop specific evapotranspiration values, or crop coefficients (K_c) were adapted from Allen et al. (1998) for a short cycle variety of maize (100 days to maturity). Simulations were based on the following additional assumptions: The period of emergence and establishment (INIT) was 0–20 days after seeding ($K_c = 0.4$), the period of vegetative growth (DEV) was 21–45 days after seeding ($K_c = 0.4–1.1$, linear interpolation), the period of tasseling, flowering and grain filling (MID) was from 46 to 75 days after seeding ($K_c = 1.1$) and the period of grain filling and drying (LATE) was from 76 to 100 days after seeding ($K_c = 1.1–0.55$ linear interpolation). A binary logistic regression was performed based on observations of harvest success/failure of each planting event from the seasons 2005–2006 to 2009–2010, as a function of rainfall and maximum consecutive dry days in each growing phase. This model was used to predict harvest success/failure for the remaining nine seasons, from 1995–1996 to 2004–2005.

The crop water satisfaction index (Frère and Popov, 1979) for each planting event was calculated using INSTAT (Stern et al., 2006) to serve as a proxy for % attainable yield. Soil water holding capacity was assumed to be 100 mm, derived from the soil texture data for an average soil in the study area (predominantly loamy sand to silty clay soils) at a rooting depth of 1 m (Allen et al., 1998). For each successful cropping event, relative yield (% of attainable yield) was calculated based on the crop water satisfaction index. Attainable yield was assumed to be 1.8 t/ha, the highest yield of the local maize measured under good conditions (Section 2.3.2) (also found by Leonardo, 2007).

We estimated the total area planted per household in each year as a function of the number of days suitable for planting (see above), percent of planting days spent planting, number of teams of oxen available and the area planted per team of oxen per day. We assumed six work days per week because most people do not work on Sundays. Labor exchange arrangements, in which labor is exchanged for use of oxen to plow fields, affect the total area of land that can be plowed by a household each year. Members of a household that exchanged labor to access oxen could not spend all potential work days planting their own fields because they would be working for someone else. Conversely, a household could not use their team of oxen to plant their own land on all potential planting days if the oxen were being used to plant others' fields in exchange for labor. The number of oxen per household was determined by interviews and observation. We assumed the area planted per day was 0.22 ha, based on the assumption that 0.05 ha were plowed and sown per hour with one team of oxen (based on field measurements), and an average of 4 h plowed per day. Therefore:

$$\begin{aligned}\text{Total area planted (ha/HH)} = {} & \text{No. of planting days} \\ & \times \text{No. of teams of oxen/HH} \\ & \times \text{\% of days worked/100} \\ & \times \text{area(ha)planted/day/team of oxen}\end{aligned}$$

When this estimated area exceeded the total area of fields available to a household, e.g., because of many favorable planting days, the total area of the household fields (determined independently) was used. Total production was calculated as the estimated relative yield (% water satisfaction) per ha for each successful cropping event × total area planted in each successful cropping event. The total amount of seed sown was calculated from the total area planted (successful and not successful planting events) × 25 kg/ha, a figure based on interviews and validated through estimations based on local planting practices (number of seeds per hole and spacing).

To quantify the contribution of labor exchange practices to maize production, we estimated how much could be produced by hand hoeing by households that had no oxen. Area planted per day per person was estimated to be 0.016 ha (Heney, 2009). The same calculation was made as described above, replacing 'team of oxen' with 'person' and all days were worked by all laboring people (no discount for labor exchange).

2.4. Maize characteristics and people's preferences

To study the characteristics of and preferences for the local maize we held focus group discussions in September 2007, in each of eight villages, with elderly women identified by the leader of each village as those most knowledgeable about agriculture. Groups of 5–16 women discussed and ranked by order of importance within each topic: (1) the uses, (2) preferred characteristics and (3) the pests and problems of maize.

In addition to focus group discussions, we collected maize ears between 2007 and 2009 ($n = 120$), characterized them and planted out a sample to characterize the morphology of the plant (IPGRI, 2000). With ears that represented the range of morphological diversity found in the study sites, we conducted individual interviews in two villages with elderly women ($n = 10$) knowledgeable about seed, to explore seed selection criteria, storage practices, distinction between landraces, and preferences for variety characteristics. Women were asked to make groups of similar ears and define the rationale for each group, its name and general characteristics. Then they were asked to identify three groups they would discard if they had to and three groups that they would keep if they could only keep three. Rationales were discussed with respect to selection criteria and storage practices.

2.5. Post-harvest conditions

In May of 2010 all the granaries in the village of Chinhangane that still contained maize 9–12 months after the last harvest ($n = 9$) were sampled to assess post-harvest damage. Each granary was evaluated for the type of roof, and general condition. Between 19 and 22 ears from the center of the stored maize left in each granary were evaluated. The percent kernels damaged, dominant color of the kernels, cob and the type of kernel was recorded for each ear.

3. Results

3.1. Multiple-year cycles of food self-sufficiency

Patterns of food self-sufficiency over the last 12 years in Massingir were characterized by years of abundant production which provided sufficient food to bridge subsequent years when crops failed (Fig. 1). A good harvest was attained approximately 1 year out of every five. Among the seven households that reconstructed 12-year calendars, the overall patterns of food self-sufficiency were similar, despite the differences in resource-endowment among households with respect to assets: head of cattle, household labor and area of land available for planting (Fig. 1). Some households in Massingir were self-sufficient for food for 1–3 years after a good rainfall year and an abundant harvest, often reinforced by subsequent smaller harvests. This period was followed by 1–2 years when the primary source of their household food was purchased or gifts. Accurate data on income was not available. During consecutive years with drought, households produced small amounts of maize on residual water during the dry season (Fig. 1). Food obtained through the World Food Program's "Food for Work" was cited as an important source of food in 2002–2003, but since 2005 the role of food aid in this region has been minimal.

Maize production per person over this time period (1999–2010) calculated from household recall data ($n = 22$) (Fig. 2) reflects the patterns of food-self-sufficiency reported by the households in Fig. 1. Based on actual consumption rates of maize meal per person derived from interviews, we used a conversion factor of 1.51 kg grain for 1 kg of ground maize meal (Trabalho de Inquerito Agricola, 2008) to calculate the grain equivalents of required maize per person per year. Mean per capita consumption of maize meal was 0.46 kg per day, 168 kg per year of maize meal, or 253 kg per person per year of dry grain. We therefore determined 250 kg of dry grain to be the baseline figure for annual maize requirement per person, a figure also used in previous studies on food security in southern Africa (Cumming, 2005; Eilerts and Vhurumuku, 1997). In terms of caloric requirements this figure represents 2496.60 kcal/person/day and reflects the average kcal/person/day recorded in Southern Africa (van Wesenbeeck et al., 2009). It does not, however, account for hunger periods, seasonal differences in consumption or nutritional needs. In the season from 1999 to 2000, severe floods led to a median production of 958 kg per person. In Nanguene, the season of 2005–2006 had a median production of 543 kg per person. In these 2 years, some households produced as much as 3.4 tons per person and most households managed to produce enough to eat for at least 2 years; these were considered excellent years. In three of the 12 years (2000–2001, 2003–2004 and 2008–2009), most households produced enough grain to feed the household for at least for 1 year and were

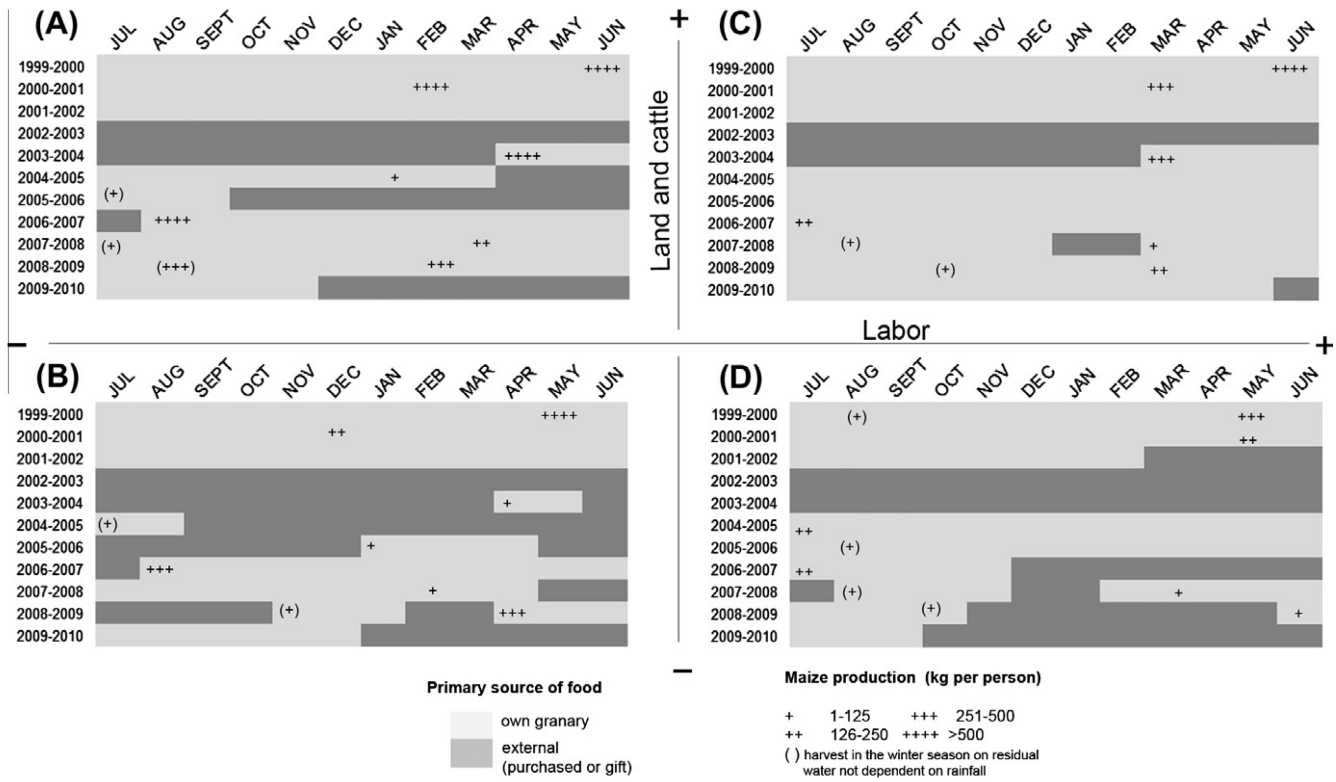

Fig. 1. Patterns of food self-sufficiency in Massingir, Mozambique from 1999 to 2010, illustrating when households were primarily eating from their own maize production and when they were eating from external sources. Each quadrant is an example of a single household representing households with different combinations of labor, cattle and available land based on detailed interviews as described in Section 2.2. (A) Household with two working-aged members, 15 head of cattle and 18 ha of fields. (B) Household with two working-aged members, no cattle and 4 ha. (C) Household with six working-aged members, 14 head of cattle and 12 ha. (D) Household with five working-aged members, two head of cattle, and 5 ha. Symbols represent time of reported harvest per person in the household. + is any harvest from 0 to 125 (6 months of food), ++ = 126 to 250 (1 year of food), +++ = 251 to 500 (2 years of food) and ++++ ⩾ 500 kg per person (more than 2 years of food). Dark gray bars represent time when the household was eating primarily from an external source of food, and light gray bars represent when the household was eating from its own granary.

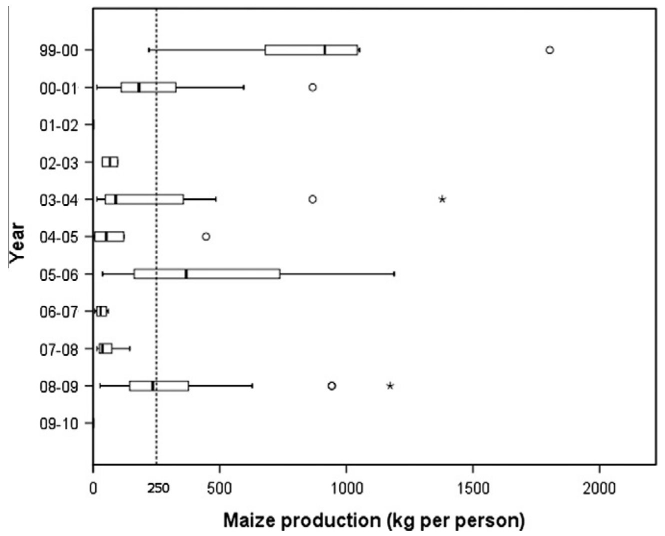

Fig. 2. Time series of household maize production expressed as kg per person in 22 households in Massingir, Mozambique 1999–2010. Households that reported no harvest in a certain year were not included for that year, and four points over between 3000 and 4000 kg per person (two in 99–00, one in 00–01 and one in 05–06) are not shown due to small family size that resulted in large per person estimates. The dotted line at 250 kg represents yearly consumption requirement in grain equivalents for one person based on actual consumption rates.

considered good years. Small harvests in subsequent years that were considered bad years (2004–2005 and 2007–2008) helped tide some households over until the next harvest. In 2 years, none of the households harvested any grain (2001–2002, and 2009–2010), and even in bad years where some harvest was reported (2002–2003, 2004–2005, 2006–2007, 2007–2008), more than half the households (20, 17, 17 and 14 out of 22 households, respectively) did not produce anything. Maize is the staple food grown and eaten, but is intercropped with other crops, mainly pumpkin, watermelon, cowpea, sweet potato and groundnut in descending order of importance. These crops were consumed when available, but did not last until the dry season. Foods found in the forest also contribute to the nutrition of the diet, such as wild herbs, marula nuts (*Sclerocarya birrea*), fish, caterpillars or worms, and meat (Verbeek, 2009). Rice, beans and bread is also occasionally purchased. Children identified a total of 40 items that they eat in the rainy season, and only five in the dry season.

Focus group discussions revealed that maize was primarily sold when there was a large surplus such as the 1999–2000 season. Households with access to cash tended to purchase food before stored grain ran out to make the household stock last as long as possible. When households purchased food, 32 out of 141 (23%) did so with existing money as their first response to lack of stored grain (Table 1). Most households engaged in multiple activities when in need of food or money and many of the ‘sources of income’ overlapped with ‘response to lack of food’. Sale of livestock is a prime example. Major sources of income included selling livestock, labor migration and trans-border trade, sale of goods or paid labor (Table 1). Livestock numbers varied considerably among households (Fig. 3a). Of the 141 households surveyed, 79 (56%) reported the sale of livestock as a source of income; however, between 2006 and 2008, years of very little harvest during the rainy season, many households did not sell any cattle or goats. Most of those who did sold only one animal (Fig. 3b). This is likely to be because of a combination of reasons: the 2005–2006 harvest produced enough to last for multiple years in some households who also helped other households that did not have food, some households produced enough on residual water during the dry seasons to get by, and those who did purchase food used existing cash or could rely on the income from a single head of cattle.

3.2. Courting the rain

3.2.1. Increasing chances of production: risk spreading and risk taking

Residents of the Massingir region used many practices to maximize their maize harvest in the face of unpredictable rainfall, some of which were employed at an individual household level, and some of which involved social arrangements and were employed collaboratively (Table 2). Planting as much land area as possible each season was the key practice (median 1.2 ha per person, with a maximum of 6 ha per person). Spatial and temporal staggering of planting are two practices that are used to increase further chances of production. Interviews indicated that households have between 2 and 12 fields, distributed across up to six different cropping areas. People commonly plant on portions of multiple fields before planting the entirety of any single field. Temporal staggering of planting entails sowing every time it rains, for as many days as the soil is moist enough for the seed to germinate. This increases the chances of receiving adequate rainfall in quantity and distribution during a growing cycle (Fig. 4). In 2009–2010 we observed six separate planting events, including one in April, the beginning of the dry season. Estimates based on daily rainfall indicate that people could potentially plant up to eight times in a season. Each planting event lasted between four and 14 days.

3.2.2. Timely access to resources: management of resources and overcoming input limitations

Timely access to resources determines a farmer’s capacity to carry out the practices described above. Farmers must have access to sufficient quantity and quality of cleared land, oxen for plowing when it rains, labor to drive the plow and seed to plant. Ox-drawn mould-board plowing is the predominant form of land preparation; very few people till their fields using hand hoes. Households that do not have the necessary resources collaborate with other households to overcome input limitations. For example, households that do not have oxen for plowing engage in labor exchange with other households called *kukaxela.* The general rule for *kukaxela* is that for 3 days of labor on the oxen owner’s fields, a worker is rewarded 2 days of use of the oxen on his or her own fields (Table 2).

Farmers sow between 20 and 30 kg maize seed per ha, planting 3–5 seed per hole at a spacing of 40–80 cm within a row and 60–100 cm between rows. Despite the large amount of seed required, lack of seed was not a major limiting factor to production. In the 2007–2008 season, after one failed harvest and 16 months after the last good harvest, 13 (38%) of 35 farmers surveyed reported that they did not have as much maize seed as they would have liked, but 28 (80%) had still planted from their own saved seed and had not obtained seed elsewhere.

3.2.3. Minimizing losses: risk avoidance

Once maize has produced ears with grain in the field, risk avoidance is the principal practice engaged in by individual households and in collaboration with other households. These practices include protecting the crop against animals such as elephants in the field and avoiding post-harvest losses in the granary (Table 2).

3.3. Variability among households

Households had a median of eight people in total, ranging from one to 27. The variability of total household maize production among households in the same season from the same village was

Table 1
Sources of income, and first and second responses to lack of food in Massingir, Mozambique, expressed as number of households that mentioned each category and the percentage in brackets. Each household mentioned between one and four sources of income (n = 141).

Activity	Sources of income (%)	First response to lack of food (%)	Second response to lack of food (%)
Sell goat or cow	79 (56)	39 (28)	23 (16)
Labor migration and trans-border trade	46 (33)	–	–
Sell agricultural product	39 (28)	4 (3)	7 (5)
Informal labor	33 (23)	17 (12)	14 (10)
Charcoal production/sales	28 (20)	6 (4)	0 (0)
Collect or make things to sell	27 (19)	5 (4)	5 (4)
Sell chickens	16 (11)	5 (4)	4 (3)
Small business	18 (10)	–	1 (1)
Salaried job, Moz	11 (8)	–	–
Temporary job, Moz	8 (6)	–	–
Fishing	7 (5)	2 (1)	0 (0)
Buy food with existing money	–	32 (23)	4 (3)
Ask family for food or money	–	8 (7)	8 (9)
Ask for a loan	–	8 (6)	6 (4)
Plant again	–	4 (3)	5 (4)
Wild fruits	–	3 (2)	8 (6)
Nothing mentioned	4 (3)	7 (5)	56 (40)
Total	316 (221)	141 (100)	141 (100)

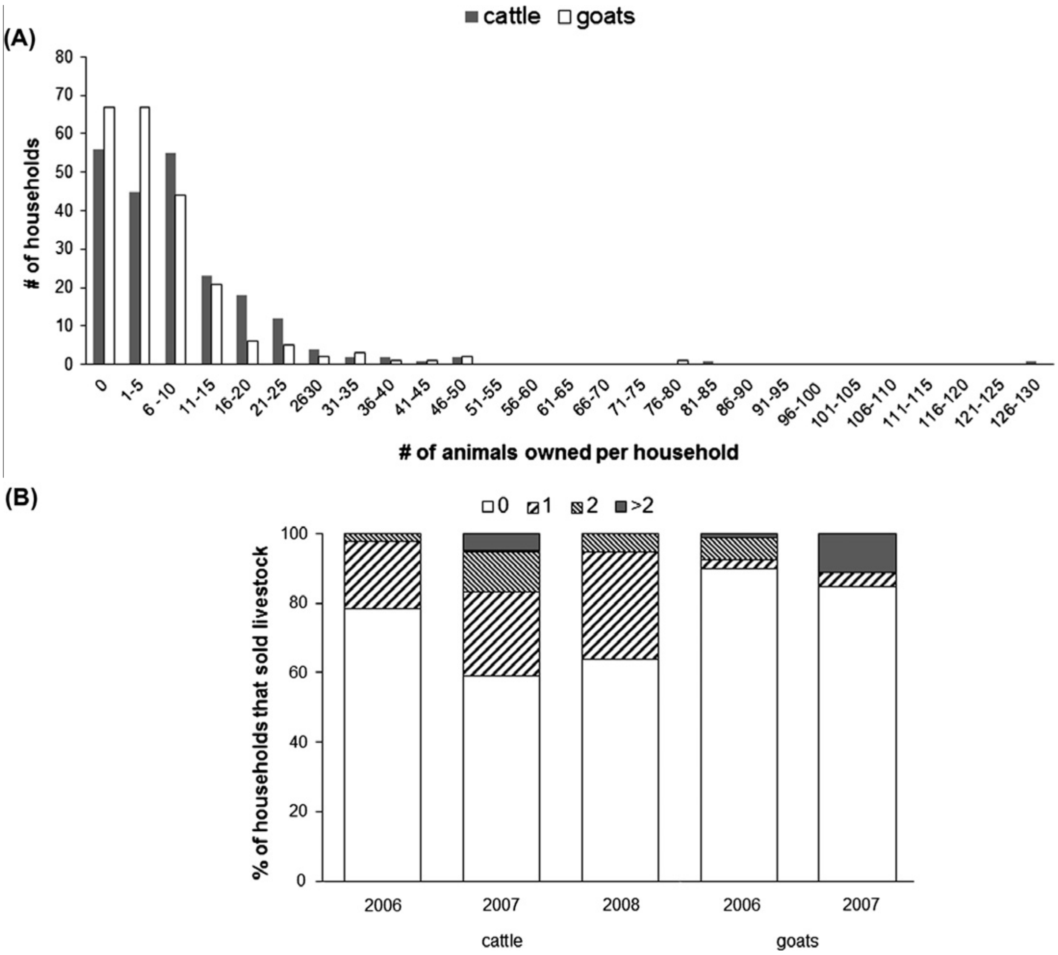

Fig. 3. Livestock and holding (A) and sales (B) among households in Massingir, Mozambique from 2006 to 2008. (A) Livestock holdings in 228 households in 2007–2008. (B) Proportion of households that sold 0, 1, 2, or >2 cattle and goats in 2006 (n = 80), 2007 (n = 55) and for cattle only in 2008 (n = 16).

enormous. In Chinhangane, for example, yields ranged from 377 to 11,688 kg per household and between 75 and 1172 kg per person in the 2008–2009 season (Fig. 5). Using data sets from three villages we explore the causes of this variability: one complete, but small, data set (Nanguene, n = 13), and two larger data sets for which total field area per household was not available for one (Chinhangane, n = 49) and production was not available for the other (Macavene, n = 128). The total field area held by the household was the only significant variable explaining maize produced per household in a regression analysis on the data from Nanguene (r = 0.682, n = 13, P = 0.021). Field area per household was correlated to the number of cattle per household (Spearman's rho = 0.486, n = 128, $P < 0.001$) and to the number of people in a household (Spearman's rho = 0.462, n = 128, $P < 0.001$) in

Table 2
A list of adaptive cropping practices, the objectives of each practice, how they work, where they are carried out, whether or not they are individual household (IND) practices or social arrangements (SOC), and the type of adaptation involved: Risk taking (T), risk spreading (S), risk avoidance (A), management of resources (M), or overcoming limitations (O).

Motive for practice	Adaptive practice	How it works	IND/SOC	Type
A. Obtain access to necessary inputs at the right time	1. Default seed selection	• Seed is not selected or separated from grain for consumption until the moment before planting: default selection for post-harvest qualities	IND	M
	2. Saving seed multiple years	• Households save seed from year to year, preserving local varieties, prepared to plant at the first sign of rain	IND	M
	3. Off-season seed multiplication	• Seed multiplication on small plots (river's edge or any depression in the landscape that retains moisture) during the dry season	IND	M
	4. Seed exchange or gifts	• Exchange of seed with others to get access to lost varieties or to seed when in need— can be paid in labor, food, other types of seed or given as a gift	SOC	O
	6. Land lending	• Asking for the use of plots of land to get access to a field if household does not have one, or to a field in a particular location—mostly no payment in exchange	SOC	O
	7. Labor exchange	• Payment for labor in money, or in food, seed and sometimes by land lending (local name for practice: *xikoropa*)	SOC	O
	8. Cattle lending	• The use of someone else's cattle for plowing a field. Three days of work on the oxen owner's field is rewarded by 2 days of use of their oxen (local name for practice: *kukaxela*), but can also be with no payment (borrowing) or for money (rental)	SOC	O
	9. Cattle keeping for others	• Taking care of cattle for others full time allows the care-takers to use cattle in their fields and is also traditionally a service paid for by one animal per year (local name for practice: *kuwekissa*)	SOC	O
B. Cope with scarce and unpredictable rainfall	10. Plant as much area as possible	• This increases overall chances of producing maximum yields	IND	S
	11. Spatial distribution	• Planting in different fields across the landscape	IND	S
	12. Temporal distribution	• Planting every rainfall event, including in the dry season	IND	S/T
	13. Crop/soil combinations	• Planting certain types of crops on certain soil types, for example, groundnut on sandier soils and maize on heavier soils.	IND	M
	14. Use of local varieties	• Preferential use of local and open pollinated varieties that are well adapted to local conditions	IND	S
	15. 3–5 seeds per hole	• To ensure that at least one plant survives, compensate for poor germination, establishment or performance	IND	S
	16. Intercropping	• Planting of other crops between rows of maize to increase crop production, decrease weeds	IND	M
	17. Dry sowing	• Planting before the rains to get a head start on the use of available water	IND	T
	18. Planting in dry season	• Planting if it rains in the dry season	IND	T
C. Avoid losses in the field	19. Premature maize harvesting	• Harvest of maize while it is still not completely dry to avoid elephant attacks risking elevated post-harvest losses	IND	A
	20. Off-season planting location agreement	• Agreement among farmers to plant together in the same place during off-season to reduce animal raids of fields	SOC	A
	21. Village nocturnal vigilance	• Farmers guard field at night with fire and pot-banging to keep elephants and hippos away	SOC	A
D. Avoid post-harvest losses (seed and grain)	22. Storing cobs with husks	• Maize is stored in the granary with husks to minimize post-harvest pest damage	IND	A
	23. Tight granary construction	• Granaries built with drooped thatched roofs to reduce wind and minimize entrance of pests	IND	A
	24. Cooking under granary	• Cooking under granary exposes the maize to smoke and makes is less susceptible to pest attacks	IND	A

Macavene. The number of cattle and the number of people in the household were significant variables in a regression analysis on the log of total household maize production in Chinhangane when land area was not included ($r = 0.680$, $n = 44$, $P < 0.001$). When the regression was repeated excluding households with fewer than two cattle (minimum needed for plowing), the only significant variable was the number of cattle ($r = 0.591$, $n = 26$, $P = 0.001$). The number of people in the household and number of working aged members of the household were both correlated with total number of cattle ($r = 0.554$, $n = 44$, $P < 0.001$ and Spearman's rho = 0.603, $n = 44$, $P < 0.001$).

Out of 50 households interviewed in Chinhangane (20 of which were female-headed households), 29 households plowed their fields with their own oxen, of which 22 (75%) were male-headed. Of all households that engaged in *kukaxela*, 9 out of 17 (52%) were female-headed. Only female-headed households reported renting or borrowing cattle. Households that had no oxen and engaged in *kukaxela* to gain access to oxen for plowing produced significantly less maize per person than those that used their own oxen for plowing (Mann–Whitney test, $P < 0.001$) (Fig. 6a). There was no significant difference in production between male- and female-headed households who had the same source of animal traction (Fig. 6a) and there was no significant difference in total area of fields between male and female-headed households (Fig. 6b), but they had fewer cattle ($P < 0.01$) (Fig. 6c), and fewer working aged people per household ($P < 0.05$) (Fig. 6d).

3.4. Rainfall

A logistic regression model containing the variables: rainfall during emergence and establishment (INIT), rainfall during the vegetative phase (DEV) and maximum number of consecutive dry days during the reproductive phase for each cropping season predicted correctly 100% of the observed responses. This model was used to predict the success/failure of each planting event for the remaining nine seasons (1995–2004). The water satisfaction

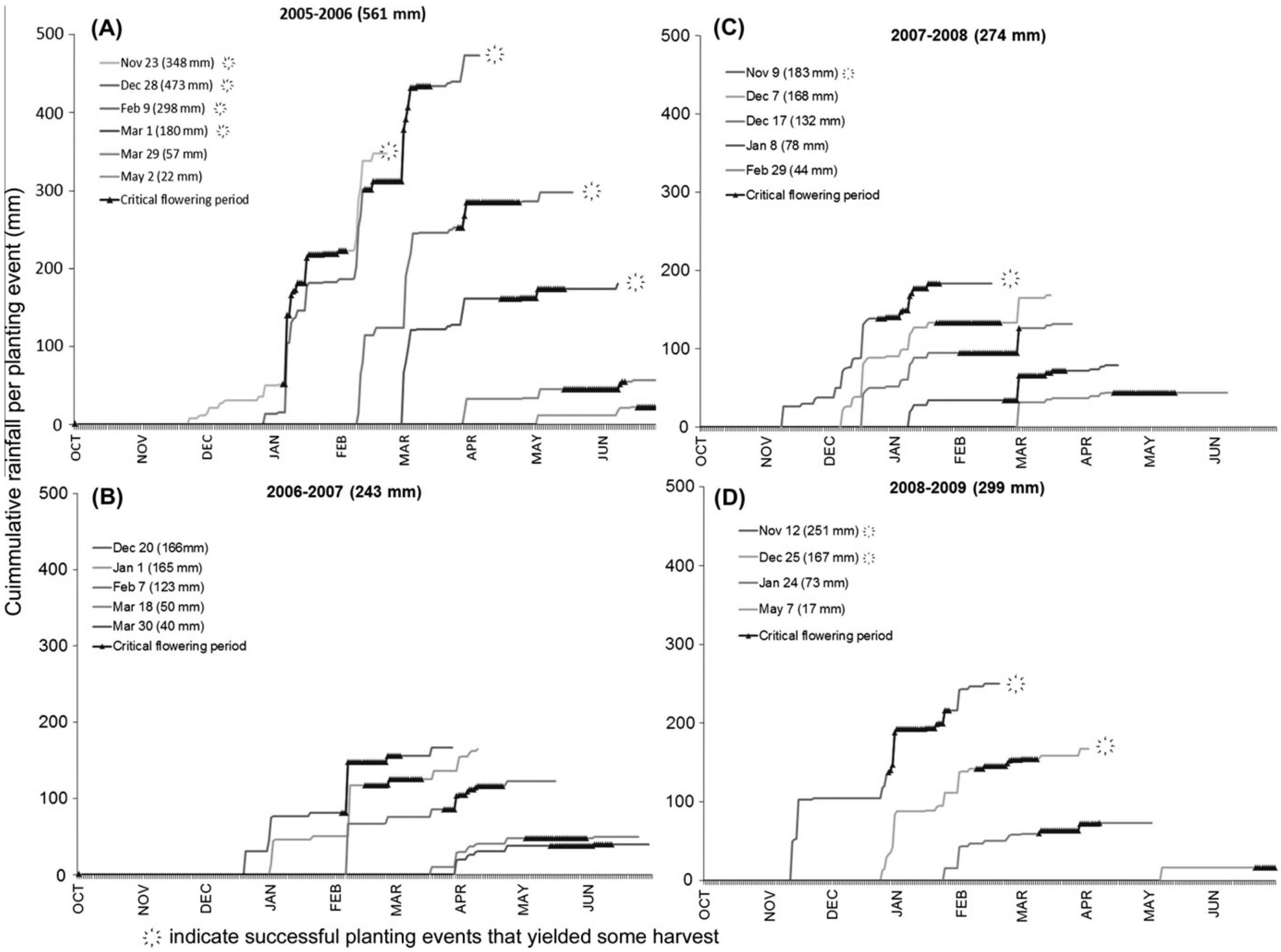

Fig. 4. Cumulative rainfall for each planting event, highlighting the 30 day critical period of flowering for each planting event. Four rainy seasons are presented: (a) 2005–2006, (b) 2006–2007, (c) 2007–2008 and (d) 2008–2009 in Massingir, Mozambique.

index was used to estimate percent attainable yield for each planting event. There was a significant correlation between the maize production data based on recall and the predicted maize production derived from the model ($r = 0.884$, $n = 62$, $P < 0.01$). Between 2005 and 2009, 8 of 22 (36%) observed planting events were successful. When success/failure of the harvest was predicted for the seasons between 1995 and 2004, a similar trend emerged; 35% of all planting events were successful. Predicted yield (when >0) varied from 20% to 100% of attainable yield, with an average of 67% (Appendix).

We found that 53% of planting events in the first rainfall of the season were successful, followed by 46%, 42% 28%, and 36% in the next four rainfall events, respectively. There were no predicted successful events in the later three rainfall events (Fig. 7). The crop water satisfaction index, however, was highest in the second rainfall and even the 5th rainfall event had as high as 80% crop water satisfaction (Fig. 7). The estimated amount of seed needed to sow on every suitable planting day represented 4.5% of total estimated harvest, and 8.5% of harvest recall figures over the 15 years. Estimated yields from hypothetical hand cultivation were predicted to be half as much as when using labor exchange practices.

When the inter-annual rainfall variability and the variability among households with respect to land, cattle and labor was taken into account, we estimate that an average household of eight members needed approximately 11 ha to produce enough maize as the staple crop to sustain the household for 2 years (Fig. 8).

3.5. Characteristics of the local maize

The maize grown in the region is a short-duration (matures in 100 days), open-pollinated landrace; local people refer to it as 'mavele ya hina' in Shangaan, translated as 'our maize', and differentiate it from maize from other areas, including commercial varieties, commonly called 'apoio' a Portuguese word meaning 'support'. The two most important features that differentiated the local maize from other maize, according to interviews and focus group discussions, were its perceived drought tolerance and post-harvest storage qualities. Granaries are structures with a volume of around 15 m^3 that are elevated approximately 2 m above the ground, with the enclosed area below used as a kitchen. Maize is stored in the granary on the cob and with the husks intact and is constantly exposed to smoke from the kitchen below. Improved varieties, although recognized for their higher yields and improved performance under irrigation or adequate rainfall conditions, were said to suffer more readily from high temperatures, and prone to rotting quickly in the granary because the husks do not close well over the ear in the way that the husks on the local maize do (Fig. S1). Ear characterization of local maize revealed that of 151 ears, 97 (64%) of them were missing an average of 1.5 cm of kernels ($n = 39$) on the top of the ear which is associated with the tightness with which the husks closed around it (P. Fato, personal communication) (Fig. S2).

Different names are given to physical characteristics of the maize ear, particularly with respect to color of the kernels, cob

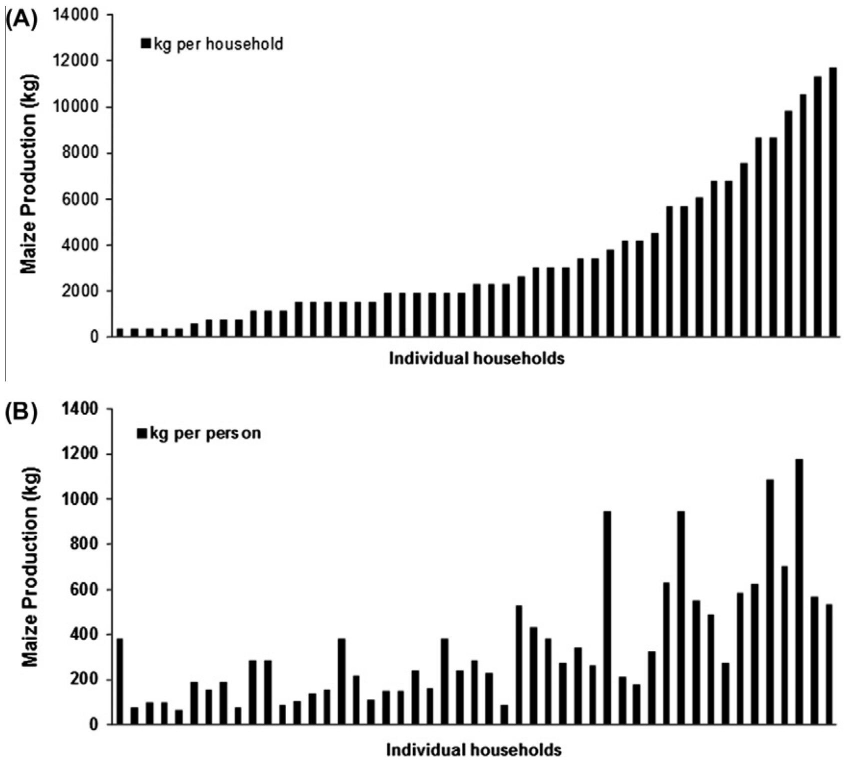

Fig. 5. Variability in harvest expressed as (A) the total production, kg per household, and (B) kg per person for 50 households in the same village in Massingir, Mozambique presented in rank order of production per household.

and husks, but all maize is treated as one single landrace. Seed is not kept apart from the harvested grain but selected from stored grain when needed for planting; women began to separate ears for seed from ears for consumption during the food preparation process when the granary stocks began to run out. The most important trait for seed selection was that seeds were intact, not broken or with holes, indicating that storage capacity was constantly selected for. The stacking of the ears in the granary is an indirect selection practice. Larger ears, well covered by husks, are stacked at the bottom of the granary, and therefore more likely to be used for seed.

3.6. Post-harvest storage

Post-harvest insect pests were named in focus group discussions as the second biggest threat to the maize crop, after crop damage by elephant. It was repeatedly mentioned that post-harvest problems were worse during the study period (2006–2010) than ever before. After 12 months storage, 103 of 189 (56%) ears evaluated from nine granaries showed signs of post-harvest pest damage. The majority of the damaged ears had between 75% and 100% damaged kernels (Fig. S3). There was no significant difference between the damage caused to maize depending on its kernel type (dent or flint) (Table S1). There were large and significant differences found among granaries. Granaries in good condition had significantly less insect damage than those in poor condition (Mann–Whitney, $P < 0.001$), and traditional granaries with thatched roofs had less damage than granaries with corrugated metal sheet roofs, or with no roof at all (Mann–Whitney, $P < 0.001$) (Fig. 9).

4. Discussion

Our results suggest that a combination of many social and technical practices makes it possible to be food self-sufficient in the semi-arid ecosystem of Massingir. These practices could be more regularly taken into account in scenario analyses in two ways. First, the time scale of analysis needs to be adjusted to capture the dynamics of temporal variability (Butt, 2010). In the case of inter-annual variability in cropping patterns, the time scale should be expanded from annual to 4- or 5-year cycles to account for sporadic abundant harvests and storage of food reserves that cover needs for multiple years. Second, location-specific practices, such as multiple planting events and labor-exchange practices need to be accounted for, as these make it possible to produce more than expected under marginal conditions. Additionally, it is important to consider a unit of analysis larger than the household when designing interventions to support agricultural production because of inter-household linkages (Barrett, 2006).

4.1. Time scale of analysis: multiple year cycles of food self-sufficiency

Massingir is in an agroecological zone deemed unsuitable for crop production when analysis is based on individual years; mean annual rainfall is 400 mm and total crop failure is common (Kassam et al., 1982; Westerink, 1995). However, many residents produce sufficient maize in years of good rainfall to last for several years (Figs. 1 and 2). The practice of storing maize over multiple-years was as an important strategy for surviving periods of drought between 1000 and 1600 AD in the southwestern United States (Spielmann et al., 2011). Sorghum and millet, crops that have better storage capacity than maize, used to be stored for multiple years in southern Mozambique, until they almost entirely disappeared in the 1930s (Berg, 1987). Sorghum or millet may also be more robust in the face of drought, but farmers prefer to grow maize because of the elevated labor requirement of these crops, the high market value of maize and taste preferences. We found that maize characteristics indicating good storage capacity, specifically ears with long and tight husks were among the most important preferred traits.

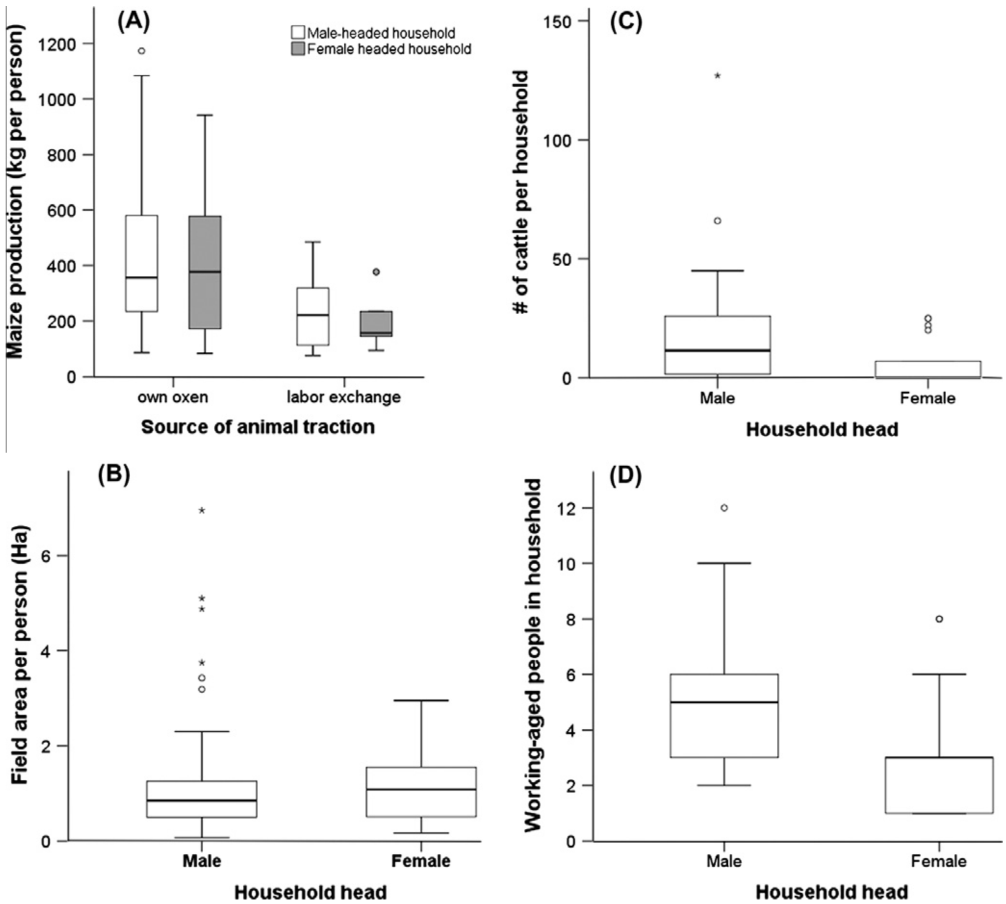

Fig. 6. Differences between male and female-headed households in Massingir, Mozambique in 2009 ($n = 50$) with respect to, (a) source of animal traction for plowing in Massingir, Mozambqiue in 2009 (own oxen: male-headed households, $n = 22$, female-headed households, $n = 7$; labor exchange: male-headed households $n = 8$, female-headed households n=9), (b) total field area per person, (c) number of cattle, and (d) household labor.

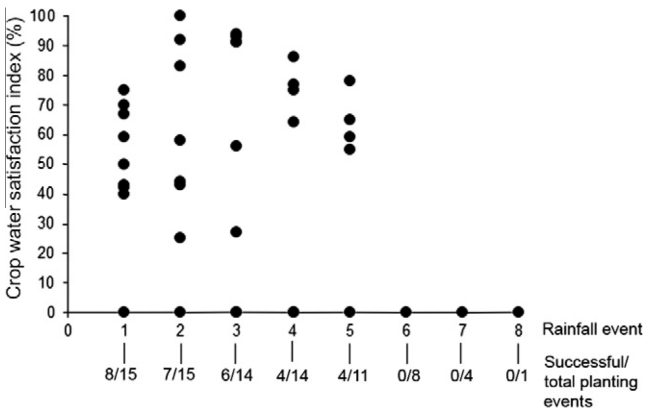

Fig. 7. Crop water satisfaction index (a proxy for % attainable yield) as a function of the rainfall events in 1995–2010.

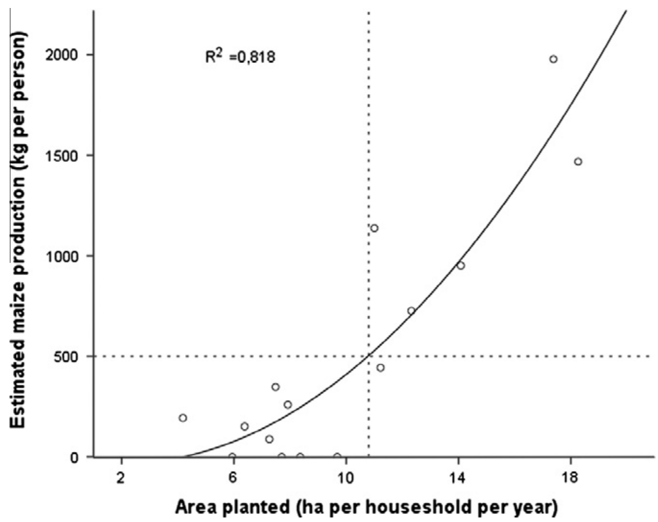

Fig. 8. Average estimated maize production per person over 15 years of variable climatic conditions, and considering heterogeneity of household assets (land, cattle and labor) as a function of area planted per year. Area planted per household per year was calculated for an average household size with 8 members. At least 11 ha are necessary to produce enough maize to sustain the household for 2 years (250 kg per person per year).

Instead of experiencing yearly hunger periods before the subsequent harvest (seasonality) as is common in much of southern Africa and other parts of Mozambique (Hahn et al., 2009; Handa and Mlay, 2006), general trends indicated 'seasonality' cycles of a longer duration. Multiple-year periods of food self-sufficiency were especially evident for households with more cattle and land (Fig. 1a and c); patterns of annual hunger periods could be seen among more vulnerable households in some years (2007–2010) (Fig. 1b and d). Better understanding of these cycles is imperative for designing interventions. People may not need annual assistance to get through 1 year with harvest failure, depending on the previous years' harvest. Conversely, lengthy hunger periods of 2–3 years can have major negative effects on poverty and health.

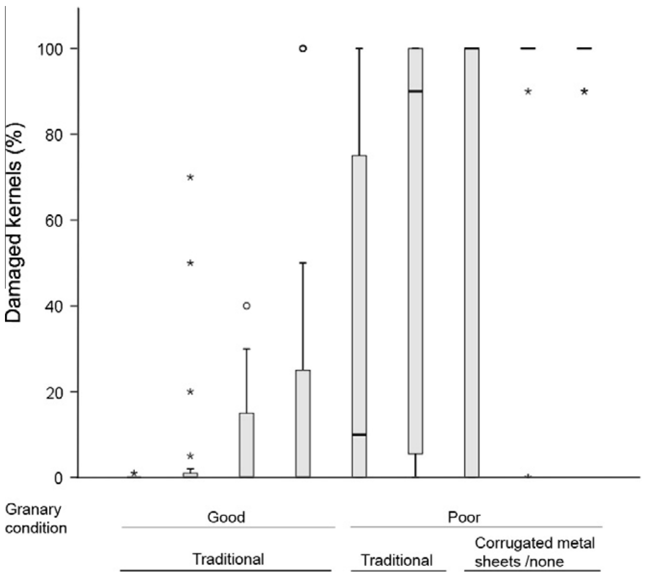

Fig. 9. Maize ear damage from post-harvest insect pests in Massingir, Mozambique in May 2010. Ear damage (%) per granary, presented by condition of the granary (good/poor) and the type of roof (traditional/corrugated metal sheets or none). 189 ears from 9 granaries were sampled. Granaries in good condition had significantly less insect damage than those in poor condition (Mann–Whitney, $P < 0.001$), and traditional granaries with thatched roofs had less damage than granaries with corrugated metal sheet roofs, or with no roof at all (Mann–Whitney, $P < 0.001$).

Households with the means to buy food before their stock in the granary ran out consumed their own maize more slowly. Labor migration and cross-border trade comprised an important source of income for some households, but for others migration was a rite of passage for young men and generated minimal or no remittances, sometimes costing the family money (Norman, 2005). Livestock, as in many places in Africa, is an asset that is sold when in need of cash (Moll, 2005). When asked about sources of income, people responded that they sell livestock (Table 1), but detailed observation and probing questions revealed that livestock was only sold in times of need (Fig. 3b). Sales of livestock result in an undesirable decrease in assets; households that have sufficient money rarely sell livestock (Hoddinott, 2006). The fact that households claimed that they were eating primarily from their own granary did not necessarily imply that they had a diet that was nutritionally balanced.

Primary dependence on livestock would lead to rapid rates of herd depletion. One 50-kg bag of maize flour can feed an average family of eight people for 12 days and, during the study period, the cost fluctuated around 800 Mozambican meticais (between US$25 and 35). A goat sold for 600–900 meticais in Massingir in 2008–2010, equal to or less than the cost of a 50 kg bag of maize meal, meaning that a household would have to sell a goat every 12 days to feed themselves on the basis of goat sales. A head of cattle sold for between 5000 and 15,000 meticais (US$200 and 600) depending on the size of the animal and the market value at the time of sale. When food stocks in the region are depleted, the market becomes flooded with livestock which forces prices down. At the same time, the price of maize meal and rice rises due to shortage in supply. In a best case, the sale of a single head of cattle sold at a top price can provide households with food for 6 months if they do not spend the money on anything else. Interviews indicated that it was rare to sell two or more cattle per year (Fig. 3b). Livestock sales play a role in purchase of food, providing a safety net when the granary grain stocks dwindle, but do not sustain household food security.

4.2. Cropping practices expand production potential

Cropping practices that are risk-taking and risk-spreading, such as planting with each rainfall event make food production possible in this marginal environment. The rainfall distribution is as important for crop production as total annual rainfall. For example, the 2008–2009 cropping season received a total rainfall of 299 mm and more than half of the households interviewed produced enough to sustain the food needs of the household for 1 year (Fig. 5). By contrast, a total rainfall of 342 mm fell in the 2002–2003 season, but it was a year of harvest failure for most households (Fig. 2).

Research suggests that some negative consequences of climate change on agricultural production can be avoided through shifting planting dates (Crespo et al., 2011; Harrison et al., 2011). The effect of dry spells within the season on maize production critically depends on their timing within the crop cycle (Denmead and Shaw, 1960; Doorenbos and Kassam, 1979). By planting each day that germination is likely to be successful, farmers increase the chance that subsequent rainfall events will coincide with critical periods in the growing cycle of the crop to achieve some harvest (Figs. 4 and 7), although yields attained may be small (Barron et al., 2003). Staggering of planting dates has been documented in semi-arid areas of Zimbabwe (Murungweni, 2011), and documented as a strategy in Mexico to avoid pest attacks (Altieri and Trujillo, 1987). The practice of planting repeatedly with every substantial rainfall event, even at the end of the rainy season, is a seemingly illogical practice that demands a large amount of seed (Schouwenaars, 1988). However, our results suggest that even in the 5th rainfall event a crop can receive 80% of its water requirements as indicated by the crop water satisfaction index (Fig. 7). Despite the fact that 65% of planting events were predicted to fail, seed accounted for only 4.5% of total predicted harvest and 8.5% of reported harvest over the long term. In the short term, particularly after years of total harvest failure when food was scarce, sowing repeatedly on large areas of land can require the equivalent in seed of one year's food supply for one person (250 kg s). However, households still chose to allocate this seed to planting because of what they stood to gain in harvest.

Planting fields distributed across the landscape has been documented as a risk-spreading practice primarily in regions with many agro-ecological niches (MacDonald, 1998). In Massingir, this practice carried out not among different agroecosystems, but because of the patchy nature of rainfall in the region, also documented in Mexico (Kirkby, 1974; Thompson and Wilson, 1994). Observations and interviews revealed that rainfall events may provide adequate rain for planting in one field while neighboring fields remained dry. Likewise, a field that has soils with better water holding capacity or that receives run-on water is likely to produce more in a year of low rainfall, whereas in very wet years, well-drained fields would produce better yields. Therefore, spreading the area planted across fields with diverse conditions increases the likelihood that some of the crop will be planted in a location favorable for a good harvest.

Given the rainfall and production variability between 1995 and 2010, we estimate that at least 11 ha of land per household is needed to produce enough maize to sustain a family of eight (median household size) for 2 years (Fig. 8). In similar cropping systems, such as the Sahel and semi-arid regions of South Africa, extensive farming has been documented as a strategy to reduce risk of crop failure and to mitigate risks of climate variability (De Rouw, 2004; Mortimore and Adams, 2001; Thomas et al., 2007).

Another risk-spreading strategy, albeit one that appeared to arise by default and was not explicitly described as a strategy by the farmers, is the use of a diverse population of open-pollinated maize instead of maintaining separate landraces. In many cropping systems farmers maintain multiple distinct varieties or landraces, each better adapted to certain conditions (Bellon, 1991). However in Massingir only one landrace was recognized. Because seed is selected just before planting, major selection pressures on the maize population are the long-term cropping environment (whatever survives drought in dry years or yields well in wetter years) and storage conditions (whatever survives post-harvest damage) (Moreno et al., 2006). Repeated selection for long-term storage has likely resulted in maize that can be saved for multiple years. Similarly, by maintaining a diverse landrace, rather than multiple separate landraces, farmers may reduce the risk of crop failure. Asynchronous development may spread flowering over a longer period as documented in pearl millet varieties in the Sahel (De Rouw, 2004), but further research is needed to verify this.

4.3. Social arrangements: reconsidering the household as the unit of analysis

The amount of grain harvested varied considerably among households in the same season (Fig. 5). Understanding the causes of this variability helps to identify which households have the capacity to be food self-sufficient and under which conditions. While household assets, such as land and cattle ownership are correlated with production, this is partly because these households can employ more risk- spreading and risk-taking practices in a timely fashion.

Households with more land can plant larger areas, and households with cattle can quickly plant as soon as it rains, taking advantage of the maximum amount of rainfall available. The first and second planting events each season resulted in the highest yields (Fig. 7), potentially because of a combination of higher rainfall per crop growing cycle and a nitrogen flush that accompanies the first rains in savanna environments (Birch, 1958). A household that has first to work on someone else's field before planting their own miss out on important soil water from the first rainfall of the planting event.

The amount of labor per household was not a significant factor for predicting maize yield when the number of oxen was included in a regression model. However, when a household had no cattle, the number of people in the household became important for production. Without cattle, production capacity depends on the labor available to engage in exchange practices and to carry out necessary cropping activities. Conversely, households with elevated numbers of cattle can lend out their oxen in exchange for labor from other households and therefore their own household labor supply is less important. Household size is correlated with maize production, but the household size is not a fixed unit. It may in fact be a function of food insecurity – a household may stay together when there is enough food to feed everyone, and decrease in size when there is not.

Because of the extensive nature of the cropping system, cultivation with a hand hoe is rare. Although households that exchange labor for the use of oxen cannot plant as much land or plant as quickly as households that have their own oxen, labor exchange allows households with no oxen to produce twice as much as they could if they had to plant by hand. Labor exchange is in itself an important adaptive strategy (Osbahr et al., 2008), but studies that identify vulnerable groups often focus on the household as a unit. Our results concerning labor exchange suggest that it is necessary to situate and assess the household production capacity within the social network of the village.

4.4. Beyond production

While farmers spread and take risks to produce as much as they can, a new threat has emerged that threatens their multiple-year cycles of food self-sufficiency. The larger grain borer (LGB) (*Prostephanus truncates*), the most destructive pest of all stored grains (Boxall, 2002), was recently reported in the area. First found in Mozambique in the province of Tete in 1999, it was documented in 2001 in Chiucalacuala district, Gaza Province (Cugala et al., 2007). A survey in 2005 found LGB in a neighboring district but not in the district of Massingir (Sitoe, 2006). Five years later we found LGB in granaries in Massingir district. This represents a major threat to food security in the region where people depend on saving their maize for between 24 and 40 months after a good harvest.

A more common post-harvest pest, the maize weevil (*Sitophilus zeamais*) causes 6–12% weight loss in maize, whereas LGB can cause 30% weight loss (Hodges, 1986; Makundi et al., 2010). LGB causes major damage in granaries after 6 months of storage and losses increase with the length of storage (Boxall, 2002). Kernel hardness had no effect on LGB damage (Meikle et al., 1998) but husk cover on the ear delayed LGB infestation in the first 6 months (Boxall, 2002; Meikle et al., 1998). The distribution of damage caused by the LGB is sporadic, unpredictable and highly variable from one granary to another (Boxall, 2002). We observed that well-constructed and maintained traditional granaries with grass-thatch roofs had less post-harvest pest infestation (Fig. 9).

Despite major damage, insect-infested maize was consumed regularly. This may have health implications because Massingir is an area where maize is prone to contamination by aflatoxin, a potent carcinogen produced in stored grain by the fungus *Aspergillus flavus.* Field contamination of maize is associated with drought-stress and high temperatures (Klich, 2007; Munkvold, 2003). Physical damage to the kernel caused by insect pests is one factor associated with elevated aflatoxin contamination in stored maize (Munkvold, 2003).

LGB thrives in an environment of between 27 and 32 °C with a relative humidity of 70–80% (Bell and Watters, 1982; Shires, 1980). Currently Massingir has mean daily temperatures between 27 and 32 °C during only the hottest 2 months of the year, and relative humidity of between 63% and 71% during the whole year. Climate change predictions for southern Mozambique range from an increase of 1.8 to 3 °C by 2050 (INGC, 2009; MICOA, 2003). This rise in temperature would mean that Massingir would have temperatures between 27 and 32 °C from 5 to 7 months of the year, providing the LBG three times longer a period with a suitable environment for their growth and reproduction. Although dispersal of LBG in the long term is not a function of climate alone, several studies have shown that it is a significant factor in explaining its relative abundance (Hodges et al., 2003; Nansen et al., 2001). This indicates that the threat of LBG to the food security in this and similar regions may worsen with climate change. For the residents of the Massingir region to remain food self-secure, they need to adapt to the new risks posed by the LGB.

5. Conclusions

Semi-arid areas are expected to expand because of climate change, and rain-fed agriculture is likely to remain an important source of food for rural residents of SSA (Cooper et al., 2008). Therefore, we need to learn from insights available from actual cropping systems in semi-arid agroecosystems to guide efforts to mitigate negative effects of climate change. We found that some residents of Massingir, a region considered unsuitable for agriculture, could attain food self-sufficiency of the staple crop (maize) for multiple years by maximizing production and storing grain after favorable rainfall events. This finding implies that our understanding of seasonality and of patterns of hunger periods needs to be extended beyond annual cycles to consider 4–5-year cycles in areas with erratic rainfall. This finding also suggests that in rural areas where extensive land is available, instead of gearing climate change policies and agricultural development interventions exclusively towards market integration, or away from dependency on agriculture, there may be potential to foster food self-sufficiency. For this approach to remain feasible, however, the increasing problems of post-harvest storage need to be addressed (Nyagwaya et al., 2010). Along with more immediate pest control measures, long husks, a proxy for improved post-harvest storage, could be tested as a selection criterion in breeding programs that focus on development of drought-resistant varieties.

Understanding current practices effective in maximizing production under erratic rainfall in marginal environments is crucial for expanding existing adaptive capacity and to identify new approaches that reduce vulnerability to social and environmental change. Although the existing cropping practices described here, for example, planting with every major rainfall event but only harvesting from 35% of the planting events, seem neither economically nor agronomically logical at first glance, they are the key to production of sufficient maize under these marginal conditions. We found that the disadvantaged farming household produces more than would be expected by employing collaborative adaptive practices, but they remain disadvantaged compared to those with more arable land, labor and oxen for plowing. Focusing on how these households could further increase production based on current practices is an example of adaptive capacities that could be expanded.

Revealing heterogeneity among households helps us to understand the many varied responses to agroecological challenges (Giller et al., 2011) and paints a more accurate picture of food security in the face of climate change. We recognize, however, that there is an inherent trade-off between gathering data at the appropriate timescale and accounting for heterogeneity (Herrero et al., 2007). Accurate, detailed household data over a period of multiple years is time consuming to collect and limits the geographical scope of the study. However, the in-depth nature of the study revealed insights unavailable through a more superficial analysis. The agricultural system described in this study can be found across the southeastern part of Mozambique – it has not been documented in the neighboring countries just across the border in South Africa or Zimbabwe – but the findings may be relevant to other locations and agricultural systems. Our results suggest that it may be beneficial for assessments and policies aimed at reducing vulnerability to climate change to look beyond seasonal agricultural production to include food self-sufficiency, improved post-harvest storage and take a wider perspective than the household as the unit of analysis. Re-examining the assumptions on which we base our research may be the most hopeful way to develop adaptive practices together with people living in these challenging environments.

Acknowledgements

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agsy.2013.03.002.

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