

Implications of climate-smart strategy adoption by farm households for food security in Tanzania

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Abstract As the climate changes, farmers in developing countries seek to employ strategies to help them sustain food production. The objectives of this paper were to identify adaptation strategies in response to climate change and the determinants for their adoption, and to explore the impact of these strategies on food security. The analysis was based on a survey of 900 small-scale farmers in a semi-arid (Dodoma) and a semi-humid (Morogoro) region in Tanzania. Farmers in the semi-humid region tended to diversify their crops, i.e. added additional crop types. Given the more challenging environment in the semi-arid region, farmers there changed their portfolio of crops, i.e. substituted some crops or cultivars with others. Logistic regressions highlighted higher tolerance to risk, land ownership, education and experiences of farmers as drivers of adoption, while income diversification had a negative effect. The propensity score matching approach showed that adopters of climate-smart strategies are on-average more food-secure. These users showed a more diverse pattern of food consumption, greater protein intake and better economic access to food. Changing crop portfolios can help households to cope with climate-related shocks such as droughts and thus appears to be the best performing strategy, especially in terms of more stable food provisioning throughout the year.

Keywords Adaptation · Climate change · Food security · Tanzania · Small-scale farming

Introduction

There is an ongoing debate about the impact of climate change in different geographic regions of the world and the value of potential adaptation strategies. Climate change is defined as the long-term change in mean annual temperature and precipitation as reported by the Intergovernmental Panel on Climate Change (IPCC 2013). As the climate changes, droughts and dry spells become more frequent, and rainfall becomes more erratic, causing water runoff and soil erosion (Below et al. 2010). A changing climate can also serve as a basis for crop pests to spread (FAO 2010). The IPCC (2013) predicts that by 2100 the increase in global average surface temperature should range between 1.5 °C and 4 °C. An increase of 1.5 °C to 2.5 °C could risk the loss of 25–42% of species habitat in Africa, thus seriously undermining food security (FAO 2007).

Predictions for Tanzania as part of the East African region show an increase in mean annual temperature of between 1 °C and 3.1 °C by 2100, and more unpredictable rainfall patterns (IPCC 2013). This is based on the Representative Concentration Pathway (RCP) 4.5 scenario, an intermediate emissions scenario that assumes a continuously increasing world population, moderate levels of economic development and less rapid and more diverse technological change than in the RCP 8.5 high emissions scenario (IPCC 2013). For about 70% of Tanzania's population, small-scale and mostly rainfed farming is the main source of income (GoT 2014). Fewer than 5% of farmers use some form of irrigation, and most are thus highly dependent on prevailing climatic conditions and suffer more from its changes (GoT 2013). Accordingly, one third of Tanzania's rural population lives

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below the basic needs poverty line and 11% are estimated not to meet the minimum food requirement of 2200 kcal per day (NBS 2013).

Farmers in Tanzania and elsewhere in sub-Saharan Africa (SSA) find it a challenge to sustain or increase their food production (Chauvin et al. 2012). Food security is defined as “when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life” (FAO 1996). The dimensions of food security are thus i) food availability, including production, distribution and the exchange of food; ii) food access that relates to affordability, allocation and personal preferences; iii) utilization of food, including issues referring to nutritional quality and quantity, social value and food safety; and iv) stability of food provisioning over time (FAO 2008a).

Climate change and food security are strongly interlinked (Tibesigwa et al. 2015; Lema et al. 2014). The impact of climate change on human livelihoods can be short term through more extreme weather events or longer term through altering temperatures and precipitation (FAO 2008b). Unstable weather conditions can reduce the stability of food supplies throughout the year, affecting food security. Fluctuating crop production leads to less predictable income and prices and more vulnerable households (FAO 2008b). Lema et al. (2014) stress the importance of building a research framework which integrates bio-physical and socio-economic aspects of food systems in order to mitigate climate change and support the development and implementation of effective measures to adapt to climate change.

The term ‘climate-smart agriculture’ (CSA) embraces an approach that has the objective of global food security and represents a framework for sustainable farm production (FAO 2016). Strategies related to CSA, such as the planting of trees or changes to the portfolio of crops grown, are possible responses to observed current or past climatic effects and are intended to mitigate adverse changes to climate now and into the future (Hisali et al. 2011; FAO 2013). However, CSA is not a “one-size-fits-all” solution that can be applied in any country or regional context. Site-specific assessments are necessary to identify suitable practices for sustainable development.

Although links between CSA and food security have been highlighted above, there appear to be no published papers based on empirical research that assess quantitatively the links between these two concepts. This paper is a first step towards establishing such a literature. No study was found which explored the effects of adaptation to climate change on aspects of food security other than the dimensions of availability or access. The “stability” pillar is especially neglected, yet this can be hypothesized to be an important factor for increasing food security in the context of small-scale farmers. This pillar captures their suffering from climate variability and is related to the other dimensions of food security (FAO 2008a).

Against this background, our paper aims to answer the following questions: a) which strategies in response to climatic

changes do small-scale farmers adopt in Tanzania? b) what are the determinants for their uptake? and c) what is the impact of adopted climate-smart strategies on food security? The responses to these questions can provide useful guidance to policymakers and practitioners to design effective climate-smart programs for the farming sector in Tanzania. This paper also helps to assess the benefit of adaptation to climate change for Tanzanian small-scale farmers in terms of food security. The analysis we provide combines several methods and indicators to cover the dimensions of food security. Propensity score matching is accompanied by Rosenbaum bounds to control for self-selection and hidden bias.

The remainder of this paper is organized as follows. The second section reviews the literature on climate-smart strategies, drivers and associated factors for their adoption, and impact on food security. Based on this, key hypotheses are derived for empirical testing. A further section briefly describes the applied econometric models and the underlying data. The empirical results are then presented and discussed, and a final section concludes.

Literature review

Identification of climate-smart strategies

There is a wide array of farming adaptation strategies to climate change. Major ones include adjustments to farm and crop management, diversification of income sources beyond the farm, soil and water conservation strategies, and planting trees or shrubs in agricultural crop and livestock production systems (e.g. Below et al. 2012; Kassie et al. 2015).

Adjustments to farm and crop management include crop diversification, intercropping, planting early maturing crop cultivars, drought- or disease-resistant crops, or changing crop planting dates (Below et al. 2012; Kassie et al. 2015; Kihupi et al. 2015). Diversification of income sources beyond the farm comprises off-farm wage- or self-employment and livestock or mixed crop-livestock farming (Hisali et al. 2011; Kihupi et al. 2015; Tibesigwa et al. 2015). The adoption of soil and water conservation strategies, i.e. minimum to zero tillage, manure and inorganic fertilizer use, has been covered in many studies, although the extent of their use differs strongly by country (di Falco et al. 2011; Kassie et al. 2015; Kihupi et al. 2015). Planting (and retaining) trees and shrubs in agricultural crop and livestock production systems is another strategy to adapt to climate change (Deressa et al. 2009). Trees can maintain or increase soil fertility and moisture retention by generating soil organic matter (FAO 2010). Planted within the field (in intercropping) or around the field as protection from wind and sun, trees can function as live fences and sources of fuel, timber or fibre (Ariga 1997; Branca et al. 2011). In addition, some trees serve as a source of food (Faße et al. 2014).

Drivers for adopting climate-smart strategies

The process of bringing an innovation to the farmer or convincing him or her to adopt a certain strategy strongly relates to the ‘innovation diffusion theory’, introduced in 1962 by Rogers (2003). According to this theory, the innovators and the early adopters represent the smallest part of the farming population, but serve as ‘door-openers’ to the rest, which may then decide to follow the innovators and adopt the innovation over different later time frames. The majority of farmers and the ‘laggards’ are more risk averse and do not act before they are convinced of the benefits of the innovation. The late majority and the laggards are often described as more traditional and poorer compared to the early majority (Rogers 2003). Empirical studies support the assumption that the adoption of new strategies is positively influenced by the farmers’ experience with an innovation, such as if the farmer was able to test the innovation in an on-farm trial (Pannell et al. 2006; Kihupi et al. 2015). The following section provides an overview of recent studies on drivers and associated factors for adopting climate-smart strategies.

Various studies explore the relationship between socioeconomic factors and the adaptation behaviour of farmers towards perceived changes in climate (Below et al. 2012; Kassie et al. 2015). For example, Deressa et al. (2009) showed that male-headed farm households are more likely to adapt to climate change, especially by using soil conservation techniques and adjustments to the crop varieties grown. Women farmers can also adapt to climate change if they are not hindered in receiving information on agricultural and management practices (Nhemachena and Hassan 2007). The information they lack could be provided by extension services. However, with an average of only one extension worker per 2500 farm households, the distribution of information in Tanzania is low compared to other East African countries such as Ethiopia, Kenya and Malawi, which have a ratio of 476, 1000 and 1603 farm households per extension worker, respectively (Kassie et al. 2015). Di Falco et al. (2011) suggested that farmers with highly fertile soils in Ethiopia choose not to adopt any form of sustainable strategy since they perceive there to be no need to do so. The diversification of livelihood strategies is another factor that can strongly influence adoption behaviour, if, for instance, the farmer is involved in off-farm activities or livestock keeping for income. By employing these activities, the farmer is less dependent on the climate or less vulnerable to climate change and so less likely to take action through using climate-smart agriculture (Synnevåg et al. 2015; Tibesigwa et al. 2015). Investment decisions are also influenced by the farmers’ willingness to take risks (Larson and Plessmann 2009). For example, Teklewold and Köhlin (2010) in Ethiopia, established that a high degree of aversion to risk decreased the likelihood of farmers adopting soil conservation measures. They argued that a reduction in the farmers’

exposure to risk, such as by more-secure land rights, could increase the probability of deciding to adapt to a changing climate. Security of land tenure has been found to positively influence the adoption of sustainable practices in Eastern and Southern Africa (Kassie et al. 2015; Hisali et al. 2011).

Impact on food security

There are few impact studies that relate climate change adaptation to food security. Working in Ethiopia, Di Falco et al. (2011) found a positive impact of adaptation to climate change on food security. Farmers in their sample responded to perceived changes to the climate over the past two decades by using the following strategies: they either changed their crop variety, adopted a soil or water conservation strategy, or planted trees. Results, using food crop productivity as a proxy for the availability of food, showed a higher quantity produced per hectare for adopters compared to non-adopters. The impact of sustainable cropland management practices on crop productivity was analyzed in a review by Branca et al. (2011). They found that higher yields can be achieved by improved agronomic practices, integrated nutrient management, adoption of some form of tillage/residue management, water management and also by agroforestry practices (Branca et al. 2011).

Faße et al. (2014) investigated the role of agroforestry among groups of farmers in Tanzania, using a Social Accounting Matrix (SAM) with natural resource accounts. Their results suggest that the lowest income group achieved the highest income generating effect from agroforestry; they used it as a source for firewood and fruits for sale or home consumption. Thus, the conservation of forests by planting trees has a positive influence on the availability of food and on access to food for rural households (Faße et al. 2014). Products from plot trees, e.g. fruits, and products found in public forests such as wild leafy vegetables are more easily available for farm households and can contribute to healthy nutrition in times of seasonal food gaps. They thus serve as a ‘buffer’ for rural households (Arnold et al. 2011; Powell et al. 2011). The incorporation of trees can enable farmers to diversify food production and food supply, generate a higher income and reduce the risk of crop failure (FAO 2010; Faße and Grote 2012).

Data and methodology

Study sites and data

A survey of 900 small-scale farmers was carried out in two regions of Tanzania in January and February 2014 (Fig. 1). One region, Dodoma, is characterized by a semi-arid climate (350–500 mm of annual precipitation) with flat plains and small hills. Its food system is dominated by sorghum and millet in combination with widespread keeping of livestock (URT 2007;

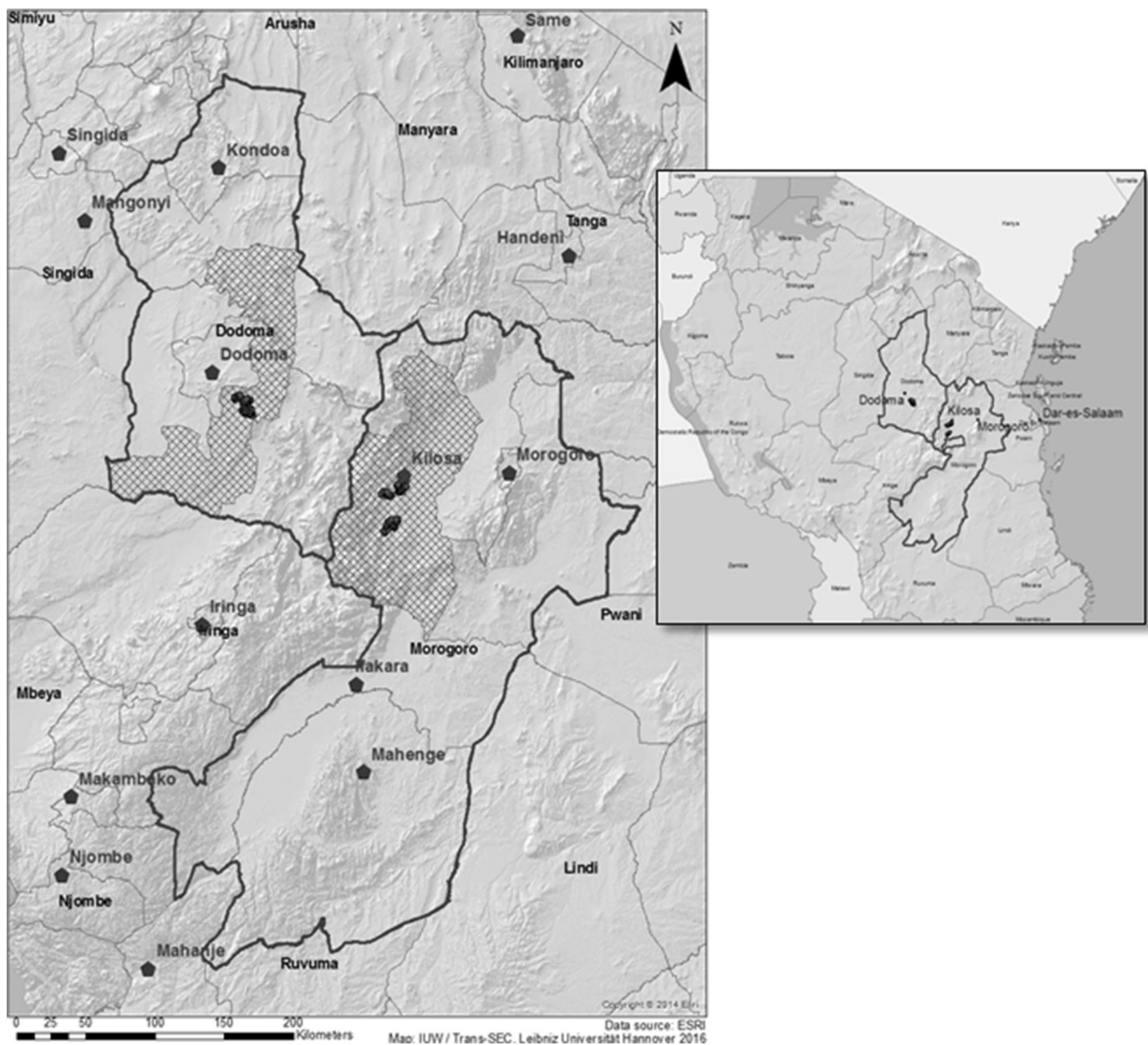


Fig. 1 Study sites in Tanzania. *Source:* Own production using ArcGIS. Notes: Study sites are located in Kilosa district in Morogoro region and Chamwino district in Dodoma region (dashed area)

Mnenwa and Maliti 2010). The second region, Morogoro, is semi-humid (600–800 mm precipitation per year) with flat plains, highlands and dry alluvial valleys. This region is more diverse than Dodoma with a food system based on maize, sorghum, legumes, rice and horticultural products, only partly in combination with livestock (URT 2007; Mnenwa and Maliti 2010). Dodoma is one of the most drought-affected and food-insecure regions in Tanzania, whereas Morogoro comprises both food-secure and food-insecure areas (URT 2007; USAID 2008).

The selection of households for the survey was based on a two-step random sampling procedure. First, study sites were selected within these two regions based on agro-ecological conditions and covering the majority of farming systems in Tanzania; i.e. Kilosa district in Morogoro and Chamwino district

in Dodoma (USAID 2008; Graef et al. 2014). Based on criteria related to comparable and differing agro-ecological and socio-economic conditions, three study villages were selected in each study site: Changarawe, Nyali and Ilakala in Kilosa; and Ilo, Ndebwe and Idifu in Chamwino. Then 150 farming households in each of the six villages were randomly selected from household lists, in proportion to the size of a sub-village.

A questionnaire¹ was administered to the 150 farmers in each village. The questionnaire was designed to measure the status of farmers in these villages in terms of their income,

¹ The Trans-SEC Household Survey Questionnaire was part of the baseline study in the Trans-SEC project; example available online: <https://www.vulnerability-asia.uni-hannover.de/8471.html>.

food consumption and food security indicators for the year 2013 as the reference period. Besides basic socio-demographic information, the questionnaire covered expenditures and income-generating activities such as agricultural production, off-farm employment, self-employment, natural resource extraction, livestock keeping, rents, returns on capital assets and remittances. The total annual net income per household and its components, including a farmer's total annual net value from crop production, were calculated in purchasing-power-parity (PPP) US\$ with the reference year of 2010. The calculations of the income and consumption aggregate were based on definitions and procedures given by Johnson et al. (1990), and were conducted using Stata13. The risk attitudes of respondents (usually the household head) were surveyed following Dohmen et al. (2011), involving the question of whether they were fully prepared to take risk or to avoid it. To get information on the food security status of a household, the questionnaire was designed to cover all questions that were necessary to calculate different food security indicators, as presented in the next subsection. To help with this, the person in the household in charge of cooking was asked detailed questions about the family's food consumption pattern (including the types of food, frequency and quantity of consumption) and their coping behaviour in times of under-provision of food.

To obtain information on their perception of climatic changes, farmers were asked whether they perceived the climate in general to have been changing in the past twenty years. If they confirmed this, then more specific questions were asked to find out how farmers perceived the change, i.e. what was their perceived major change with regard to temperature, rainfall and wind. Based on that, farmers were then asked about the ways those changes affected their agricultural activities and how, if at all, they adjusted their agricultural activities to these changes. Despite the comprehensiveness of the survey, the answers related to questions on climatic changes lacked information on the specific types of crop cultivars or specific trees the farmers chose to plant or not to plant in response to their perceived climatic changes. The survey however did provide information on the current trees and crops present on the farmers' plots in the reference year.

Methodology

Factors associated with adoption of climate-smart strategies

To identify factors associated with the adoption of climate-smart strategies, two sets of logistic regression models were used. First, a binary regression was applied due to the dichotomous nature of the dependent variable (D'Souza et al. 1993). The binary model describes if adoption has taken place ($y = 1$)

with the probability p , or the alternative to not adopt ($y = 0$), with the probability of $1-p$ (Cameron and Trivedi 2009).

$$Y = \begin{cases} 1 & \text{with the probability } p \\ 0 & \text{with the probability } 1-p \end{cases} \quad (1)$$

Following Shapiro and Wilk (1965), the normality assumption was tested with their significance test. The marginal effects are provided to determine the magnitude of the effect, its direction and likelihood (Wooldridge 2010). As there are mainly dichotomous regressors in this model, average marginal effects and the associated standard errors were calculated based on the delta method (Cameron and Trivedi 2009).

As a second model, the Multinomial Logit Regression (MNL) was used. As specified in the binary response case, the outcome y can take zero for the case of no adoption, but it can also have a value of one, two or three, denoting one of the respective 'adoption' strategies, i.e. agricultural activities that farmers stated they used in response to perceived climatic changes. A set of explanatory variables is represented by the term x , including household, farm and behavioral characteristics (Table 1). They are based on the literature we reviewed and cover potential factors associated with adoption of climate-smart strategies. A household index is given by i . The influence of a change in one or more of the covariates on the response probabilities p is the focus of attention in the MNL model, with

$$p_{ij} = \Pr(y_i = j | x_i), \quad j = 0, 1, 2, 3, \quad i = 1, 2, \dots, 672. \quad (2)$$

The interpretation is similar to that of the binary case, with one outcome as the baseline being compared with the others, but recognizing the coexistence of all outcome possibilities (Cameron and Trivedi 2009).

Impact of climate-smart strategies on food security

Farmers decided themselves which (if any) strategy to adopt, therefore the impact assessment has to control for self-selection bias. The Propensity Score Matching (PSM) approach was therefore chosen to measure the impact of climate-smart strategies on food security outcome measures (Caliendo and Kopeinig 2008). The PSM compares the outcome of each individual, here a farm household, to its counterfactual by controlling for household and farm characteristics. Therefore, the outcome for individual i that participated in some form of treatment (y_1) is compared to the outcome of a similar individual without the treatment participation (y_0), which is the basis for the Average Treatment Effect (ATE).

$$ATE = E(y_1 - y_0) \quad (3)$$

Table 1 Direction of the relationship between covariates and adoption of climate-smart strategies

Variables	Description	Direction	Source
Female	1 if household head is female	+/-	Deressa et al. 2009; Nhemachena and Hassan (2007)
Age	Age of household head in years	+	Deressa et al. 2009
Education	1 if household head can read and write	+	Below et al. 2012; Kassie et al. 2015; Goodwin and Mishra 2004
HH size	Number of nucleus household members	+/-	Deressa et al. 2009
Livestock	1 if household is involved in livestock keeping	-	Tibesigwa et al. 2015; Synnevåg et al. 2015
Off-farm wage employment	1 if household is involved in off-farm wage employment	-	Synnevåg et al. 2015
Non-farm self-employment	1 if household is involved in non-farm self-employment	-	Synnevåg et al. 2015
Awareness	1 if household head is aware of reduced soil fertility	+	Di Falco et al. 2011; D'Souza et al. 1993
Access to credit	1 if any of the household member participates in micro-credit group	+	Di Falco et al. 2011
Risk behaviour	Household's risk attitude: On a 11-point scale from 0 (=unwilling to take risks) to 10 (fully prepared to take risk)	+	Larson and Plessmann 2009; Teklewold and Köhlin 2010
Participator in on-farm trial	1 if household already participates (or participated) in on-farm trials	+	Pannell et al. 2006; Kihupi et al. 2015; Rogers (2003)
Follower	1 if household is willing to test the innovation after seeing the experience from others	+	Kihupi et al. 2015; Rogers (2003)
If located in Dodoma	1 if household is located in semi-arid region Dodoma (1) or in semi-humid region Morogoro (0)	+/-	Hisali et al. 2011; Deressa et al. 2009
Perceived land security	Perceived security of land tenure on household's plot(s): on a scale 1(not secure at all) – 4 (very secure), average if more than one plot	+	Kassie et al. 2015; Teklewold and Köhlin 2010; Van Gelder (2010)
If land individually owned	1 if land tenure status of household is "individually owned", 0 if otherwise	+	Hisali et al. 2011
Distance to village centre	Distance from homestead to extension office in km	-	Mwangi and Kariuki 2015; Bekele et al. 2011

In this context, treatment means that a household stated to have adopted one of the climate-smart strategies. The outcome variable y is a food security indicator. Since this analysis is based on observational cross-section data, where households stated to have adapted to climate change or not in the past, then the same household cannot be observed with and without adaptation. Therefore, the outcome for households who adopted some strategy in response to perceived climatic change is compared to those who did not adopt any strategy, given that the two groups do not differ systematically besides the adoption. The Average Treatment Effect of the Treated (ATT) is the difference of means of treatment and control groups of the impact variables after matching. A positive ATT can be construed as an increase in the impact variable due to the treatment and vice versa.

$$ATT = E(y_1|T = 1) + E(y_0|T = 0) \quad (4)$$

In our analysis, three different matching algorithms were used following Caliendo and Kopeinig (2008). These were Nearest Neighbour Matching (NNM), Kernel matching and Radius matching. For the first method, five nearest neighbours

were matched to each treated household depending on their propensity score distances. However, if the distance between two neighbours is large, NNM can produce bad matches. To reduce this risk and match only close neighbours within a given tolerance level, a restriction to caliper 0.1 was specified. Radius matching however has an advantage over NNM, since it uses all the comparison members within the caliper restricted to 0.1 and not only the nearest neighbours with each caliper. Kernel matching uses kernel-weighted averages to construct the counterfactual outcome. Here, a bandwidth of 0.06 was set as default. Propensity score distributions and common support areas are provided in Fig. 2. In the end, Rosenbaum bounds were computed to control for hidden bias, possibly caused by unobserved heterogeneity (Becker and Caliendo 2007; DiPrete and Gangl 2004).

Food security in its four dimensions was approximated by the following indicators, which were calculated based on the survey information. Since each of the indicators has its limitations in fully covering one dimension and can overlap, two metrics per dimension were included in the analysis for more robust results, where possible (Coates 2013; Maxwell et al. 2014; Pieters et al. 2013).

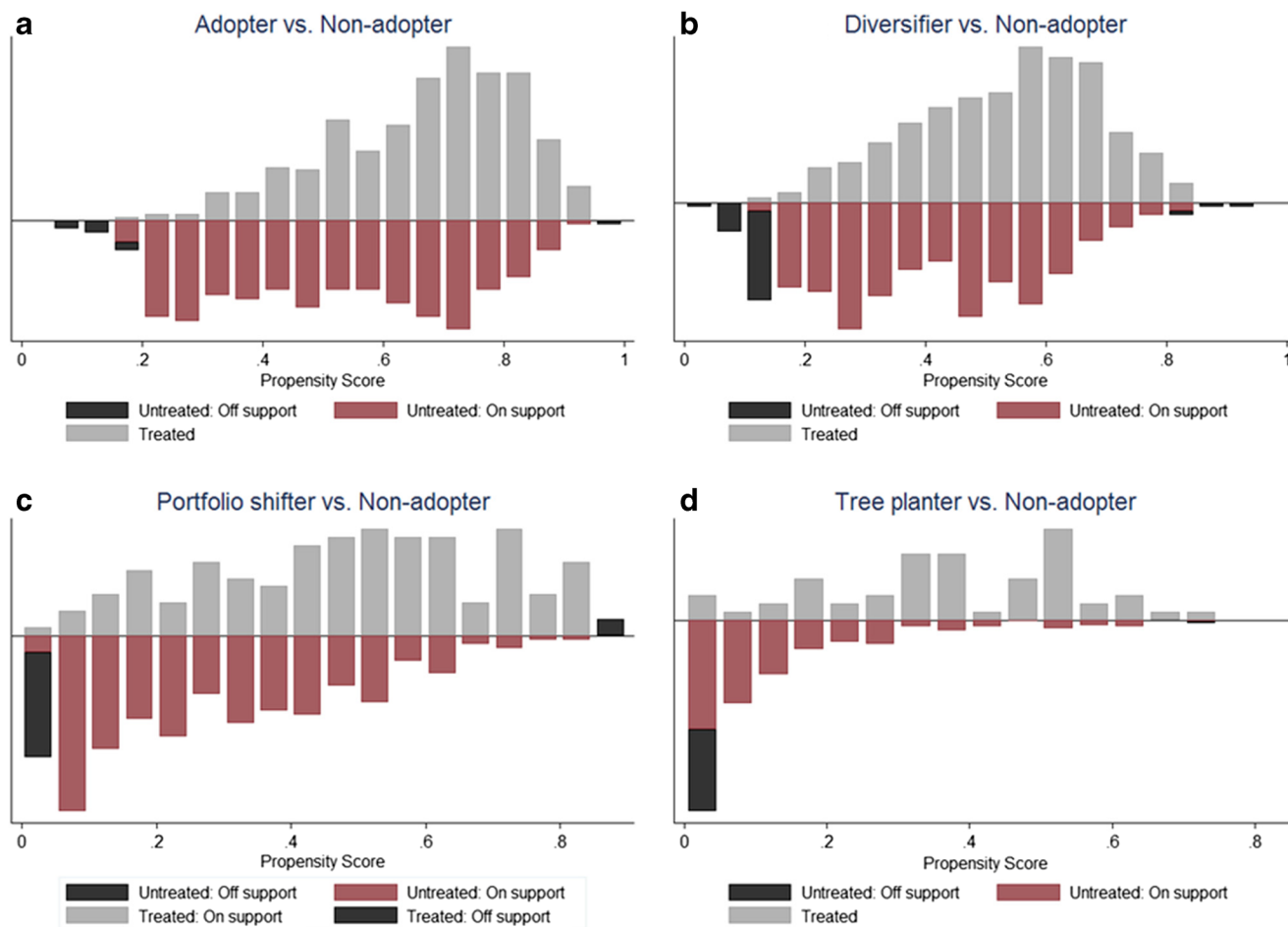


Fig. 2 Propensity score distribution and common support area for a “Adopter vs. Non-adopter”, b “Diversifier vs. Non-adopter”, c “Portfolio shifter vs. Non-adopter” and d “Tree planter vs. Non-adopter”. *Source:* Histograms of propensity score distribution and common support area for farmers in different adoption schemes based

on own calculation using Stata13. *Note:* Farmers are described as ‘Diversifier’ as they chose to increase the number of crops or cultivars as response to perceived climatic changes. ‘Portfolio shifter’ refers to farmers who chose to substitute certain crops or cultivars for others, respectively

As the analysis focused on small-scale farmers that produce most of their consumed food themselves, the farmer’s total annual net value from crop production was used as an indicator for the availability dimension of food security, i.e. the supply side, including the level of food production and stock levels (FAO 2008a; di Falco et al. 2011; Lema et al. 2014).

Physical and economic access to food was covered by the Food Consumption Score (FCS), caloric and protein intake and the household’s net income. The World Food Program (WFP 2008) indicated that the standard methodology to analyze food consumption is the FCS, which captures both the frequency and the composition of food consumption (Wiesmann et al. 2009; Maxwell et al. 2014). A higher FCS indicates higher household food security.

The utilization dimension refers to sufficient energy and nutrient intake, and to good food preparation practices, but also to the quality of the diet, i.e. whether the eating habits of members of the household or meal

composition are diversified and include protein sources, fruits and vegetables additional to their staple diets (FAO 1996). Food utilization is therefore approximated by caloric and protein intake and the FCS based on the household’s food consumption in a normal week (Wiesmann et al. 2009; Jones et al. 2013).

Food security is present only when food is available and can be accessed and utilized throughout the seasons, not just at the time after harvest. The stability of food security can be interrupted by droughts leading to crop failures and thus affecting the availability or economic access to food (FAO 1996; Schmidhuber and Tubiello 2007). The certainty or stability of food provisioning over time is covered by the number of Months of Adequate Household Food Provisioning (MAHFP) and the Coping Strategies Index (CSI) as they take into account the perceived dietary adequacy over time (FAO 2008a; Coates 2013). The CSI measures food security indirectly through questions related to food consumption

behaviour, i.e. what people are compelled to do when they do not have enough food or money to purchase food (Maxwell et al. 2014). A higher CSI score indicates greater household food insecurity. The MAHFP indicator was also based on farmers' statements in our survey (Bilinsky and Swindale 2010). For an overview of the indicators we used, see Table 2.

Results

Strategies for farmers to better cope with climatic changes through adjustments to agricultural practices were identified based on the responses from the farmers involved. In order to respond to climate changes, firstly farmers need to be aware of or even directly affected by climate change. Ninety-seven % of the sampled farmers stated they have perceived changes to climate in the last twenty years. About two thirds of the overall sample indicated a high impact of these changes on agriculture, with 76% saying their crop yields had declined. In response, around 60% reported to have changed agricultural production systems. Based on the most frequent answers,² 221 farmers were identified who had diversified their crop portfolios, i.e. increased the number of crops or cultivars they grow. In addition, 134 farmers were identified who had shifted their crop portfolio by substituting certain crops or cultivars for others. Tree planters represented a third group of adopters, with 56 observations. For those farmers reporting to have planted trees in response to climatic changes, the most common planted trees present on their plots included mango, mdawi and neem trees. According to the farmers' statements, the purpose of trees ranged from for food for their own consumption and sale, to shade for humans, livestock and also crops, as well as for firewood. Use of more fertilizer was excluded from this analysis due to inconsistent information on the kind of fertilizer applied, i.e. synthetic or mineral vs. biological or manure vs. plant-based 'fertilizer', i.e. leaving crop residues on the field.

Descriptive results

Descriptive results from Table 3 show significant differences between 'adopters' (i.e. users of one or more of the strategies given above) and 'non-adopters' in terms of household and farm characteristics. Adopters differ most strongly from non-adopters in being on average more educated, less involved in off-farm wage employment and in their attitude to take on higher risk.

The descriptive results in Table 4 account for regional differences in more detail and indicate that the adoption of climate-smart strategies can increase food security. In both Morogoro and Dodoma, adopters had a higher intake of protein on average than non-adopters. Adopters in the semi-humid Morogoro region had a higher FCS on average, indicating a higher food diversity and greater supply of food. This was associated with the preference by adopters in the semi-humid region for diversifying their crops or cultivars (Table 3). Adopters in the semi-arid Dodoma region had on average a net crop value of 330 PPP US\$, almost twice of that of non-adopters in the same region (160 PPP US\$). However, this higher crop value was still much lower than the overall average of 500 PPP US\$ and below the average of the non-adopting farmers in semi-humid Morogoro (682 PPP US\$).

Additional to possible negative implications from climatic changes, small-scale farmers in semi-arid areas of Tanzania suffer already from lower yields compared to farmers in semi-humid regions.

Factors associated with the adoption of climate-smart strategies

Results of the logistic regression, including their respective marginal effects, are in Table 5. Education of the household head played a positive role in the decision to adopt a climate-smart strategy or not (0.37). The diversification of income sources into non-farm activities strongly decreased the preference of the farmer to adopt one of the strategies (-1.38).

Following Roger's innovation diffusion theory, our results show that adoption was positively influenced by the participation of the household head in assessments of technology performance in on-farm trials (0.76). This was associated with a significant increase in likelihood of uptake if the farmer categorized himself or herself within the group of 'innovation follower' (0.77), i.e. those who stated they would be willing to test an innovation after having seen it from others, were more likely to adopt. A higher risk-taking attitude was also a factor that favoured adoption (0.17). Owning land individually also positively influenced adaptation to climate change (0.56).

The MLR results in Table 5 identified mostly the same factors associated with the adoption of CSA as did the bivariate results, especially for the decision to diversify the crop portfolio. Farmers, however favoured, 'portfolio shifting' (changing crops or cultivars) over 'diversification' (adding crops) if the farm was located in the semi-arid region of Dodoma (0.77). Education had a significant positive influence only on the adoption of crop portfolio shifting (0.51). The adoption of this strategy was less likely if the household was more involved in keeping livestock (-0.42). The negative influence of being member of a microcredit

² The most frequent strategies mentioned were adjustments to the crop portfolio (64.3%), using more fertilizer (10%) and tree planting (6.3%).

Table 2 Food security dimensions and indicators

Indicator	Description	Dimension	Source
FCS	Food consumption score (average/ year 2013)	Access/ Utilization	WFP 2008; Wiesmann et al. 2009
Caloric intake	Total kcal consumed by adult equivalent per week	Access	Wiesmann et al. 2009; Jones et al. 2013
Protein intake	Total protein consumed by adult equivalent per week in g	Access/ Utilization	Wiesmann et al. 2009; Jones et al. 2013
CSI	Coping Strategies Index (average/ year 2013)	Stability	Wiesmann et al. 2009; Coates 2013
MAHFP	Months of adequate HH food provisioning (year 2013)	Stability	FAO 2008a; Coates 2013
HH income	Household annual net income (PPP US\$, year 2010)	Access	FAO 1996
HH crop value	Household annual net income from crop production (PPP US\$, year 2010)	Availability	FAO 1996; di Falco et al. 2011; Lema et al. 2014

Source: Own elaboration based on literature review

group (-2.55) suggests that shifting the portfolio of crops is a strategy predominantly suitable for those that cannot access credit. However, during the survey, farmers reported that a loan was often taken for buying food rather than for investing in farming.

Factors that favoured the planting of trees were livestock keeping (0.81) and a decreasing perception of land security (-0.37), since in both cases a wooden fence becomes essential. Perceived land security describes the household's perception of land tenure security and ranges from 1 (not secure at all) to 4 (very secure); it can be influenced through land conflicts the farmer experiences with neighbours, pastoralists, the government or through land conflicts within the family or with a private enterprise. Ambiguous formulations of laws or village self-governance rules are possible causes for this (Van Gelder 2010).

Farmers were also more likely to plant trees if the land is owned by them individually (1.4) and not clan-owned or rented, as trees represent a form of investment. Especially for the adoption of tree planting, a smaller distance (-0.51) to the source of information (extension services) was also an important determinant. Another factor in favour of tree planting was the farmer's high degree of environmental awareness (1.5).

Impact of adaptation on food security

To assess the impact of the different adopted 'climate-smart' strategies on food security, the farmers were compared based on indicators covering dimensions of food security. The assessment was performed through pair-wise comparisons, with 'non-adopters' as the control group (Table 6). First, a general comparison of 'adopter' versus 'non-adopter' revealed an increase in the average FCS per year, indicating better food diversity and greater quantity of food for adopters. A higher FCS is supported by a higher intake of protein, i.e. the provision of better quality food. Better access to food was demonstrated by a higher income for

adopters, although this has to be interpreted with caution since the Rosenbaum bounds indicated the possibility of hidden bias.

Focusing on the 'diversifiers', both a higher FCS (3.51) and protein intake (103 g/week/AE) indicated a better provision of more and diverse nutrients than with the non-adopters. The decrease in MAHFP (-1.48) however indicated less stability in food provisioning for the adopters of diversification, since on average they were left with at least one month less of adequate food provisioning.

In our study, the 'portfolio shifters' appeared to experience much better food security. First, the results suggest better access to food, as the average households' annual net income was significantly higher for adopters of this strategy (465.65 PPP US\$). Secondly, a higher FCS (7) and protein intake (142 g/week/AE) indicated an increase in food quality and quantity. Lastly, a lower coping strategy index (-11.94) suggested more stability in food provisioning throughout the year. Portfolio-shifting households also seemed to have a higher annual net value from agricultural production (243.68 PPP US\$), but the Rosenbaum bounds indicated a possible hidden bias meaning that there could be unobserved variables affecting the treatment and the outcome variable simultaneously.

The results for 'tree planting' indicated a higher FCS (8.08), i.e. more access to food, but the effect was less strong than for the strategies that involved the adjustment of food crops. More stability of food provisioning is indicated with a significantly higher MAHFP compared to non-adopters (1.83), i.e. available products from some types of tree can smooth consumption in times of seasonal food gaps (Arnold et al. 2011; Powell et al. 2011).

Discussion

The objectives of the work reported in this paper were to a) explore strategies that farmers adopted in response to climate change, b) identify the determinants of adoption, and c) analyze the impact of their adoption on food security.

Table 3 Summary statistics by smallholder farmer adoption scheme in Tanzania

Variables	Overall (<i>N</i> = 672)	Pooled sample		By adoption model		
		Non-adopter (<i>N</i> = 261)	Adopter (<i>N</i> = 411)	Diversifier (<i>N</i> = 221)	Portfolio shifter (<i>N</i> = 134)	Tree planter (<i>N</i> = 56)
HH characteristics						
If HH head is female	0.21 (0.41)	0.20 (0.40)	0.22 (0.42)	0.22 (0.41)	0.23 (0.42)	0.21 (0.41)
Age (years)	48.61 (16.91)	49.64 (17.16)	47.95 (16.74)	46.70* (15.61)	49.81 (18.34)	48.00 (16.70)
If HH head can read and write	0.67 (0.47)	0.61 (0.49)	0.71*** (0.45)	0.74*** (0.44)	0.67 (0.47)	0.70 (0.46)
HH size (nucleus members)	4.76 (2.25)	4.90 (2.19)	4.67* (2.28)	4.59** (2.41)	4.77 (2.17)	4.79 (2.05)
If livestock keeping	0.65 (0.48)	0.68 (0.47)	0.64 (0.48)	0.65 (0.48)	0.56** (0.50)	0.80* (0.40)
If off-farm wage employment	0.35 (0.48)	0.53 (0.49)	0.24*** (0.43)	0.30*** (0.46)	0.18*** (0.39)	0.16*** (0.37)
If non-farm self-employment	0.27 (0.44)	0.31 (0.47)	0.24** (0.43)	0.27 (0.45)	0.17*** (0.37)	0.25 (0.44)
Awareness effect	0.60 (0.49)	0.56 (0.50)	0.63* (0.48)	0.57 (0.50)	0.63 (0.48)	0.88*** (0.33)
If access to credit	0.06 (0.36)	0.06 (0.24)	0.07 (0.25)	0.10 (0.30)	0.01** (0.09)	0.07 (0.26)
Risk behaviour	6.08 (2.80)	5.45 (2.85)	6.49*** (2.69)	6.81*** (2.68)	6.15** (2.72)	6.07 (2.51)
If participated in on-farm trials	0.12 (0.33)	0.09 (0.28)	0.14** (0.35)	0.15** (0.36)	0.14* (0.35)	0.13 (0.33)
If follower	0.26 (0.44)	0.21 (0.41)	0.29** (0.45)	0.22 (0.41)	0.26 (0.44)	0.59*** (0.50)
Farm characteristics						
If located in Dodoma (semi-arid region)	0.51 (0.50)	0.56 (0.49)	0.49* (0.50)	0.39*** (0.49)	0.59 (0.49)	0.63 (0.49)
Perceived land security	2.69 (1.06)	2.71 (0.95)	2.68 (1.12)	2.64 (1.10)	2.89** (1.12)	2.38** (1.09)
If land individually owned	0.14 (0.35)	0.12 (0.32)	0.16 (0.37)	0.16 (0.37)	0.09 (0.29)	0.30*** (0.46)
Distance to village centre (km)	1.60 (1.49)	1.66 (1.56)	1.56 (1.44)	1.60 (1.56)	1.67 (1.44)	1.16 (0.82)

Mean values (with standard deviation in parentheses) across schemes tested for statistically significant differences compared to non-adopting farmers using Mann-Whitney test; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Based on statements by farmers during the survey that took place at the beginning of 2014 in the semi-humid region of Morogoro and the semi-arid region of Dodoma, crop diversification, crop portfolio shifting and tree planting were identified as the most important strategies that farmers employed in response to their perceptions of climatic change. Further analysis on adaptation to climate change using logit and multinomial logit regression revealed that education was

perceived as an important facilitator of adoption since it can help the farmer to employ innovative agricultural approaches that come from neighbours or from extension agents (Kassie et al. 2015). The diversification of income sources into non-farm activities strongly decreased the preference of the farmer to adopt climate-smart strategies through a reduced dependence on agricultural activities (Goodwin and Mishra 2004).

Table 4 Summary statistics for food security variables in two regions of Tanzania

Variables	Overall (<i>N</i> = 672)	Semi-arid Dodoma region		Semi-humid Morogoro region	
		Non-adopter (<i>N</i> = 145)	Adopter (<i>N</i> = 200)	Non-adopter (<i>N</i> = 116)	Adopter (<i>N</i> = 211)
Food consumption score (FCS/year)	42.10 (16.08)	34.41 (10.51)	36.73 (17.70)	45.83 (12.43)	50.54* (18.45)
Caloric intake (AE / week)	17,595.62 (6957.643)	16,539.34 (7021.17)	17,266.55 (6791.47)	17,531.29 (7370.68)	18,668.79 (6901.31)
Protein intake (AE / week)	532.63 (430.89)	445.06 (240.10)	546.22* (508.84)	494.41 (265.92)	600.93** (396.34)
Coping Strategies Index (CSI/year)	26.29 (29.99)	38.08 (31.31)	33.34 (29.46)	20.42 (26.35)	14.73 (22.38)
Months of adequate HH food provisioning (MAHFP)	6.58 (4.26)	5.76 (3.91)	6.24 (4.26)	7.43 (4.49)	6.98 (4.95)
HH net income (PPP US\$/year)	1026.89 (1293.38)	702.85 (824.76)	1002.61 (1481.16)	1061.56 (956.42)	1253.54 (1650.74)
HH net crop value (PPP US\$/year)	499.09 (866.95)	160.61 (306.60)	330.22*** (977.25)	681.92 (817.46)	791.23 (1208.84)

Mean values (standard deviation in parentheses) tested for significant differences compared to non-adopting farmers using the Mann-Whitney test; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. AE: Adult Equivalent

The adoption decision was also associated with the experience of the farmer with on-farm trials. This result strongly suggests that farmers have to be convinced of an innovation by seeing the benefits from others first before they consider using it themselves (Pannell et al. 2006; Kihupi et al. 2015). Individual ownership of land also positively influences adaptation to climate change. As was also shown by Hisali et al. (2011), it represents a more settled land tenure arrangement.

A farmers' choice of specific adaptation strategies strongly depended on the regional setting. Farm households located in the semi-humid region tended to choose crop diversification; farms located in the semi-arid region preferred to shift their cropping portfolio according to local conditions. Deressa et al. (2009), Hisali et al. (2011) and Below et al. (2012) have all reported that households living in different agro-ecological zones (AEZ), since they are exposed to varying climatic conditions and soil types, adapt to a changing climate by using different strategies. This is unsurprising since semi-arid areas have less favourable growing conditions compared to those found in semi-humid regions (Altieri 1995). Also McCord et al. (2015) found that farmers tend to manage their agricultural systems with fewer crops given the more unsuitable conditions found in semi-arid zones. Important factors associated with the adoption of tree planting were the farmer's environmental awareness and a shorter distance to sources of information (such as extension services) (Bekele et al. 2011; Mwangi and Kariuki 2015).

The results of the PSM analysis demonstrated that appropriate adaptation to climate change can improve the food security status of small-scale farm households. Depending on the kind of strategy chosen, it has a different impact on particular dimensions of food security. With the adoption of crop diversification, a household can have better access to a more-diverse nutrition, but not necessarily throughout the year. Research in the semi-arid areas of Iringa district in Tanzania showed that farmers with a diversified portfolio of crops that included maize, sunflower, cowpea, sesame and groundnut could cope better with different climatic conditions and environmental degradation such as reduced soil fertility due to a shorter rainy season (Kihupi et al. 2015). Although crop diversification represents a potential strategy to improve food security (Njeru 2013), it can also be adversely related to food security, such as when cash crops are included in the diversified crop mix that partly displace food crops (Fleuret and Fleuret 1980; Anderman et al. 2014).

A shift of the crop portfolio is a strategy often used in SSA and South Asia in response to climate change (Kassie et al. 2015, Synnevåg et al. 2015). This can be done by replacing the current crop species with one that is more tolerant of drought, or switching to an earlier maturing cultivar of the same crop (Kihupi et al. 2015; Below et al. 2010). With our farmers, further work is needed to explore the types of crops and cultivars that the farmers might best move to, and how they may be best incorporated into their cropping systems. 'Portfolio shifting' is especially relevant considering an expected decrease in suitable rainfed land area and its related cereal production potential in African countries by 2080.

Table 5 Factors associated with adoption of climate-smart strategies in Tanzania: Estimates from logistic regressions

Adoption variables (base = 0)	Logit regression		Multinomial logistic regression		
	Adopter (<i>n</i> = 411)		Diversification (<i>n</i> = 221)	Portfolio shift (<i>n</i> = 134)	Tree planting (<i>n</i> = 56)
	Coef	m.e.	(1)	(2)	(3)
If HH head is female	0.16 (0.23)	0.03 (0.05)	0.14 (0.26)	0.21 (0.31)	-0.13 (0.45)
Age	0.01 (0.03)	0.00 (0.01)	0.03 (0.03)	-0.00 (0.03)	-0.00 (0.05)
Age squared	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	-0.000 (0.00)
If HH head can read/ write	0.37* (0.20)	0.07* (0.04)	0.32 (0.23)	0.51* (0.27)	0.23 (0.41)
Household size	-0.02 (0.04)	-0.00 (0.01)	-0.04 (0.05)	0.02 (0.05)	-0.04 (0.09)
If livestock keeping	-0.22 (0.20)	-0.04 (0.04)	-0.21 (0.22)	-0.42* (0.25)	0.81* (0.43)
If off-farm wage employment	-1.38*** (0.19)	-0.27*** (0.03)	-0.90*** (0.22)	-2.02*** (0.29)	-2.06*** (0.44)
If non-farm self- employment	-0.62*** (0.21)	-0.12*** (0.04)	-0.34 (0.23)	-1.13*** (0.30)	-0.68* (0.41)
Awareness effect	0.30 (0.19)	0.06 (0.04)	0.13 (0.21)	0.31 (0.25)	1.50*** (0.47)
If can access credit	-0.41 (0.36)	-0.08 (0.07)	-0.05 (0.38)	-2.55** (1.06)	-0.28 (0.65)
Prepared to take risk	0.17*** (0.04)	0.03*** (0.01)	0.20*** (0.04)	0.13*** (0.05)	0.22*** (0.07)
If participate in on-farm trials	0.76** (0.29)	0.15** (0.06)	0.83*** (0.32)	0.48 (0.38)	0.93* (0.53)
If follower	0.77*** (0.22)	0.15*** (0.04)	0.54** (0.26)	0.54* (0.29)	2.43*** (0.41)
If located in Dodoma	-0.00 (0.22)	0.00 (0.04)	-0.53** (0.25)	0.77*** (0.29)	0.68 (0.42)
Perceived land security	0.03 (0.09)	-0.01 (0.02)	0.01 (0.10)	0.17 (0.12)	-0.37** (0.18)
If land individually owned	0.56** (0.28)	0.11** (0.05)	0.84*** (0.30)	-0.53 (0.41)	1.40*** (0.45)
Distance to village centre	-0.08 (0.06)	-0.02 (0.01)	-0.081 (0.07)	-0.02 (0.08)	-0.51*** (0.19)
Constant	-0.49 (0.82)		-1.46 (0.97)	-1.75 (1.06)	-3.51** (1.58)
Pseudo R^2	0.1609				
Wald Chi squared (48)	272.77***				
Log likelihood	-711.44				
Shapiro/ Wilk	0.9553				
Observations	672				

Base category of farmers who chose not to adopt; standard errors (S.E.) in parentheses; *p*-values: * *p* < 0.10, ** *p* < 0.05, *** *p* < 0.01

This estimation by IPCC (Parry et al. 2007) indicates an expansion of the arid to semi-arid areas by a further 5 to 8% at

the expense of wetter areas. Related to this, the production of maize is likely to be notably reduced or even disappear in

Table 6 The impact of adopting 'climate-smart' agriculture on household food security compared to a 'non-adopter' in Tanzania. Average treatment effects (ATT) estimates are from Propensity score matching

	Nearest neighbour matching		Kernel matching		Radius matching		Γ
	ATT	S.E.	ATT	S.E.	ATT	S.E.	
Adopter vs. Non-adopter							
FCS (Average of year)	4.11***	1.64	3.40***	1.57	2.84**	1.29	1.2
Caloric intake	277.37	822.03	223.16	789.06	357.92	625.70	
Protein intake	97.41***	33.32	89.61***	31.56	85.57**	34.16	1.1
CSI (Average of year)	-5.23	3.38	-5.18	2.96	-4.29	2.50	
MAHFP	-0.27	0.48	-0.21	0.39	-0.31	0.47	
Household net income	224.94**	128.89	218.50***	97.68	189.91**	107.42	-
Household net crop value	74.89	92.52	72.45	76.84	61.97	71.71	
Diversifier vs. Non-adopter							
FCS (Average of year)	3.51**	1.61	2.51*	1.61	2.32*	1.58	1.1
Caloric intake	574.99	818.21	639.42	655.39	565.42	662.42	
Protein intake	103.32***	31.13	98.16***	32.38	96.48***	31.92	1.3
CSI (Average of year)	-0.11	3.63	-0.87	3.49	-1.84	3.06	
MAHFP	-1.48***	0.51	-1.28**	0.50	-1.18***	0.55	1.5
Household net income	127.45	133.78	110.15	124.11	105.16	117.78	
Household net crop value	-6.78	94.06	0.26	94.00	13.46	89.18	
Portfolio shifter vs. Non-adopter							
FCS (Average of year)	7.00***	2.66	4.97**	2.29	5.45**	2.43	1.1
Caloric intake	443.75	1237.12	630.33	1078.54	556.84	1005.94	
Protein intake	115.85*	69.30	142.07*	76.27	113.76*	66.77	1
CSI (Average of year)	-11.50***	4.59	-11.94***	4.31	-11.54***	3.83	3
MAHFP	0.62	0.68	0.19	0.61	0.40	0.44	
Household net income	440.22***	188.77	465.65**	179.73	416.01**	164.87	1.2
Household net crop value	243.68**	117.39	218.31*	104.01	206.49*	118.85	-
Tree planter vs. Non-adopter							
FCS (Average of year)	5.90*	3.35	8.08**	3.72	6.06*	3.42	2
Caloric intake	-2824.41	2036.69	-2351.26	2111.44	-2735.29	2082.32	
Protein intake	-70.92	85.76	-44.30	67.34	-75.08	65.95	
CSI (Average of year)	-1.65	7.40	-0.43	7.54	-3.01	7.58	
MAHFP	1.63*	0.94	1.83*	1.05	1.56*	1.12	1.9
Household net income	289.48	345.93	321.96	335.64	271.59	342.19	
Household net crop value	120.78	202.58	157.64	183.28	146.14	156.71	

ATT: average treatment effect on the treated; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ when compared to non-adopting farmers; S.E.: bootstrapped standard errors; Γ : Rosenbaum bounds (critical level for hidden bias); *FCS* Food Consumption Score, *CSI* Coping Strategy Index, *MAHFP* Months of Adequate Household Food Provisioning

some parts of Africa (Parry et al. 2007). Given the changing climatic conditions, maize yields in Tanzania are expected to decline by 33% countrywide and by up to 84% in the central regions, including in Dodoma (URT 2007).

Summary and conclusion

Our results have demonstrated that adaptation to climate change can improve the food security status of small-scale

farm households in Tanzania. The adoption of a certain portfolio of crops and cultivars that are suitable to a more challenging regional setting seems to be a promising strategy to enhance food security. It can be done by replacing the usually-planted food crop with a more drought-resistant or earlier-maturing cultivar of the same crop, or with another crop species, which were strategies already used by some of the farmers in this study.

To help promote these strategies, policy makers could invest in the distribution of better information through a

strengthened network of extension service offices. The farmers who planted trees such as mango, mdawi and neem in response to climatic changes, stressed their multiple purposes for either food, firewood or shading. Since our results showed a positive influence of the adoption of tree planting on food security, this is another intervention worth additional support from extension. The establishment of clear property rights can also contribute to adoption of climate-smart strategies but in practice changes to land tenure are difficult and politically highly sensitive.

Despite the comprehensiveness of our questionnaire, there were some limitations to the data due to its cross-sectional nature. Further research employing a panel survey is needed to account for time-invariant influences on the outcome variables. Future research should also focus more on finding other effective strategies besides the management of crop portfolios, such as sustainable agricultural practices or conservation agriculture, which may enable small-scale farmers to maintain stable yields and further improve their families' food security. This is especially needed for the semi-arid areas with extreme conditions aggravated by climate change, which are likely to shift or shorten growing seasons or change the portfolio of feasible crops.

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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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