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RESEARCH

Assessment of Nitrogen Management on Sunflower Yield and Its Economic Response in Smallholder Farms in a Semi-Arid Region

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Abstract
Although sunflower production in Tanzania is increasing, smallholder farmers still face a number of constraints that result in poor yields. Lack or inadequate nutrient supply is one of the main factors limiting crop productivity in Tanzania. However, mineral fertilizer is not always easily available and not economically affordable by smallholder farmers. Therefore, the use of animal manure could be a feasible and financially viable alternative, especially in the Dodoma region, where there is abundant livestock production. The aim is to analyze the effects of different animal manure rates on sunflower yield and the economic response of smallholder farms from Dodoma region. The dataset used in this study was obtained from a 2-year in loco survey. Sunflower yields under different animal manure rates were obtained using a process-based biophysical model, and results linked to an economic assessment. Results considering the 2015 and 2045 period showed a positive effect of animal manure application in sunflower yield (866.8 kg ha^{-1}) under manure rate limiting 5000 kg ha^{-1}. The high rates of animal manure showed a decrease on yield providing evidence that water stress becomes the main limit factor for sunflower growth. Taking the economic assessment into account, an animal manure rate of 3000–5000 kg ha^{-1} is the most appropriate fertilization management under the environmental and social conditions of Dodoma region, providing a profitable financial return to the farmers (283–416 USD ha^{-1}). Therefore, sunflower is an attractive cash crop for Tanzanian farmers when the soil fertilization is properly managed.

Keywords Sunflower · Fertilization · Tanzania · Crop model · Economic assessment

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Introduction

Sunflower (*Helianthus annuus* L.) production in Tanzania has shown an increase in the recent years, from 350,000 tons of seeds in 2008 and reached close to 1 million tons in 2018 (FAO, 2018), with the potential to increase further (United Republic of Tanzania, 2016). Due to its drought tolerance and adaptation to a great variety of soils, sunflower is widely cultivated in Tanzania, including in the semi-arid region of Dodoma (350–500 mm of annual precipitation), accounting for 22.5% of sunflower production in the country. However, the majority of farmers still face a number of constraints, including the predominant use of recycled seeds from previous seasons; manual labor with hand tools and animal traction; poor agronomic practices; lack of access to inputs such as fertilizer and agrochemicals; and poor extension services (RDLC, 2008). These constraints result in poor yields and poor production quality, thus affecting the availability of edible sunflower oil in Tanzania. Currently, Tanzanian sunflower production makes up 36% of national oilseed production, contributing about 40% of national edible oil requirement. Further, the production cost of sunflower oil is lower than other oilseed crops. Overall, Tanzania faces the necessity to import more than half of the edible oil consumed in the country (Mgeni et al., 2018; RDLC, 2008; United Republic of Tanzania, 2016).

Tanzanian crop productivity is limited by inadequate, if not the complete lack of, soil fertilization (Graef et al., 2014). At the same time, there is a growing need for food and other agricultural products, while soils are often threatened by degradation.

According to Graef et al. (2015), assessments of food production in Tanzania, especially in Dodoma region, indicated that intercropping, cover crop, fertilization input (manure or mineral fertilization), and soil–water management (rainwater harvesting) are feasible upgrade strategies that would sustainably improve Tanzanian food systems. Not only is the availability of fertilization input, particularly mineral fertilization a limiting factor in Tanzania, but it is also not economically affordable by smallholder farmers (95% of the farmers). Therefore, the use of animal manure as an organic fertilizer could be a feasible and financially viable alternative, especially in Dodoma region where there is a good availability of manure input due to the abundant livestock production (Graef et al., 2015). Half of smallholder farmers in Tanzania raise livestock of any kind, both for consumption and for sale (Anderson et al., 2016), and its availability is growing as total livestock numbers increased over the last decennia (Engida et al., 2015). Improving fertilization and the use of adequate soil and crop management controls the availability of water and nutrients to the plants, thus allowing farmers to increase their crop production. Since nitrogen fertilization is a critical component of crop growth and yield formation, it is important to apply an appropriate amount of nitrogen fertilizer based on the soil and environmental conditions, and crop requirements (Ozturk et al., 2017). Subsequently, avoiding unnecessary input costs to the farmers also minimizes the potential negative environmental impact through nutrient loss.

Crop models are important tools for assessing the influence of different environmental or management factors on crop development and yield (Reidsma et al., 2010). In this way, it is possible to analyze the effects of nitrogen fertilizer application on sunflower crop yield and identify the best fertilizer management approach for Tanzanian conditions. However, implementing such fertilizer management could occur excessive costs to farmers. Consequently, the link between crop models and economic assessments can be a useful tool for estimating production costs and farmer profit; in particular, the trade-offs between economic and management strategies to optimize production planning decisions for sunflower production in Tanzania (Vilvert et al., 2018).

Therefore, the aim of this study is to link a crop model with an economic assessment in order to analyze the effects of different animal manure management options on sunflower yield and the economic response of smallholder farms in Tanzania. We hypothesize that the use of animal manure as a fertilization management will improve the sunflower production and consequently increasing household incomes. As consequence, ensuring in the future an adequate availability of edible oil for domestic consumption, as well as reducing the dependence on imported vegetable oils. The increase in local and global market demand for sunflower oil is due to consumer interest in its high nutritional values compared to other vegetable oils. Consequently, increases in sunflower yields in Tanzania will be rapidly absorbed by these assured markets and, hence, economic opportunities and revenues for farmers (Mgeni et al., 2018; United Republic of Tanzania, 2016).

Material and Methods

Database

Field data were obtained from an extensive survey carried out within the framework of the Trans-SEC (Trans-SEC—Innovating Strategies to Safeguard Food Security Using Technology and Knowledge Transfer: A People Centered Approach) project (Graef et al., 2014). The resulting data includes an overview of household activities in two different years as the reference period, 2013 and 2015, as well as in two regions of Tanzania, Morogoro and Dodoma. In each target region, three case study sites (villages) were selected to represent the regional farming system. The survey total sample consists of 899 households. After an extensive analysis of the survey data from both periods, the Dodoma region was selected as the target region for our study due to its importance for sunflower production and due to a significantly greater number of farmers cultivating sunflower in comparison with Morogoro. In total, 149 households cultivated sunflower in Dodoma region in 2013 and 276 households in 2015. However, only 109 households cultivated sunflower in both periods.

Soils in the targeted households are mainly Chromic Lixisols, Haplic Acrisols and Sodic Vertisols (Reinhardt & Herrmann, 2017) with low soil organic carbon (on average below 0.3%), pH (in H_2O) ranging from 5.0 to 8.7 (with most of the sites between 5.7 and 6.1), low nitrogen levels (average of 0.04%) and low to very low plant available P levels (0.3–11.7 mg kg^{-1}) (Reinhardt et al., 2020). Soils in the region are seasonally waterlogged or flooded (Msongaleli et al., 2015).

As the soil of the target region is defined as low fertile, adequate plant nutrient supply would be important to obtain a successful sunflower yield. Access to mineral fertilizers is limited and application of animal manure depends on available labor and which crop delivers the best input–output ratio. Of the 109 households cultivating sunflower in both periods, only 20 households applied animal manure as an organic fertilizer at least in one of the survey years.

Crop Modelling Procedures

Location

The crop modelling procedure was done for Dodoma region, specifically for households in the Ilolo, Ndebwe and Idifu villages (Fig. 1). From the Trans-SEC survey, a total of 22 datasets from households (comprising specific sunflower yield and animal manure amount) was available for both crop seasons. Detailed soil profile information was obtained from the WISE v1.1 database (ISRIC & Batjes, 2015). The region is characterized by low and erratic rainfall with a unimodal regime.

The long-term mean annual rainfall is about 511 mm, with average temperatures of 22.7 °C. The onset of rainfall usually occurs in late November or early December, with the rainy season extending through April (Fig. 2). As the rainfall pattern in the study region is variable within the rainy season, cultivation is restricted to a few areas where water availability is higher and the soil has a higher water holding capacity.

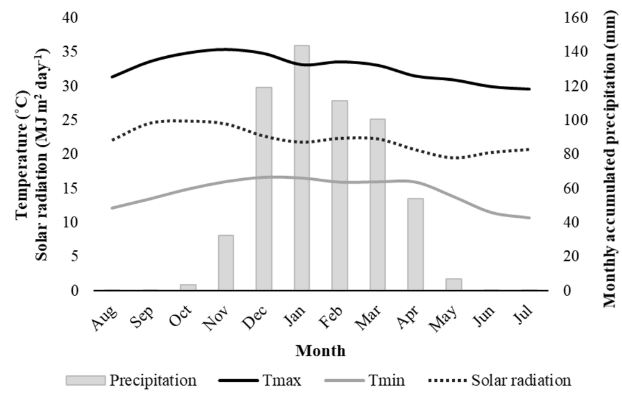


Fig. 2 Meteogram depicting monthly accumulated precipitation, solar radiation, maximum and minimum temperature for the Dodoma region. Data based on 1981–2020 series obtained from NASA/POWER (2022)

Model Evaluation

To generate projections of sunflower yield, a crop simulation model was employed. The crop modelling process was done using the OILCROP-SUN model (Villalobos et al., 1996)

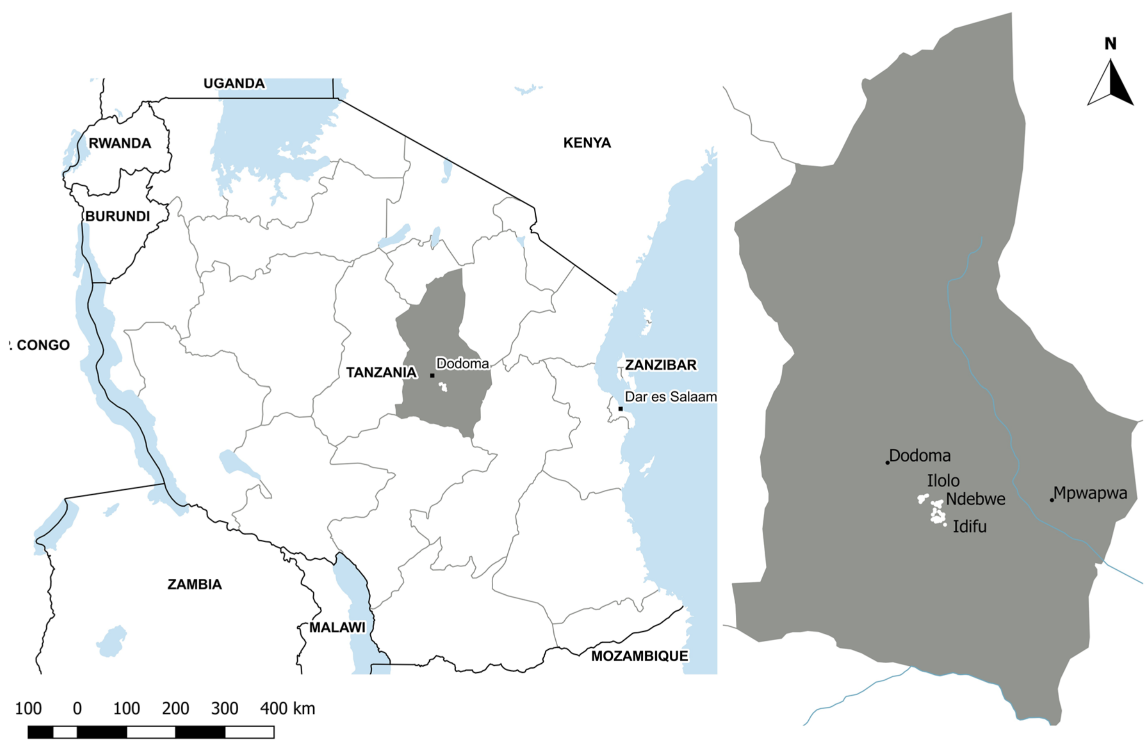


Fig. 1 Tanzania map highlighting the Dodoma region (grey area) and the GPS localization (white circles) of the 109 sunflower households taking part of the study

embedded in DSSAT (Jones et al., 2003), an established decision support system already used in several impact assessment studies.

For this assessment, the prerequisites to select the households that integrated the model evaluation procedure were the availability of information regarding: (1) the exact location of the farm (in order to identify the appropriate soil and weather information); (2) a record of the amount of animal manure applied (kg ha^{-1}); (3) the yield of sunflower seeds (kg ha^{-1}); and (4) the sunflower seeds yield must not be lower than the standard deviation of the total sample (to avoid outliers and exclude situations where farmers lost their fields due to attacks of pests or animals).

In order to define the sunflower cultivar, since this information was not available, a series of simulations were carried out using all DSSAT available cultivars to identify which one mimics observed yields when the same parameters of fertilization, soil and weather are used. From the available genotypes, the sunflower cultivar SH-3000 was selected. Difference-based indices, such as mean absolute error (MAE) (Willmott & Matsuura, 2005), root mean squared error (RMSE) and relative root mean squared error (RRMSE), were used to evaluate the simulation outputs.

Model Simulation

After the successful results from the model evaluation, simulations were conducted to analyze the sunflower yield from 2015 through 2045 under the application of 10 different dosages of organic manure (0, 250, 500, 750, 1000, 2000, 3000, 5000, 7500, 10,000 kg ha^{-1}).

The planting date was set to occur on December 22nd each year, after the onset of the rainy season (usually late December). The final sunflower plant population density was defined at 30,000 plants per ha, planted at 7 cm depth in rows with 75 cm of spacing between rows. This low plant population, the space between rows, and planting depth represent common regional practices, as identified in the surveys. Animal manure use was set individually for each farm and year, based on survey data. The concentration of N in the animal manure is assumed to be 1.5%. No irrigation was applied. DSSAT was instructed to start the simulations on November 1st each year to provide a more realistic soil water balance at sowing. Harvest was set to take place two weeks after physiological maturity, as calculated by the model.

Since weather data was not available for the study sites, a gridded data set from the Inter-Sectoral Impact Model Intercomparison Project—ISI-MIP (Warszawski et al., 2014) was used. This data set provides a bias-corrected dataset with daily values for temperature (Tmax, Tavg, and Tmin), precipitation, relative humidity, and solar radiation. These data are well accepted and are also used in 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 follow: GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM.CHEM, and NorESM1-M, totaling 15 different projections of three RCPs, as in Lana et al. (2018). All the models have the capability to explicitly represent biogeochemical processes that interact with the physical-climate processes. To capture the fertilization effect of increasing levels of atmospheric CO2, the concentration of CO2 was adjusted yearly according to the respective RCP (Meinshausen et al., 2011).

The format of climate files was adjusted for DSSAT structure, and simulations were run for each projection and representative concentration pathway (RCP). For the analysis of results, yields are averaged in an ensemble (2015–2040) to reduce the inter-annual variability effect and provide more robust information (Randall & Wood, 2007).

Economic Assessment

The economic assessment of the simulated fertilizer response of sunflower yields under smallholder conditions in Tanzania is based on the data from gross margins calculated for survey data collected in 2013 and 2015 in the study region of Dodoma. Gross margins are a partial cost–benefit calculation that provides a good indication of the profitability of a production activity when fixed and labor costs are not available or do not matter as they would be similar for all alternative production activities. When we compare different cropping activities under smallholder conditions in Africa, these assumptions are valid as long as there are no investments in machinery concerned. The calculated revenues from sunflower production are based on crop yields based on survey data of consumed and sold product multiplied by the mean price for a crop at the regional level. The average costs for seeds, herbicides, and insecticides are subtracted from the calculated revenues (fungicides were not used for sunflower cultivation). Furthermore, the average variable machinery costs (land preparation and harvest) and the average costs for services are deducted from revenues. We corrected for outliers and assumed that, apart from fertilizers, all costs are independent of the yield achieved.

For the evaluation of the simulated average yields response to different animal manure rates we calculated a price for the animal manure based on the assumption that the manure originates from dairy cattle (light breed, 5000 kg ECM), which excrete 76 kg N and 27 kg P_2O_5 per year (DüV, 2017). This leads to the conclusion that it contains 1.5% nitrogen (N) and 0.23% phosphorus (P). For further calculation, the average fertilizer prices for urea (46% N) and triple superphosphate (TSP, 20% P) in Tanzania are 627 USD t^{-1} and 658 USD t^{-1}, respectively. The pure nutrient price is 1.38 USD kg^{-1} for urea and 3.29 USD kg^{-1} for TSP (average for years 2010–2018 according AfricaFertilizer.org (2018)).

Based on the percentage of N and P contents and the respective pure nutrient price, the animal manure for each element is evaluated in monetary terms (0.02046 USD per kg urea-N, and 0.00765 USD per kg TSP-P). The total is then calculated resulting in a price for the used manure amounts based on the contained nutrient value (0.02811 USD per kg manure).

Results and Discussions

Agricultural Production in Dodoma Region

Agricultural production in Dodoma takes place in small-scale agricultural units, with farms averaging 2.42 ha in 2013 and 2.51 ha in 2015. Livestock production is also present in the majority of the households (368 from 449 households raise at least one kind of livestock), it is important for home consumption, animal traction, as well as for farm income and flexible capital stock.

Calculations using the Trans-SEC survey data indicated that farms with any kind of livestock had an average of 4.9 animal units per household (with beef cattle and oxen accounting for 71% of all animal units). When dividing the animal units by the area used for agriculture in each household, the animal unit density is of 2.9 animal units per hectare of crop area.

Agricultural production is largely subsistence oriented with only a few crops produced for the local market, such that 77% of the overall recorded yields in 2013 was kept for own consumption, leaving 23% of the overall yield to be sold on the market. In this variable weather situation, with a high risk of drought periods, it is important to spread the risk of a crop failure by cultivating different crops with different growth patterns, as well as holding some livestock, which functions as a risk insurance capital in drought periods. Despite a large number of households cultivating the most important crops, there is a wide variation across farms and the main staple food crops are not grown by all households. The crops are typically cultivated in mixed cropping or crop rotation and sunflower is normally intercropped with groundnuts (*Arachis hypogaea* L.), millet (*Pennisetum glaucum* L.), sesame (*Sesamum indicum* L.), sorghum (*Sorghum bicolor* L.), maize (*Zea mays* L.), and bambara nuts (*Vigna subterranean* L.).

When analyzing only the data from the 109 households that cultivated sunflower during both Trans-SEC survey periods in Dodoma region we also detected that agricultural production takes place on small-scale farm units with landholding areas of about 2.83 hectares for 2013 and 2.77 hectares in 2015 (Table 1). The majority of the farmers owned their land, but some only owned part of the land they cultivate, while renting, seasonally, other plots. Sunflower is cultivated on small plots with areas averaging on 0.6 ha. The decision to rent new land plots and on the plot size intended for each crop depends on seed availability, climate conditions, and economic factors, thus explaining the annual variation in sunflower production, land size, and tenure status of the households.

In relation to sunflower management, the seeds were recycled from the previous season, no agro-chemical was used, while weeding and harvesting were carried out manually and mainly with familiar labor. The households applying organic fertilizer used only animal manure as source of fertilization. Similar fertilization patterns are observed in different Sub-Saharan regions, where animal manure is the main source of fertilization and mineral fertilizer is rarely used (Ciceri & Allanore, 2019). In general, the animal manure was applied without any criteria and in different amounts based on manure availability (own production) and poor technical information. The inappropriate use of animal manure can lead to nutrient losses as well as water source contamination, general pollution, and crop yields not being positively affected (Kumar et al., 2013). Therefore, the farmer's access to agronomic extension services and technical information is crucial for facilitating the proper use of animal manure as soil fertilization that improves sunflower production and maintains sustainable agriculture practices. After harvest,

Table 1 Average, maximum and minimum land size of the households (hh) and sunflower plot size; as well as sunflower final yield in the years 2013 and 2015 for the 109 sunflower households that cultivated sunflower in both survey years

	2013			2015		
	Total hh area (ha)	Sunflower area	Sunflower yield (kg ha^{-1})	Total area hh (ha)	Sunflower area	Sunflower yield (kg ha^{-1})
Average	2.83	0.60	262.08	2.77	0.62	507.94
Min. value	0.81	0.10	4.94	0.40	0.10	19.77
Max. value	14.47	3.24	1,507.33	27.11	6.07	3,706.54

the final sunflower production is divided to be used as seeds for the next season, for household consumption, or for sale as cash crop. Sales are accomplished through middlemen who then sell the seeds to oil processors. In general, the household description is in accordance with the current characteristics of the Tanzanian sunflower value chain, as described by Vilvert et al. (2018).

Table 2 shows, for the 2013 survey data, the averages for the most important cash crops cultivated among all the households taking part of the survey, as well as, additionally, the minimum and maximum values for the resulting gross margins. The gross margins that farmers achieve with their sold products differ widely between farmers as yields and crop management strategies are highly variable, depending on the levels of manure and pesticides as well as the use of machinery and hired labor. The comparison also shows that sunflower has a wide range of yields and gross margins, with averages below those of millet and sorghum. The wide differences on yields are also seen between crop seasons, in 2013 the average sunflower yield was 320.1 kg ha^{-1} (Table 2) followed by an increase in 2015 with an average yield of 469.9 kg ha^{-1} (data not shown). The high level of yield variability between both households and crop seasons is one of the biggest constraints faced by smallholder farmers in semi-arid areas (Arce & Caballero, 2015), especially due to climate variability. The increase in sunflower yield between 2013 and 2015 is also shown among the households who cultivated sunflower in both survey years (Table 1). However, compared with the 2014 Tanzanian average sunflower yield of almost 1,000 kg ha^{-1} (FAO, 2018), there is still potential for improvement in these specific households.

Moreover, results in Table 3, provide an overview of the crops sold on the market, indicating that 12% of the average household income from crop production is gained from sunflower. The data show that sunflower is already treated as a cash crop, but to a lesser extent and with lower revenues than cereals (sorghum, bulrush millet and millet), sesame and groundnuts. However, the range of gross margins is similar

Table 2 Comparison of the crop production data (area and yield), production cost data (input costs contain seeds, fertilizers and pesticides when used), and average, minimum (min.) and maximum (max.) gross margins between the most important crops produced in Dodoma region during 2013

Crop	Area	Yield	Input costs	Machine costs	Hired labor	Revenue	Average gross margin	Min. gross margin	Max. gross margin
	(ha)	(kg ha^{-1})	(PPP USD ha^{-1})[a]						
Sorghum	0.83	405	6.45	10.66	9.14	150.92	124.67	– 558.47	1501.76
Bulrush millet	0.99	356	5.31	5.64	11.01	129.07	107.11	– 513.89	1931.55
Millet	1.04	445	10.45	4.62	8.45	123.60	100.07	– 73.04	653.52
Sesame	0.78	380	16.51	14.15	10.87	118.88	77.36	– 672.99	1757.30
Groundnuts	0.77	519	17.66	14.44	11.51	81.37	37.76	– 849.10	1364.93
Sunflower	0.65	320	4.43	10.48	7.34	68.12	45.87	– 389.29	1501.76
Cowpeas	0.56	171	12.25	8.06	2.82	38.00	14.87	– 295.39	338.53
Maize	0.69	336	9.66	5.30	4.14	37.99	18.90	– 330.21	636.34

[a]Values were calculated from the Tanzanian currency (TZS-Tanzanian shilling) to Purchasing Power Parity (PPP) USD with the reference year 2010

Table 3 Average share of crop sold, average income from sold crop and the percentage of income of each crop from the total household income of the most important crops produced in Dodoma region during 2013

Crop	Share of crop sold (%)	Income from sold crop (PPP USD ha^{-1})[a]	Share of income per crop of the total income from crop production (%)
Sesame	69.0	9.74	28.0
Sunflower	38.0	3.83	12.0
Groundnuts	36.0	7.68	22.0
Cowpeas	26.0	0.18	1.0
Maize	15.0	0.85	2.0
Sorghum	13.0	5.58	16.0
Bulrush millet	6.0	5.80	17.0
Millet	5.0	0.68	2.0

[a]Values were calculated from the Tanzanian currency (TZS-Tanzanian shilling) to Purchasing Power Parity (PPP) USD with the reference year 2010

to that of cereals, thus indicating that there is potential for improvement of the crop management that would thereby increase yields and revenues.

Crop Model Analysis

Model Evaluation

From the initial 22 datasets of households applying animal manure in the Dodoma region, only 12 (four from 2013 and eight from 2015) could be used for the evaluation process. Farms with yields lower than the standard deviation from the initial sample were excluded. The reason is that those yields could not be explained by any management, soil, or weather effect and, therefore, cannot be adequately simulated by the model. In fact, in some situations, livestock invaded the fields and foraged or otherwise damaged the crops. The results of the evaluation process indicate that the crop model could mimic the sunflower seeds yields from field observations ($n = 12$) of the two available crop seasons (Fig. 3).

According to Jamieson et al. (1991), the simulation is considered excellent if the RRMSE is lower than 10%, good between 10 and 20%, fair from 20 to 30%, and poor if greater than 30%. The MAE measures the average of absolute errors between predicted and observed values. If all simulated and observed values are the same, then MAE, RMSE, and RRMSE should be equal to zero.

Overall, the results certify that the model mimics field observations for yields with respect to the effect of different animal manure applications, even though specific data regarding planting dates, as well as the losses caused by pests, diseases, and other stressors, is lacking. Data related to phenology and aboveground biomass was not available for comparison.

Yield Simulation

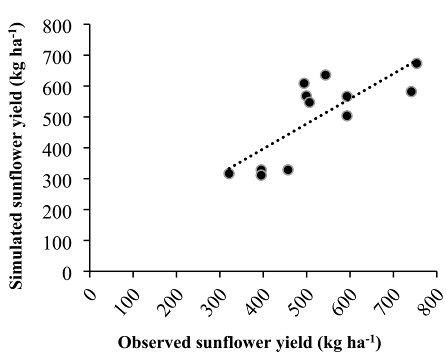
Results from the crop model simulation for the target period (2015–2045) shows the positive effect of animal manure application on sunflower yields in the Dodoma region (Fig. 4a). The increase of sunflower average yield is linear between 0 and 2000 kg ha^{-1} of manure application, indicating that the main limiting factor in this situation is N, as accounted by the model.

Since the scenarios used for running the 2015–2045 simulations did not present a significant variation in terms of accumulated precipitation during the cropping season, nor a shift on the onset of the rainy season for Dodoma (as shown by Lana et al. (2018)), climate change effects are unlikely to be a source of yield variation.

In semi-arid regions like Dodoma, the main factors limiting crop productivity are water and N supply. However, as sunflower is tolerant to drought periods, in areas facing limited water availability, improving soil fertilization (especially N) is essential for improving plant nutrition, which can help to enhance sunflower drought tolerance, to alleviate the adverse effects of water stress, and, consequently, to improve sunflower yield (Ahmad et al., 2014).

Meanwhile, animal manure applications above 2000 kg ha^{-1} show a decreasing yield increment rate, thus providing evidence that water stress becomes more limiting than N. Application rates above 5000 kg ha^{-1} of animal manure present even a reduction in sunflower yields. One possible reason for this decline in yield is that plants, when well supplied with N at the beginning of the season and in combination with adequate supply of water, have a good vegetative growth. Later, when entering the reproductive stage, the higher plant biomass, specifically the leaf area index, increases the water demand for the plant. As this occurs at the end of the rainy season, the soil water supply might not be sufficient to attend the plant evapotranspiration demand, which then leads the plant in a stress mode, reducing the allocation of photoassimilates into the seeds. Therefore, the use of an adequate amount of animal manure is important for sunflower plants to better cope with the water limitations of the Dodoma region and, at the same time, improve seed yield.

From the agronomic perspective, the higher rates of animal manure application could have a long-term beneficial effect due the increment in the soil water holding capacity.



Year	Average Yield Observed	Average Yield Simulated	MAE	RMSE	RRMSE
	-------kg ha^{-1}-------		kg ha^{-1}	kg ha^{-1}	%
2013	392	321	158	71	17,2
2015	591	586			

MAE: Mean Absolute Error; RMSE: Root Mean Squared Error; RRMSE: Relative Root Mean Squared Error

Fig. 3 Results of the validation process for the DSSAT crop simulation model using difference-based indices comparing simulated and field observations (n = 12 households data) of sunflower seeds yield in two different seasons (2013 and 2015) in Tanzania

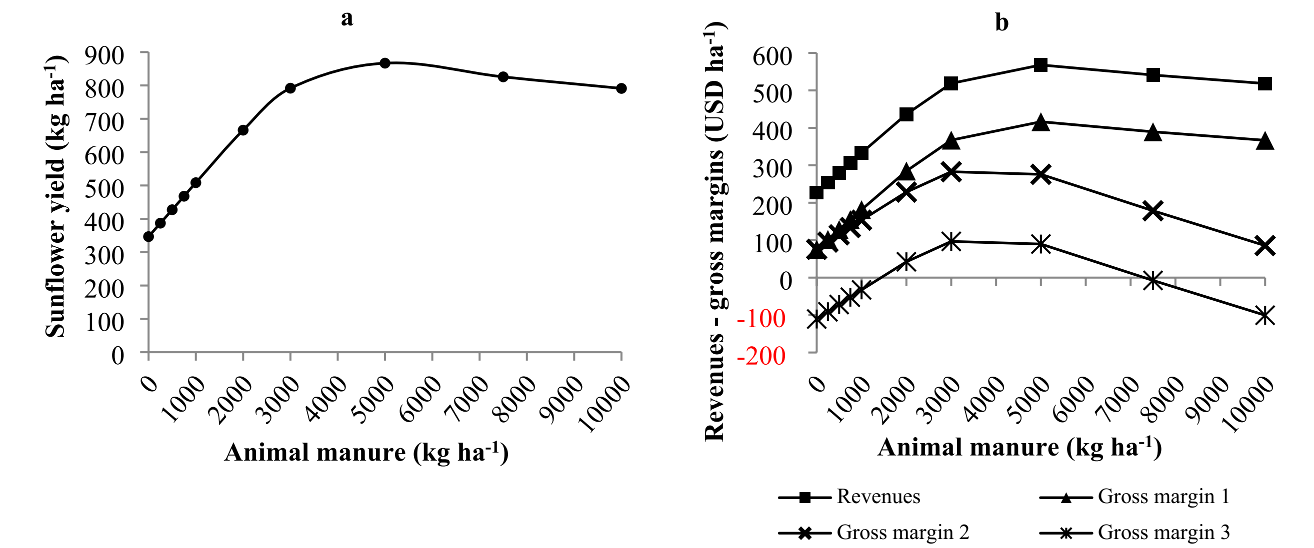


Fig. 4 **a** Simulated effect of animal manure application rates (X axis) on sunflower yield (Y axis), data show the average sunflower yield along the years 2015 to 2045; **b** simulated results from revenues and gross margins (GM) for sunflower production at different animal manure rates (GM1: revenues minus variable costs, excluding animal manure; GM2: GM1 minus value of animal manure; and GM3: GM2 minus value of hired labor)

However, studies using crop models are not conclusive in this regard. In addition, the combination of different sustainable intensification practices could be a good strategy for improving the benefits of soil fertilization and providing a higher and more stable sunflower yield. Further, in addition to integrated pest management and use of quality seeds, we can cite the use of soil water conservation techniques, like minimum tillage, to improve soil moisture in dry areas (Mohammadi et al., 2013), and adequate crop rotation for improvements in soil N and C (Snapp et al., 2018). Obviously, the successful implementation of these strategies would also need governmental cooperation and support to improve the extension services that engage in knowledge transfer and motivate farmers to invest in these new technologies.

The yields obtained by using the different animal manure application rates are also important for the economic analysis performed here. While, from the yield perspective, the application rate of 5,000 kg ha^{-1} (equivalent to 75 kg N ha^{-1}) would be the most advantageous, when considering economic aspects related to the cost of animal manure and its application, the conclusions might be different. In order to accomplish this analysis, the outcomes from the crop modelling procedure are used as input for economic assessment.

Economic Analyses of the Simulation Experiment

The data of costs and benefits in this economic analysis of improved sunflower production are based on survey data regarding the level of input use. Prices for seeds and pesticides are partly obtained from the survey and complemented by national data. The survey data show a high variability on yield between farmers and depend on the yearly varying pest pressure and availability of quality seeds. We calculated a price of animal manure based on the relative availability of nitrogen and phosphorus within the animal manure compared to mineral fertilizers. Finally, we obtain three levels of gross margin (GM) depending on the amount of inputs considered and the assumptions regarding the availability and the opportunity costs of animal manure, seeds, and labor.

Figure 4b shows the corresponding graphs for gross revenues: GM1—revenues minus variable costs, excluding animal manure; GM2—revenues minus total variable costs, including animal manure; and GM3: revenues less total variable costs and hired labor. If animal manure is abundant and free of charge and no other inputs need to be purchased, then we obtain the curve GM1 with a peak around 5,000 kg ha^{-1}. Higher animal manure applications would lead to decreasing yields. That means that, from an economic point of view, an animal manure application level of 5,000 kg ha^{-1} corresponds to the economic optimum. The peak results in a gross margin of 416 USD ha^{-1}, which is a very good result compared to other crops. However, animal manure is not always free of costs (when farmers do not produce a high amount of animal manure with their own livestock production) and animal manure could also be used for other crops with unknown returns. Additionally taking the high variability of input use and yield levels into account, we cannot conclude that sunflower is the best option, but rather that it is one of several good options if free animal manure is available for use.

The curve titled as GM2 takes the relative value of animal manure into account and leads to a different response function with a peak around 3000 kg ha^{-1}. This means that taking the monetary value of nutrients within the animal manure into account, or using mineral fertilizers, would lead to a lower economic optimum for an animal manure application level of 3000 kg ha^{-1}, equivalent to 45 kg N and 7 kg P. This is equivalent to a gross margin of 283 USD ha^{-1}, which is still attractive for farmers. However, if farmers have to hire labor, the gross margin (GM3) is further reduced to a level that is no longer attractive for farmers. In a study conducted with maize in Kenya (Duflo et al., 2008), have also shown that the use of mineral fertilizer at an appropriate rate and taking into account the local environmental conditions leads to yield increase with a profitable financial return, even taking in account the cost of purchasing the mineral fertilizer.

The economic analysis shows that, under smallholder conditions in the Dodoma region, there is the potential to increase yields and that, even when using purchased fertilizer, sunflower could be an attractive cash crop for farmers if properly managed. Thereby, an animal manure application level of 3000–5000 kg ha^{-1} would be appropriate, depending on the opportunity costs for animal manure and the growth potential defined by soil and weather conditions. This result is in accordance with the crop model analysis indicating that the application rate of 5000 kg ha^{-1} is the most advantageous for sunflower production in Dodoma region. As shown in Fig. 4a, the highest technical efficiency of the nutrients with the scarce manure is obtained when application levels remain in the linear part of the response curve. This level of animal manure fertilization would provide an increase in sunflower yields by almost 400 kg ha^{-1}, leading to an average yield of 866.8 kg ha^{-1}, still far from the national average yield of around 1033 kg ha^{-1} in 2018. The average yield in 2018 in Tanzania is still below the average yield in South Africa (1433 kg ha^{-1}), the largest sunflower seed producer among African countries. However, in both cases, it is still less than half of the average yield of Ukraine (2297 kg ha^{-1}), one of the major sunflower producing countries (FAO, 2018). However, when comparing the sunflower production between these countries, we should take into account that the sunflower production in African countries relies on smallholder farmers who have limited access to quality inputs, certified seeds, and financial services, leading to lower yields and quality of production (United Republic of Tanzania, 2016). With further agricultural improvements and government investments, sunflower production in the Dodoma region – and nationally has great potential for significant improvement.

In this regard, visualizing the key role of sunflower as a cash crop and the potential contribution to the economic development of Tanzania, since 2016 the government is implementing the Sunflower Sector Development Strategy, a public–private partnership. This strategy intends to develop the sunflower sector from 2016 to 2020. The goal is, first, to increase sunflower production by facilitating the availability and accessibility to fertilizers and quality seeds, use of modern technologies and good management practices, implementation of coherent and supportive policies, as well as developing the market. Then prioritizing the achievement of food security and social inclusiveness, as well as promoting economic growth and integration into regional and global markets (United Republic of Tanzania, 2016). Therefore, the results of this paper could be used as a technical support to the agriculture extension workers working on this strategic program, providing agricultural advisory services about the suitable fertilization practices for sunflower production in Dodoma region. Moreover, this could also encourage current sunflower farmers to continue producing sunflower with further management improvement, visualizing the improvement on economic returns.

Conclusions

The data from the field survey carried out in the Dodoma region and further analysis indicated that other crops than sunflower (sorghum, bulrush millet, millet, sesame and groundnuts) are more economically attractive in terms of revenue for local farmers under the current cropping system, despite the fact that the range of sunflower gross margin is similar to that of the above-mentioned crops. This evidences that there is potential for improvement in the sunflower agronomic management that would increase yields and thereby revenues.

The crop model simulations coupled to economic analysis evidenced that the maximal agronomic efficiency on yields and gross margins results from an application rate of animal manure between 3000 and 5000 kg ha^{-1}. This work also evidenced that manure application rates above this threshold can even reduce the crop yield in semi-arid regions, since low water availability limits the benefits of fertilization.

In addition, according to the economic assessment, sunflower production can be attractive for the smallholder farmers in Dodoma region as long as the input level concerning pesticides is minimal and animal manure applied as fertilizer is available at the farm with no extra cost.

Therefore, sunflower can be an optimal cash crop for agricultural diversification under the environmental conditions of the semi-arid region of Dodoma. Appropriate sunflower genotypes could also potentially respond better to increased manure fertilizer application rates, resulting in increased yields. While crop models are important tools for design and assessment of cropping systems, more field-based research is needed to establish aspects such as best sowing densities and cropping system management. The high local and global demand for sunflower oil and the high protein content of its seeds will rapidly absorb future increases in the production of sunflower in Tanzania, leading to higher revenues for smallholder farmers and positive impacts on household food security.

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Declarations

Conflict of Interest The authors reported no potential conflict of interest.

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