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ORIGINAL PAPER

# Is dry soil planting an adaptation strategy for maize cultivation in semi-arid Tanzania?

**Marcos A. Lana**[1,2] · **Ana Carolina F. Vasconcelos**[3] · **Christoph Gornott**[4] ·
**Angela Schaffert**[5] · **Michelle Bonatti**[2] · **Johanna Volk**[6] · **Frieder Graef**[2] ·
**Kurt Christian Kersebaum**[2] · **Stefan Sieber**[2]

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**Abstract** Agriculture has the greatest potential to lift the African continent out of poverty and alleviate hunger. Among the countries in sub-Saharan Africa, Tanzania has an abundance of natural resources and major agricultural potential. However, one of the most important constraints facing Tanzania's agricultural sector is the dependence on unreliable and irregular weather, including rainfall. A strategy to cope with climate uncertainty in semi-arid regions is to proceed with the sowing of the crop before the onset of the rainy season. The advantage is that when the rains start, seeds are already in the soil and can begin immediately the process of germination. The objective of this paper was to assess the effectiveness of dry-soil planting for maize as an adaptation strategy in the context of a changing climate in Dodoma, a semi-arid region in Tanzania. For this assessment, the DSSAT crop model was used in combination with climate scenarios based on representative concentration pathways. A probability of crop failure of more than 80% can be expected when sowing occurs during the planting window (of 21 days) starting on 1st November. The next planting window we assessed, starting on 23rd November (which was still before the onset of rain), presented significantly lower probabilities of crop failure, indicating that sowing before the onset of the rainy season is a suitable adaptation strategy. Results also indicated that, despite not reaching the highest maize grain yields, fields prepared for dry-soil planting still produced adequate yields. The cultivation of several fields using the dry planting method is a strategy farmers can use to cope with low rainfall conditions, since it increases the chances of harvesting at least some of the cultivated fields. We conclude that dry-soil planting is a feasible and valid technique, even in scenarios of climate change, in order to provide acceptable maize yields in semi-arid Tanzania.

**Keywords** DSSAT · Sub-Saharan region · Maize yield · Seed germination · Sowing date · Food security

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✉ Marcos A. Lana
marcos.lana@slu.se; lana@zalf.de

Ana Carolina F. Vasconcelos
ana3carol@yahoo.com.br

Christoph Gornott
gornott@pik-potsdam.de

Angela Schaffert
a.schaffert@uni-hohenheim.de

Michelle Bonatti
michebonatti@gmail.com

Johanna Volk
jo1994hannav@zedat.fu-berlin.de

Frieder Graef
graef@zalf.de

Kurt Christian Kersebaum
kersebaum@zalf.de

Stefan Sieber
stefan.sieber@zalf.de

[1] Swedish University of Agricultural Sciences (SLU), Ulls väg 16, 75007 Uppsala, Sweden

[2] Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany

[3] Federal University of Campina Grande, Campina Grande, Brazil

[4] Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

[5] Hohenheim University, Hohenheim, Germany

[6] Freie Universität Berlin, Berlin, Germany

## 1 Introduction

Agriculture has the greatest potential to lift Africa out of poverty and to alleviate hunger. Given the nature of African agriculture, where a large proportion of farmers are smallholders and subsistence-based, it is essential to invest in and develop accessibility to quality inputs, markets for produce, good soils and soil management techniques, innovative finance tools and other resources that are needed for sustained agricultural production (Graef et al. 2017).

The agricultural sector in Tanzania is hampered by low productivity, poor infrastructure, and a lack of technology, being dominated by smallholder farmers cultivating average farm sizes of between 0.9 ha and 3.0 ha. About 70% of Tanzania's crop area is cultivated by hand hoe, 20% by ox plough and 10% by tractor, and almost all is rain fed. The production of food crops dominates the agricultural economy (KPMG 2015).

This background was confirmed in an extensive survey carried out in Tanzania by the Trans-SEC Project (Innovating Strategies to Safeguard Food Security using Technology and Knowledge Transfer: A People-Centred Approach) (Below et al. 2015; Graef et al. 2014, 2017; Löhr et al. 2016; Mutabazi et al. 2015). The major constraints facing the Tanzanian agricultural sector are the reduction in the available labor force, low land productivity due to the application of poor technologies, and dependence on unreliable and irregular weather (Mmbaga and Lyamchai 2002). Both crops and livestock are adversely affected by periodic droughts. Irrigation holds the key to stabilizing agricultural production in Tanzania, to improving food security, increasing the productivity and incomes of farmers, and producing higher valued crops such as vegetables and flowers (Evans et al. 2012). However, some other barriers to improve local food production and security are not directly tied to a lack of irrigation, but are related to the availability of farm credit, access to seeds and fertilizers, quality of seeds, farm implements and market reliability (Mdemu et al. 2017).

One of the major uncertainties with the future trajectory of agricultural productivity in Africa is the likely impact of a changing climate (IPCC et al. 2007). Several studies (Kurukulasuriya et al. 2006; Lesch et al. 2005; Nelson et al. 2010; Seo et al. 2009; Thornton et al. 2006) provide strong evidence that predicted changes in temperature and rainfall caused by global warming may impose additional serious constraints on agriculture in Africa (Benin et al. 2016). Climate change will have a direct impact on the availability of water for irrigated crops. In addition to changes with precipitation, climate-change-induced higher temperatures increase the water requirements of crops (Nelson et al. 2009).

Climate change is likely to make matters worse with further increases in rainfall variability being predicted (Agrawala et al. 2003; Schlenker and Lobell 2010). Climate change is also expected to alter pest and disease outbreaks, increase the frequency and severity of droughts and floods, and increase the likelihood of poor yields, crop failure and livestock mortality (Harvey et al. 2014). The ability of agricultural communities and other agricultural stakeholders in sub-Saharan Africa to cope with the constraints and opportunities of current climate variability must first be enhanced in order to be able to adapt to climate change and the predicted future increase in climatic variability. Tools and approaches are now available that allow for a better understanding, characterization and mapping of the agricultural implications of climate variability and the development of climate risk management strategies specifically tailored to the needs of stakeholders (Cooper et al. 2008).

Specific concerns about climate variability include variability in the onset and cessation of rainfall, rainfall amount, and frequency and duration of periods of soil water deficits. This variability greatly affects crop yield in rainfed systems, and is a major disincentive to the adoption of yield-improving practices, which then challenges researchers to develop adoptable practices and varieties. Therefore, knowledge of the seasonal climate variability and its associated risks is important to the improvement of crop management (Liben et al. 2015).

The shifting of planting date based on cultivar properties could prevent critical stages of crop development from coinciding with periods of extreme high temperature and water deficit, consequently helping to reduce yield loss from climate change (Tao and Zhang 2010). Generally, crop yields may suffer substantially with either a late onset or early cessation of the growing season. Shifting of planting date ensures that the seed, once in the soil, has sufficient moisture to trigger the germination process and further crop development. However, in order to be successful and effective this strategy needs the farmers to be available all the time before the expected onset of rainfall (Mugalavai et al. 2008).

Under the conditions observed in rural communities of Tanzania, especially in the semi-arid regions, farmers usually farm several field areas, sometimes many kilometers apart; the principle behind this is to take advantage of better soils and reduce the risk of total crop failure associated with the small-scale spatial distribution of precipitation. To be able to use fields in different areas, waiting for the onset of rainfall is not an adequate strategy. Therefore, farmers often practice so-called 'dry soil planting', when they seed the crop into dry soil a few days before the expected start of the rainy season (KPMG 2015). The advantage of this practice is that when the rainfall starts seeds are already in the soil and can immediately start to germinate. This is especially important in regions where the rainy season is not long enough to provide adequate moisture during the whole cropping cycle.

As an example, according to Liwenga (2008), in Mvumi, Tanzania, planting activities are normally carried out some two to three weeks before the expected time for the onset of the rains; in that study villagers explained that early planting is done prior to the onset of the rains so that crops could benefit from all of the moisture provided during the short rainy season. The same author, citing Holtland (1994), explains that seedlings make optimal use of the natural nitrogen (N)-flush that occurs after the first rain-showers. As N availability is, after water, the greatest constraint to cultivation in the Dodoma region, the difference between dry planting and planting a week after the onset of the rains can be considerable.

Nevertheless, despite the advantage of a faster start, planting into dry soil also poses the risk that germination is initiated by a precipitation event that is not the start of a rainy season. In this situation, the crop can start to germinate but then die during subsequent drying of the soil and seedling. In other situations there is also a risk that if the seed stays for a long period in the soil without sufficient moisture to trigger germination, high temperatures can cause loss of vigor, or it can be damaged or eaten by insects or other animals (Benin et al. 2016; Cooper et al. 2008).

In addition to planting dry seeds, seeds can be ‘primed’ with water, an enhancement method that might improve seed performance under stress conditions such as drought or when freshly harvested or aged seeds are used which might fail to germinate (Lutts et al. 2016). Harris et al. (1999) demonstrated how simple soaking seeds in water before sowing can increase the speed of germination and emergence, leading to better crop stands, and allow seedlings to grow much more vigorously. Some farmers in Zimbabwe already have experience of soaking maize and sorghum seeds in water before sowing, in an attempt to improve establishment, but the practice appears to be neither widespread nor regularly followed, probably because farmers need the opportunity to experiment for themselves; to do their own research and development (Harris et al. 2001).

Maize is the staple food for the majority of Tanzanians, providing about 60% of Tanzanian’s dietary calories and 50% of the protein. With about five million ha, Tanzania has the largest planted area of maize in all Southern and East Africa. Maize production has significantly increased over the past 10 years, largely through expansion of area planted rather than increased grain yields. Over the past 50 years, maize production has kept pace with the increase in population (FAOSTAT 2016).

Most maize (80%) is produced by small-scale farmers and is grown both for subsistence and as a cash crop. Between 65% and 80% of all maize is consumed within the producing households: only 20% to 35% enters commercial channels. Maize comprises an average of 16% of national household food expenditures, though there are big regional variations. The choice to grow maize, even in areas of insufficient rainfall, is driven by a strong dietary preference for maize over the more drought-adapted traditional cereals such as sorghum and millets. Efforts are being made to develop more drought tolerant cultivars of maize available to Tanzanian farmers and to increase irrigation (Doebley et al. 2010).

Most maize production in Tanzania is under low-input rainfed conditions. Simple hand hoes, farm-recycled seed, little use of synthetic fertilizers or agrochemicals and minimal weeding are the usual technologies and inputs employed. Maize crops frequently fail because of insufficient soil moisture. Irrigation is not usually available or selected as an option for maize, and on-farm water harvesting techniques are not yet well known or used (Wilson and Lewis 2015).

Drought is a major threat to maize in many parts of Tanzania. Maize production can be a risky and unreliable business because of erratic rainfall and the high susceptibility of maize to drought, while the performance of local drought-tolerant cultivars is poor (Mmbaga and Lyamchai 2002). Erratic rainfall is making maize farmers in Tanzania vulnerable to low yields, which translates to food insecurity. Tanzania suffered the effects of a prolonged drought in the recent years (Doebley et al. 2010). These observations agree with the information gathered from farmers in the region during a comprehensive survey about many aspects of food security in the region (see Trans-SEC: Innovating Strategies to Safeguard Food Security using Technology and Knowledge Transfer: A People-Centred Approach - www.trans-sec.org).

In order to assess and understand the effects of climate change, crop models can be a useful tool to assess the influence of climatic and other environmental or management factors on crop development and yield (Reidsma et al. 2010). The Decision Support System for Agrotechnology Transfer – DSSAT v. 4.5 contains the Crop System Model CERES – Maize model (Jones et al. 2003) and can help to a) determine best planting dates, b) define fertilizer timing and amounts, c) support precision agriculture and d) detect/investigate potential impacts of climate change on agriculture. In the embedded CERES – Maize model, the development and growth of the crop is simulated on a daily basis from planting until physiological maturity. The model calculations are based on environmental and physiological processes that control the phenology and dry matter accumulation in different organs of the plant. The DSSAT also has other embedded models that can simulate the flow of nutrients and water balance in the soil. Despite the complex array of processes simulated by the crop model, some important processes such as effects of pests and diseases are still not well depicted (Donatelli et al. 2017), as are the impact of extreme events such as floods and hail (Alexandrov and Hoogenboom 2000) or high temperatures (above 35 °C) during anthesis, which reduces pollen viability (Porter and Semenov 2005).

Considering that smallholder farmers in Tanzania cultivate several fields at the same time, of which only some may be under a dry-soil planting management system, it can be expected that dry-soil planting is and will still be part of the strategies to reduce the risk of crop losses and help ensure food security in the context of a changing climate. Based on that, the objective of this paper was to assess the effectiveness of dry-soil maize planting as an adaptation strategy in a semi-arid region of Tanzania. This assessment was done using a calibrated CERES – Maize crop model and tested different climate scenarios for the 2020–2059 and 2060–2099 periods.

## 2 Methodology

### 2.1 Location

Our assessment was done for the Dodoma region of Tanzania, as part of the activities of the Trans-SEC Project (see Graef et al. 2017). The study region lies between latitudes 5°50′S to 6°10′S and between longitudes 35°40′E to 36°05′E, at an elevation of 1020 m above sea level. The dominant soil of the target region is defined as a ferralic Cambisol (FAO), which is low in fertility and seasonally waterlogged or flooded (Msongaleli et al. 2015). Detailed information about the soil used in this assessment is presented in Table 1. The area is characterized by low and erratic rainfall with a unimodal rainfall regime. The long-term mean annual rainfall is about 511 mm with average temperatures of 22.7 °C (Fig. 1). The onset of rainfall usually occurs in early-mid December, and the rainy season extends until April. As the rainfall pattern in the study region is variable within the rainy season, maize cultivation is restricted to areas where water availability is higher and the soil has a higher water holding capacity.

### 2.2 Climate scenarios

Data for future climate scenarios are available from the Inter-Sectoral Impact Model Intercomparison Project – ISI-MIP (Warszawski et al. 2014) as a bias-corrected dataset with daily values for temperature (Tmax, Tavg, Tmin), precipitation, relative humidity, and solar radiation. These data are well accepted and also used for the Agricultural Model Intercomparison and Improvement Project – AgMIP (Rosenzweig et al. 2013). The selected Representative Concentration Pathways (RCPs) for our study were the high-emission scenario RCP8.5, the medium-low-emission scenario RCP4.5 and the low-emission scenario RCP2.6 scenario (Moss et al. 2010). For each RCP scenario, five different projections (model-derived estimates of future climate) were used, as follows: GFDL-ESM2M (Dunne et al. 2013), HadGEM2-ES (Johns et al. 2006), IPSL-CM5A-LR (Hourdin et al. 2013), MIROC-ESM.CHEM (Watanabe et al. 2011), and NorESM1-M (Iversen et al. 2012), totaling 15 different projections of three RCPs. All the models have the added capability of explicitly representing biogeochemical processes that interact with physical-climate processes. To capture the fertilization effect of increasing levels of atmospheric $CO_2$ (Long et al. 2006; Tubiello et al. 2007), the concentration of $CO_2$ was adjusted yearly according to the respective RCP (Meinshausen et al. 2011).

### 2.3 Crop modeling

To generate projections of maize yield and assess the impact of weather scenarios and dry-seed planting management, a crop simulation model was employed. The crop modeling process was done using DSSAT (Jones et al. 2003), an established crop model already used in several impact assessment studies (Rivington and Koo 2011).

The maize cultivar used in this study was a locally adapted, open pollinated cultivar called Situka, with a yield potential at around 4 t $ha^{-1}$ in Dodoma (according to reports from local technicians), and commonly cultivated by local farmers because of its early maturity and tolerance to low levels of soil nitrogen (N), a typical condition of the study area (Msongaleli et al. 2015). This cultivar was already calibrated and validated for DSSAT (Mourice et al. 2014a, b) for Morogoro, situated 250 km east from Dodoma, where it can reach yields of 6.6 t $ha^{-1}$. However, for this study, a further validation step was done using three years of field data including soil, weather, agronomic management and yield (Kimaro et al. 2008, 2009)

**Table 1** Soil profile parameters of the study region in Dodoma, Tanzania, indicating physical and chemical parameters for different soil depths

| Layer depth cm | Clay % | Silt % | Organic carbon % | pH in water | Cation exchange capacity cmol/kg | Total nitrogen % | Lower limit (LL) $cm_3/cm_3$ | Drained upper (DUL) $cm_3/cm_3$ | Saturation (SAT) $cm_3/cm_3$ |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 19 | 5 | 0.41 | 4.8 | 6 | 0.07 | 0.122 | 0.188 | 0.375 |
| 30 | 20 | 4 | 0.31 | 4.6 | 8.2 | 0.06 | 0.121 | 0.181 | 0.366 |
| 45 | 23 | 4 | 0.23 | 4.5 | 9.2 | 0.12 | 0.145 | 0.206 | 0.366 |
| 60 | 25 | 5 | 0.14 | 4.5 | 10.2 | 0.05 | 0.145 | 0.205 | 0.361 |
| 75 | 34 | 2 | 0.14 | 4.6 | 10 | 0.05 | 0.190 | 0.249 | 0.364 |
| 105 | 30 | 4 | 0.06 | 4.6 | 6 | 0.04 | 0.166 | 0.227 | 0367 |

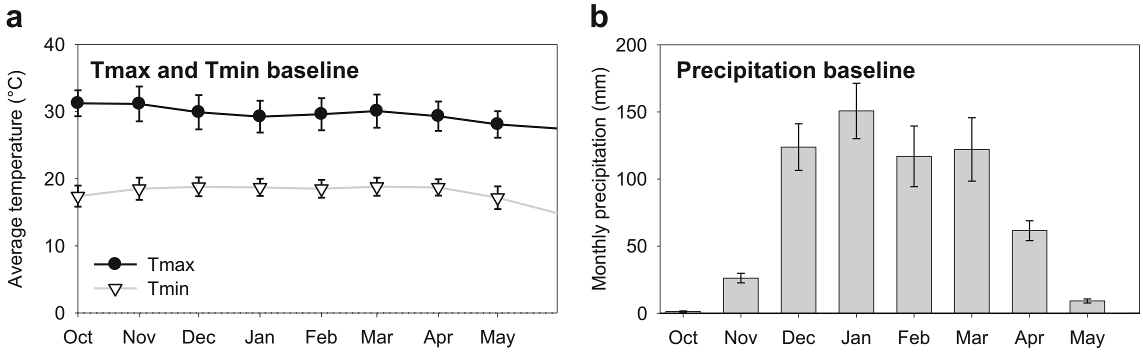

**Fig. 1** Averages of (**a**) maximal and minimal monthly temperatures (°C) and (**b**) monthly precipitation (mm) for the study site in Dodoma, Tanzania, during the crop season (data refer to the 2000–2015 period). Bars indicate the monthly standard deviation of each parameter

from research experiments conducted in nearby villages to confirm the ability of the model to simulate past observations in the study region. Difference-based indices such as mean bias error (MBE) (Addiscott and Whitmore 1987), mean percentage error (MPE), root mean squared error (RMSE) (Fox 1981) and relative root mean squared error (RRMSE) (Jørgensen et al. 1986) were used to evaluate the simulation outputs. The final maize plant population density was defined at 33000 plants per ha, planted at 7 cm depth in rows with 75 cm spacing between rows. This low plant population density, the space between rows and planting depth represent the common practices in the region. Fertilizer use was set to 2000 kg ha$^{-1}$ of dry cattle manure, equivalent to 40 kg ha$^{-1}$ N, to be applied on the day of planting. No irrigation was applied. DSSAT was instructed to start the simulations on 1 January each year to provide a more realistic soil water balance at sowing. For planting dates taking place after 1 January, the simulation started on 1 January of the previous year. Harvest was set to take place two weeks after physiological maturity, as calculated by the model. The format of climate scenario files was adjusted for DSSAT structure using the Weatherman software (Wilkens et al. 2004). Simulations were run for each projection and RCP. For the analysis of results, yields generated with different projections were merged in ensembles (according RCP) in order to provide more robust information (Randall and Wood 2007).

### 2.4 Adaptation strategies

Initially, in order to establish a yield baseline, simulations using all the RCPs were run for the 2000–2015 period using the different planting windows (described in the next paragraph), starting on 1st of November and at every 21 days, until 1st of February, totaling seven planting windows. The objective was to verify if the simulations could mimic the best planting window (mid-December) and crop management as informed by the local farmers and technicians involved in the Trans-SEC project. Yields from the same planting window were averaged to identify the one with the highest yields (best planting date). Once the best planting window was defined for the baseline period, the next step was to run simulations using this planting window for the 2020–2059 and the 2060–2099 periods.

In order to mimic the actual practice in the region of dry soil planting (that means that farmers plant the seeds into dry soil and wait for rainfall onset within 21 days), five planting windows (each of 21 days) were defined, starting on 1 November. The assumptions were that 1) in the dry soil planting systems the seed would remain viable for 21 days and initiate the germination process only if the soil moisture of the top 20 cm reached at least 30% of the soil field capacity, and that 2) based on soil texture and soil bulk density the soil module embedded in the crop model was able to correctly simulate the soil moisture. Although maize seed can absorb moisture from the soil even when soil moisture conditions are far below permanent wilting point (Muthukuda Arachchi et al. 1999), the minimum external water potential permitting maize germination observed by Hunter and Erickson (1952) was shown to be −1.25 MPa. The same authors reported that maize seed started to germinate only when seed moisture exceeded the critical value of 30.5% of field capacity. If during the planting window the critical soil moisture was not reached, it is assumed that the seeds wereno longer in a condition to germinate, and the yield was set to zero. If germination starts, but a dry spell kills the seedling (crop abortion) or the crop produces less than 400 kg ha$^{-1}$ of grain, then the crop season was considered lost (crop failure).

## 3 Results

### 3.1 Model and cultivar validation

As the crop model and the Situka cultivar were already validated for a different region of Tanzania (Mourice et al. 2014a, b), but not for a nearby location, a second validation was considered necessary. Simulations using the same conditions (real data for weather, soil, agronomic management) of the field experiments done by Kimaro et al. (2008, 2009) including a nearby region, were done. The results of the validation were satisfactory, indicating that the model could mimic maize grain yields from field observations of three available crop seasons (2004–2006), as presented in Table 2. As the MBE term describes the direction of the error bias, the positive value of 160 kg ha$^{-1}$ indicates that the predictions were overestimated (in absolute values) compared to the observations. If all simulated and observed values are the same, then MBE, MPE, RMSE and RRMSE should be equal to zero. Overall, the results certified that the model could adequately mimic field observations for maize yield. Nevertheless, it is important to emphasize that the experiments used to generate these observations were village-level research experiments, and not data gathered from maize crops on smallholder farm fields, where yields are probably often lower. Data related to phenology and above ground biomass were not available for comparison in this exercise.

### 3.2 Definition of best actual planting dates

Simulations run for the 2000–2015 period using the data for the RCPs identified the planting windows beginning on the dates 12 December and 6 January as the ones with the highest grain yields (Fig. 2). This coincided with the onset of the rainy season as reported by the local farmers from the study sites (Fig. 1).

### 3.3 Climate change scenarios

For Tanzania, and in particular for the Dodoma region, the RCP's showed slight changes in the precipitation amount during the crop season (Fig. 3). No significant shift in the onset of the rainy season was identified for the study region. For the 2020–2059 period, the scenarios indicated a stability or reduction in accumulated precipitation until February–March (using the 2000–2015 period as baseline). For the rest of the crop season, the RCPs tended to deviate in terms of accumulated precipitation. For the second period (2060–2099), the models projected a slight reduction in accumulated rainfall at the beginning of the cropping season, with later increments in precipitation in the 4.5 and 8.5 RCPs. In contrast to projections for other regions of the world, the precipitation pattern in Tanzania should not change its timing, especially for the first period (2020–2059). In terms of the amount of rainfall, the 4.5 and 8.5 RCPs indicated an increase in precipitation volume for the later period (2060–2099), when compared to the baseline (Fig. 3b), while the RCP 2.6 indicated a reduction in accumulated precipitation.

For air temperature (Fig. 4), all RCP's indicated an increment for Tmax and Tmin. For the first time slice, the three RCPs showed relatively similar increments in both Tmax and Tmin. For the 2060–2099 period, there was a clear distinction between the different RCPs, with the highest increase observed for the RCP 8.5, followed by the RCP 4.5 and finally the RCP 2.6.

**Table 2** Results of the validation process for the DSSAT crop simulation model using difference-based indices comparing simulated and field observations of grain yields from maize cv. Situka in three different seasons (2004–2006) in Tanzania. MBE: mean bias error; MPE: mean percentage error; RMSE: root mean squared error; RRMSE: relative root mean squared error

| Year | Yield (Kg.ha$^{-1}$) | | MBE | MPE | RMSE | RRMSE |
|---|---|---|---|---|---|---|
| | Observed | Simulated | Kg.ha$^{-1}$ | % | Kg.ha$^{-1}$ | % |
| 2004 | 2504 | 2491 | 158 | 8 | 204 | 9.7 |
| 2005 | 1900 | 2093 | | | | |
| 2006 | 1901 | 2196 | | | | |

*MBE*, Mean Bias Error; *MPE*, Mean percentage error; *RMSE*, Root Mean Squared Error; *RRMSE*, Relative Root Mean Squared Error

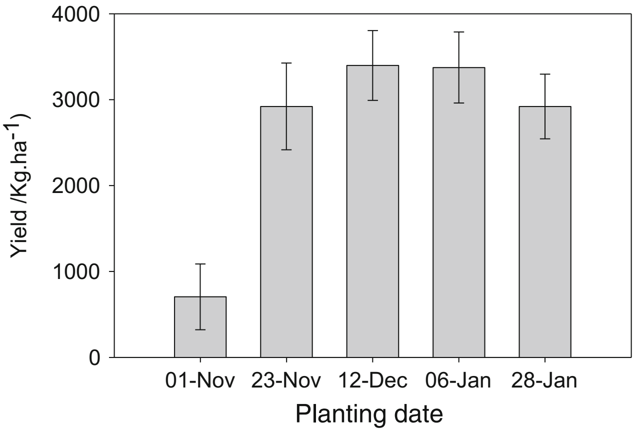

**Fig. 2** Assessment of best maize planting dates according to grain yield using the Ceres maize model for the 2000–2015 period (referred to as baseline) in the study site in Dodoma, Tanzania. Bars represent the standard deviation of yield

### 3.4 Impact assessment with the use of dry soil planting

When using dry-soil planting as a strategy to make possible the cultivation of several different fields per farm, we assessed that the very early dry soil planting window (starting date 1 November) for both time periods (2020–2059 and 2060–2099) presented more than an 80% probability of failure for all RCPs, while the next planting windows reduced the probability of failure to less than 20% (Fig. 5a and b). In the best situation, when planting occurs near mid-December, the chances of losses from crop failure are very low. The dry soil planting practice in the selected region can only be said to occur when done before mid-December. After this planting window, with the very likely onset of the rainy season, sowing will take place into already wet soil.

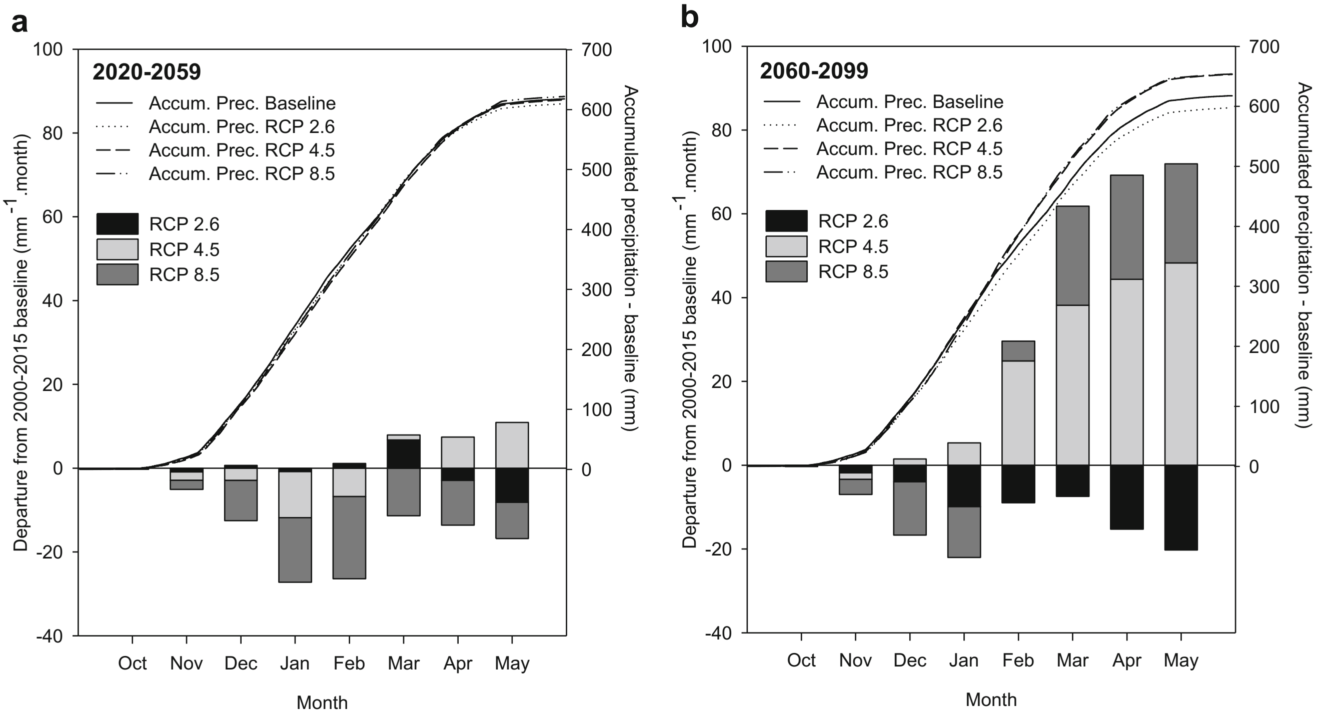

**Fig. 3** Modelled accumulated precipitation along the cropping season in Dodoma, Tanzania represented by the 2000–2015 baseline (solid line) compared to different representative concentration pathways (RCPs) (dotted and dashed lines) for (**a**) 2020–2059 and (**b**) 2060–2099. Stacked bars represent the monthly accumulated precipitation departure from the baseline according different RCPs

Dry-seed planting is said to occur when the soil, at the time of sowing, has insufficient moisture to trigger germination, which as seen in Fig. 6a and b, are planting windows starting on 1st of November and 23rd November. In many years, the

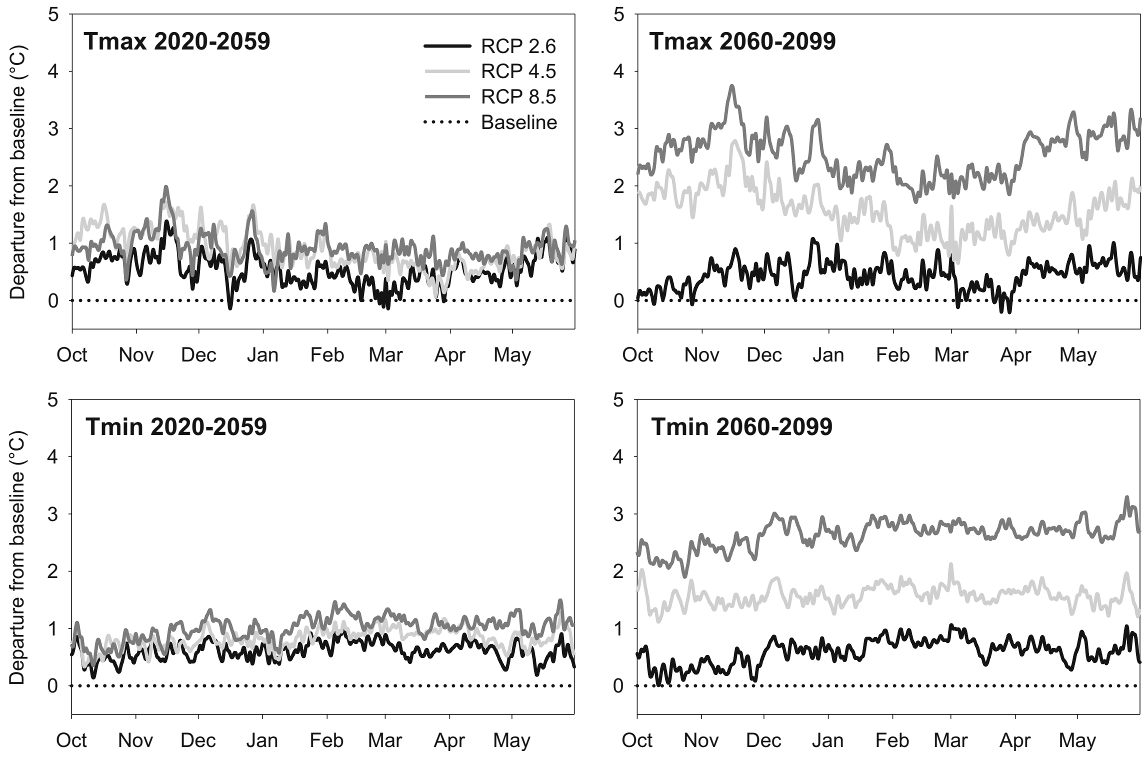

**Fig. 4** Maximal (Tmax) and minimal (Tmin) temperature changes in Dodoma, Tanzania according different representative concentration pathways (RCPs) for two time periods (2020–2059 and 2060–2099). The dashed line represents the baseline relating to the 2000–2015 period

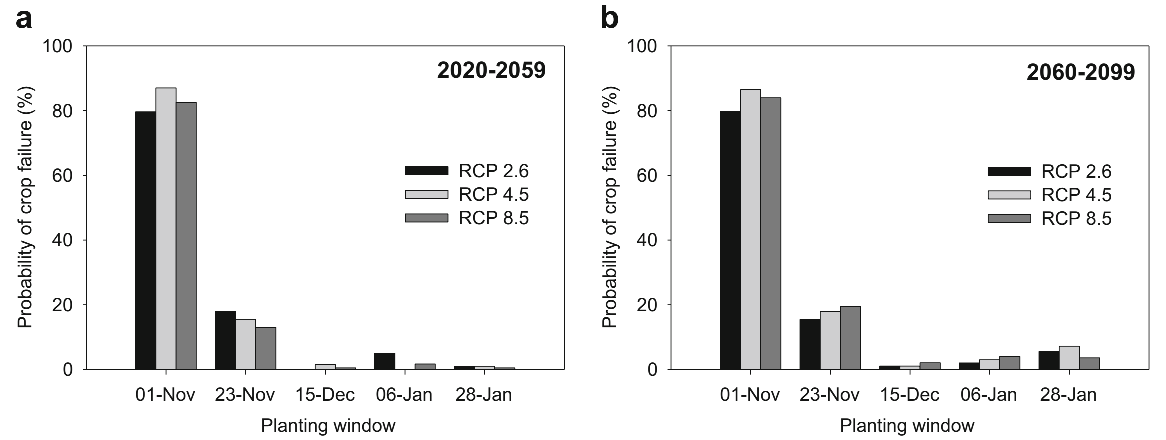

**Fig. 5** Frequency of maize crop failure (defined as grain yields lower than 400 kg ha$^{-1}$) derived from all representative concentration pathways (RCPs) according different planting windows (each of 21 days) using dry soil planting as a strategy in Dodoma, Tanzania. Values for the 2020–2059 period are on the left (**a**), while the 2060–2099 period are on the right (**b**). The date on the x axis indicates the start of the planting window

third planting window also does not meet the minimal soil moisture levels (30.5% of field capacity) at the beginning, as seen by the high dispersion of symbols in Fig. 6 indicating the start of the germination process. By advancing the planting window, the start of germination tends to concentrate on or very close to the beginning of each planting window, because of sufficient soil moisture to trigger germination. Especially for the two last planting windows, in both time periods, we observed that for almost all RCPs and years, the soil already had enough moisture for immediate seed imbibition and the start of germination. This higher soil moisture availability at the planting time, however, does not automatically ensure good crop performance, as yield will also be defined by climatic events that occur well after germination.

For maize grain yield, the most successful planting windows for both time slices were between 23 November and 6 January, as seen in Fig. 7. As yield is defined by several parameters, it is assumed that the above mentioned planting windows were the ones combining the best emergence conditions for the crop (soil moisture) as well as adequate water supply during the crop's growth cycle. Late planting date windows, despite the high values of initial soil moisture that allow for immediate germination, failed to provide an adequate amount of rainfall during the vegetative stages and especially during the reproductive stages of maize development, which occur towards the end of the rainy season. As seen in Fig. 3, precipitation ceases in April, when the plants that germinated during the latest planting times are expected to be in the grain

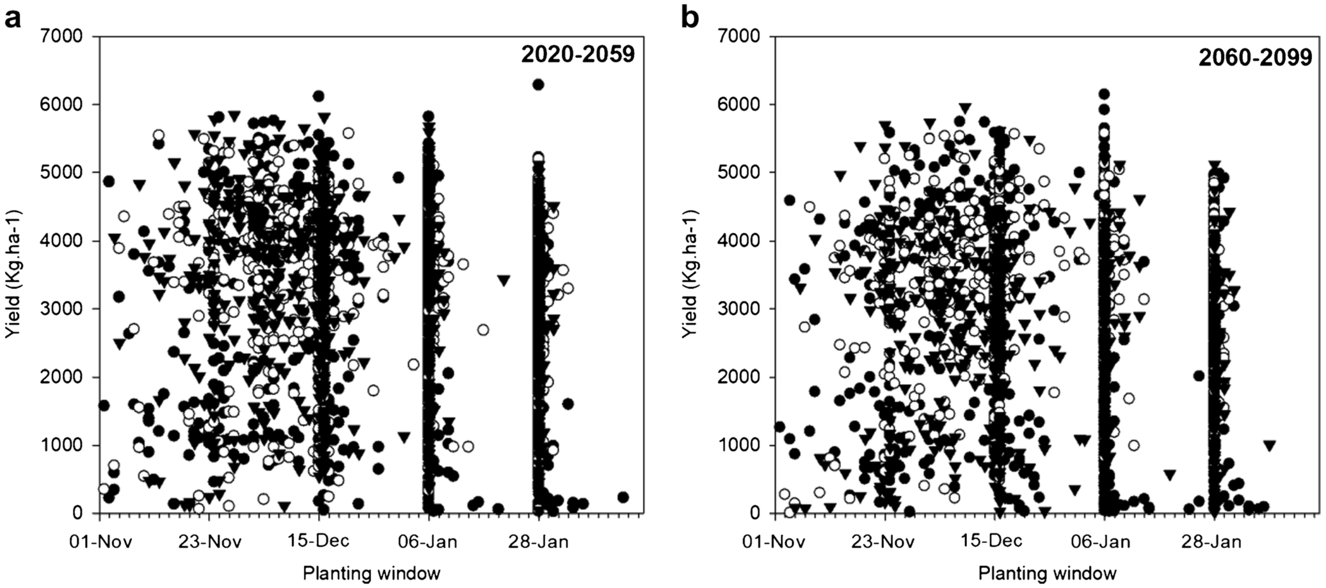

**Fig. 6** Maize grain yields simulated by the DSSAT model using different scenario periods and different planting windows (dates in the X axis indicate the start of the planting window) using the dry soil planting adaptation strategy for Dodoma, Tanzania; (**a**) 2020–2059; (**b**) 2060–2099. The different representative concentration pathways (RCP's) are represented by ○ (RCP 2.6), ● (RCP 4.5) and ▼ (RCP 8.5) and indicate when the critical threshold of soil moisture for seed imbibition was reached

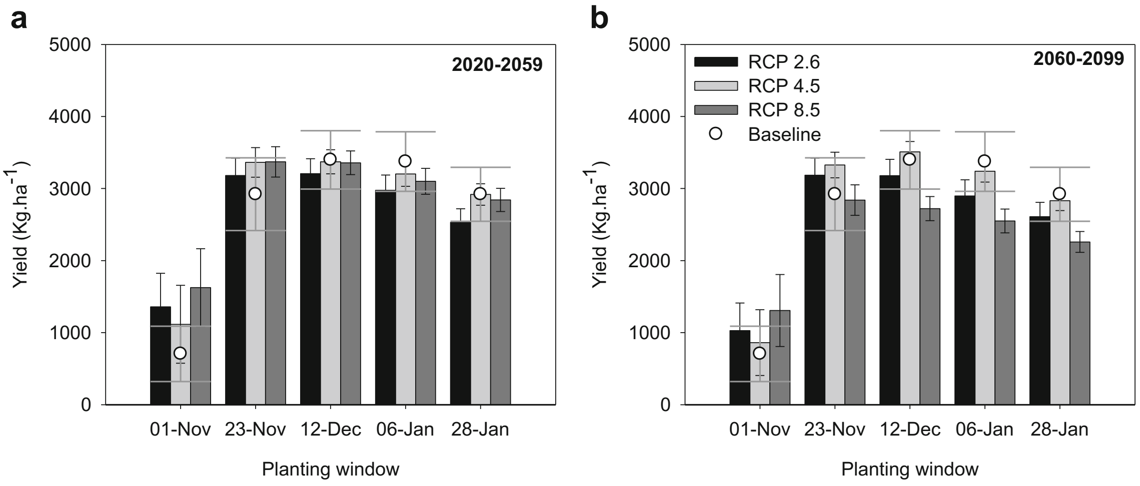

**Fig. 7** Maize grain yields generated for different planting windows and representative concentration pathways (RCPs) in two time periods (slices): 2020–2059 (**a**) and 2060–2099 (**b**) for Dodoma region, Tanzania. The baseline yield (2000–2015) is represented by the white circle symbol for each planting window in both time slices. Bars indicate the standard deviation

filling phase. Comparing the baseline yields (for 2000–2015) and projected yields for 2020–2099 from both time periods (slices) (Fig. 7), no large changes in yield were expected to occur under both time slices.

## 4 Discussion

In cropping systems reliant on rainfall as the sole source of moisture for crop growth, seasonal rainfall variability is inevitably mirrored in both highly variable crop production levels and in the risk-averse livelihood and coping strategies that have emerged over time in smallholder farming communities.

For this assessment, the Ceres crop model evaluation using the Situka maize cultivar was considered adequate since values of MPE and RRMSE are close to zero. This shows that, when input parameters are known, the model can properly mimic field observations such as the ones of Kimaro et al. (2008, 2009) used in this exercise for model evaluation. The RRMSE below 10% can be considered excellent, according Jamieson et al. (1991). The RMSE (204 kg ha$^{-1}$) provides the square root of the average of squared differences between prediction and actual observations, while the RRMSE indicates as a percentage how heterogeneous the simulation results are in relation to the observations. The difference between the MPE and the RRMSE (1.7%) shows that, by using the RMSE as the base component, errors are magnified. Also a positive MBE is desirable, indicating that the model over-predicted yields, according Willmott (1982). Another aspect that supports the ability of the crop model to mimic field observations is that the simulations using weather scenarios for the period 2000–2015 matched the best planting dates reported by farmers in the study region.

For temperatures in East Africa, models project increments in surface air temperature over land between the end of the century (2070–2099) and the present day (1980–2010). Similarly, for annual precipitation, all models indicate an increase of 5% to 20% in precipitation (Warszawski et al. 2014). These different future climate scenarios allowed the 'mapping' of the uncertainty of impact assessments on crop yields and have already been used in several other assessments as listed by Müller et al. (2010), but with different levels of precision.

Despite the significant increases in temperature predicted for the later time period (slice) (2060–2099) (Fig. 4), these deleterious effects could be neutralized or partially reduced by the increment in precipitation (Fig. 3) observed in the middle of the cropping season. An increment in temperature will also accelerate the development of the crop, which may help to avoid the occurrence of the grain filling phase after the end of the rainy season. Additionally, the viability of maize pollen decreases with exposure to temperatures above 35 °C (Dupuis and Dumas 1990), and this effect can be enhanced under high vapor pressure deficits (Hatfield and Prueger 2015). It is important to note that there is a differentiation between the RCPs only in the 2060–2099 period (Fig. 7b), when RCP 4.5 projected the highest yields. For this RCP, the significant increment in temperature was neutralized by the increment in accumulated precipitation.

Data from a field survey carried out by Mourice et al. (2014a, b) for the Wami Basin (which includes the study region) shows that reported yields of maize on smallholder farms range from 50 kg ha$^{-1}$ to 3600 kg h$^{-1}$, with an average of only 860 kg ha$^{-1}$. The discrepancy observed between the yields from Table 2 (which originated from field experiment observations and simulations) and the ones reported above can be attribute to many factors, ranging from agronomic management (sowing date, plant population, fertilizer use, cultivar, irrigation), biophysical factors (soil type, soil compaction, fertility, water or temperature stress, attack of pests, weeds, diseases) to other problems such as animal grazing, theft and lodging. Specifically with regard to crop models an important aspect to be considered is that under field conditions crops will often be subjected to stressors that are not included or not simulated in the model (e.g. pests, diseases, and many others). As stated by Donatelli et al. (2017), this capability to fully model the farm situation is still missing in many crop models, although developments in recent decades are moving towards the quantitative description of the impact of pests and diseases on yield. Differences in management (cultivar, plant population, planting date and soil and nutrient management), soil and weather also contribute to increase this gap. Luhunga et al. (2017), using a fixed $CO_2$ concentration of 360 ppm, also assessed the impacts of climate change scenarios on maize production in the Wami river basin of Tanzania using a single planting window of 15 days (1–15 December), reaching slightly lower baseline yields for maize. Both studies used the same maize cultivar (Situka), but without conducting a further calibration to verify the plausibility of the model for other regions, as recommended by Grassini et al. (2015). Since the region where the crop model was applied does have diverse environmental conditions, it is important to test, adjust, and validate model parameters as necessary.

Regarding dry-soil planting as an adaptation strategy, Akinnagbe and Irohibe (2014) reported that in Tanzania, to avoid crop production risks due to rainfall variability and drought, staggered planting into dry soil before the onset of rains is very common for many farmers. The cultivation of several fields using the dry planting method is therefore regarded as a special feature of adapting to low rainfall conditions since it increases the chances of harvesting at least some of the cultivated fields.

Another aspect that favors dry-soil planting as an ex-ante drought risk adaptation strategy to help ensure food security is to shift and extend the cultivation area to different fields (Westengen and Brysting 2014). The spatial diversification of fields is an effective ex-ante drought risk coping strategy that reduces exposure to risk (Shiferaw et al. 2014). Under such conditions, the risk of income shortfall is reduced by growing maize crops on several fields, and reduced even more when different crops are cultivated. According to Pandey et al. (2007), this principle is used in different types of diversification common in rural societies. Examples include the spatial diversification of farms, diversification of agricultural enterprises and diversification from farm to non-farm activities.

Although ex-ante strategies can be costly in terms of foregone opportunities for income gains because of the choice of safer but low-return activities by farmers, they might help with reducing fluctuations of income (Pandey et al. 2007) and can reduce food insecurity. Moreover, since the availability of labor is one of the major factors affecting the performance of agriculture, the cultivation of some plots before the rainy season maximizes labor efficiency. In this situation, farmers prepare and cultivate the most distant fields before the expected start of the rainy season (Graef and Haigis 2001), leaving the cultivation of the closest fields for the beginning of the rainy season.

Despite the potential to reduce crop losses and therefore to affect food security, the employment of dry-soil planting needs to be followed by other initiatives to reduce mining of soil nutrients (Bekunda et al. 2004), improvement of soil water retention potential, the reduction of soil erosion, diversification of crops, among others. Practices to design climate-change-resilient farming systems are comprehensively described by Altieri et al. (2015) and can foster the local food security by diluting the risk of total crop loss, reducing the variability in yields and ensuring a source of income.

## 5 Conclusions

Planting into dry soil is an important strategy for farmers managing several fields under circumstances of low water availability. The main advantage of this practice is the planting before the onset of the rainy season, while the main drawback is that a delay in the onset of the rainy season will increase the risk of a false start or crop failure.

For this impact assessment, a crop model (the Ceres model in DSSAT) was satisfactorily validated for a maize cultivar (Situka) in the Dodoma region of Tanzania, indicating its ability to respond to different planting dates and climate change scenarios.

The climate change scenarios did not indicate a considerable shifting in the onset and end of the rainy season, but changes in the accumulated precipitation during the cropping season were predicted for the 2060–2099 period. For temperature, an increment in maximum temperature during the cropping season for the 2020–2059 period of about 1 °C was predicted for all representative concentration pathways (RCP's), while for the 2060–2099 period increments ranged from <1 °C to almost 3 °C, depending on the RCP.

Regarding the probability of failure of the maize crop (yields <400 kg $ha^{-1}$), early planting windows (beginning 1 November) presented up to an 85% chance of failure, with the lowest failure probability occurring with the 15 December planting window. The model simulation results indicated that fields prepared and sowed under the concept of dry-soil planting (no more than 21 days before the onset of the rainy season) had a considerably lower probability of crop failure for the two different tested periods (2020–2059 and 2060–2099).

We conclude that dry-soil planting is a feasible adaptation strategy for farmers to cultivate more fields with maize and therefore reduce the risks of food insecurity in the Dodoma region of Tanzania.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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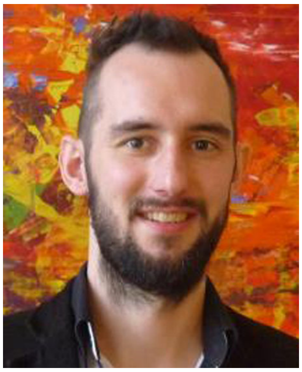
**Marcos Alberto Lana** holds a degree in Agronomy and a Masters in Agro-ecosystems from the Federal University of Santa Catarina State, Brazil. He holds a Doctoral degree in Crop Production from the Christians-Albrecht Universität-Kiel, Germany. Currently Marcos works as scientist and lecturer at the Swedish University of Agricultural Sciences in Uppsala, and as a visiting scientist at the Centre of Agricultural Landscape Research (ZALF), Müncheberg, Germany. His work is focused on the use of crop models to assess the impact of climate change on crops and precision farming, so as to propose suitable adaptation strategies for the rural sector. Marcos is also involved with the development and adoption of agroecology as a tool to support sustainable farming systems. He is active in different regions of Europe, Africa and Latin America. He also teaches at the Humboldt Universität–Berlin and advises Bachelors, Masters and PhD students.

**Ana Carolina F. Vasconcelos** holds a degree in Agricultural Engineering and a Masters in Development and Environment from the Federal University of Paraíba, Brazil. She holds a PhD in Agronomy (Soil and Plant Nutrition) from the University of São Paulo. Ana has experience in the field of Agricultural Engineering, with emphasis on Soil Fertility and Plant Nutrition, working mainly on salinity, climate change, and adaptation strategies to climate change.



**Christoph Gornott** has a Masters of Science and is currently a PhD student at the Potsdam Institute for Climate Impact Research (PIK) in Germany. He is completing his PhD thesis about regional yield assessments by using statistical and process-based crop models. He is experienced in project management in several ongoing projects. Within the Trans-SEC (BMBF, BMZ) project, he has four years of experience with crop modelling and food security assessment. At PIK, Christoph has worked on regional crop yield modelling, climate impacts and improvement of agricultural production systems, as well as links between crop field trials and crop modeling. He also has a masters degree in agricultural economics and a bachelors degree in agricultural science (both from the Humboldt University Berlin).

**Angela Schaffert** holds a Masters Degree in Agricultural Sciences in the Tropics and Subtropics. Currently she is a PhD student with the University of Hohenheim in Germany. Her ongoing research activities focus on crop water use efficiency in drought-prone areas in Tanzania, with an emphasis on the effect of tied-ridges on soil water conservation. Previously, she did research in southern Ethiopia on the potential of carbon sequestration in savannahs.

**Michelle Bonatti** is an Agronomy Engineer from the Federal University of Santa Catarina, Brazil, and holds a Masters degree in Rural Development from Buenos Aires University, Argentina. She is a PhD student at the Humboldt University of Berlin, working on the development of analytical frameworks and educational response tools to improve food and nutritional security in Tanzania. Michelle is also a Conflict Mediator at the Conflicts Resolution Centre of Santa Catarina State and an Educator for Sustainable Development at Santa Catarina University, Brazil. Over 10 years she has worked in eight research projects, with five NGOs, and has received three prizes for scientific academic performance. Currently Michelle is a scientist with the Centre of Agricultural Landscape Research (ZALF), in Germany.

**Johanna Volk** is a BSc Geographical Sciences student at the Freie Universität Berlin. She is currently working on her thesis in association with the Centre for Agricultural Landscape Research (ZALF) on the impacts of climate change scenarios on rain fed maize production in a sub-region of Tanzania. Johanna is acquiring research skills in crop modelling in order to simulate and analyze future agricultural outputs under different scenarios of climate change. During her studies, she engaged in issues related to food security through a physical and human geography perspective, with an emphasis on soil science and development studies. A fellowship from the German Academic Exchange Service (DAAD) made it possible for her to spend a semester abroad at Stellenbosch University, South Africa and work for a local NGO, the Women on Farms project.

**Frieder Graef** works at the Centre for Agricultural Landscape Research (ZALF) in Müncheberg, Germany. He holds a PhD in tropical agriculture from the University of Hohenheim, Germany, and specialised in soil science, GIS and land evaluation. Frieder is scientific coordinator of the German-Tanzanian research project Trans-SEC. This stakeholder-driven project aims at improving food security for the vulnerable rural poor population in Tanzania, applying upgrading strategies along local and regional food value chains. Previously he worked at the Federal Agency of Nature Conservation (BfN) in Bonn, Germany, where he was involved in the regulation of genetically modified organisms (GMO). There his special focus was on cultivation systems, and strategies for monitoring their potential effects on biodiversity and ecosystems.

**Kurt Christian Kersebaum** works as senior scientist at the Institute of Landscape Systems Analysis from the Leibniz Centre for Agricultural Landscape Research – Müncheberg, Germany. He is an agricultural engineer with a PhD in horticulture and holds a Dr. Habil in geoecology from the University of Potsdam. His main expertise is in agro-ecosystem modelling with a focus on water and matter dynamics, crop growth and climate change. He has authored or co-authored more than 180 scientific works, is the national delegate for Germany in the management committee of COST ES 1106 EU (AGRIWAT Assessment of EUROpean AGRIculture WATer use and trade under climate change), is editorial board member of several scientific journals and associated with different scientific associations. He also received the R. Ahuja Ag. Systems Modeling Award from the American Soil Science Society.

**Stefan Sieber** is an agricultural economist working as a senior scientist and head of the department of Economics of Sustainable Land Use at the Centre of Agricultural Landscape Research (ZALF). He holds a PhD in agricultural sciences from the University of Bonn. He has extensive experience in agricultural sector modelling, particularly in terms of impact assessment of environmental and sustainability policies and in applied monitoring and evaluation methods of international development projects worldwide (Europe, Latin America and Africa). Stefan has managed more than 25 research projects and has authored or co-authored more than 35 peer-reviewed publications, 12 peer-reviewed contributions for books and research series, as well as 80 conference papers. He is currently completing his second PhD (Habilitation) and is a lecturer on the master's program "Environmental Sociology and Environmental Policy" at the Humboldt University of Berlin.