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CLIMATE CHANGE ADAPTATION IN VULNERABLE CROP AND LIVESTOCK PRODUCTION SYSTEMS IN MGETA, TANZANIA

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ABSTRACT

Increased occurrence of drought and dry spells during the growing season have resulted in increased interest in protection of tropical water catchment areas. In Mgeta, a water catchment area in the Uluguru Mountains in Tanzania, water used for vegetable and fruit production is provided through canals from the Uluguru South Forest Reserve. The clearing of forest land for cultivation in the steep slopes in the area is causing severe land degradation, which is threatening the water catchment area, livelihoods, and food security of the local communities, as well as the major population centers in the lowlands. In this paper, the economic performance of a traditional cropping-livestock system with East African (EA)-goats and pigs and extensive vegetable production is compared with a more sustainable and environmentally friendly crop-dairy goat production system. A linear programming (LP) crop-livestock model, maximizing farm income considering the environmental constraints in the area was applied for studying the economic performance of dairy goats in the production system. The model was worked out for the rainy and dry seasons and the analysis was conducted for a basic scenario representing the current situation, based on the variability in the 30 years period from 1982-2012, and in a scenario of both lower crop yields and increased crop variability due to climate change. Data obtained from a sample of 60 farmers that were interviewed using a questionnaire was used to develop and parameterize the model. The study found that in the steep slopes of the area, a crop-dairy goat system with extensive use of grass and multipurpose trees (MPTs) would do better than the traditional vegetable gardening with the EA goat production system. The crop-dairy goat system was superior both in the basic and in a climate change scenario since the yield variation of the grass and MPTs system was less affected compared to vegetable crops due to more tree cover and the use of perennial grasses. However, the goat milk production in the area was constrained by inadequate feeding and lack of an appropriate breeding program. Hence, farmers should enhance goat milk production by supplementing with more concentrate feed and by implementing goat-breeding principles. Moreover, policy measures to promote such a development are briefly discussed.

Key words: dairy goats, climate change, risk analysis, Tanzania, production system

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INTRODUCTION

For more than a decade, climate change and variability have featured strongly in the development discourse across the world, and awareness and effects of climate change on the environment and livelihoods are becoming more apparent than ever before [1,2]. In Tanzania, much attention has been paid to the performance of different farming production systems. Among the farming systems that have particularly attracted the attention of scholars are those in Mgeta, a high altitude water catchment area in the Uluguru Mountains. Generally, a review of literature on agriculture in Mgeta reveals that the farming systems in the area have evolved from being centered on cereals, through being based on vegetables with East African (EA) goats and other livestock species, to the current system in which dairy goat production is an integrated component. In the earlier systems, land degradation has been widely reported [3]. In some places of Mgeta, the land degradation is currently so severe that it is threatening not only the water catchment for domestic use but also the livelihoods of the local communities. Increased occurrence of drought and dry spells during the growing seasons in recent years might have reinforced the problem. Developing and expanding a robust cropping system that would be more appropriate in the steep slopes to replace some of the most erosion-vulnerable vegetable crops is clearly needed if agriculture is to persist in the area. Integrating dairy goats into such a system could improve the environmental situation, since dairy goats are more productive and can be tethered or stall-fed while using minimal land area, thus avoiding land degradation due to overgrazing [4].

Farmers in Mgeta grow vegetable crops in pure stand and in intercropping systems on bench terraces and in steep slopes, especially tomatoes, potatoes, cabbage, beans, green peas and maize. In early 1988, dairy goats were introduced through a project implemented by Sokoine University of Agriculture (SUA) with Norwegian governmental support [4, 5]. In addition to dairy goats, East African meat goats (EA-goats) and pigs were kept for meat and provision of manure for vegetables. Due to the need for milk by the family, farmers upgrade the EA-goats to dairy breed by crossing with Norwegian dairy bucks. Moreover, increasing goat milk production might be advantageous since a market for milk or milk products such as yoghurt can be found both locally and in the neighboring towns. However, the production of yoghurt needs to be developed to take advantage of the market opportunities [6]. Currently, dairy goat milk production is limited due to inadequate breeding and feeding practices and intervention in those areas could become a long-term strategy for increasing goat milk production in the Mgeta area.

In this study, the current production system was assessed and opportunities for improvements concerning economic performance and environmental impact explored. In particular, a traditional cropping-livestock system with EA-goats and pigs and extensive vegetable production is compared to a system with dairy goats and more use of MPTs and grass and with less vegetable production. A linear programming (LP) model was developed for the comparison. Further, the description of field data collected in Mgeta and the economic analysis conducted are shown. This is followed by a presentation of model results and a discussion of policies for promoting a sustainable and more environmentally friendly production system in the area.

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MATERIALS AND METHODS

The study area and sampling

The study was undertaken in Mgeta, a high altitude water catchment area located in Mvomero District of the Morogoro region, eastern Tanzania, about 50 km from Morogoro town (Figure 1). The Mgeta division sits in undulating hills ranging from 1100 to 1900 m above sea level. Two season cycles (rainy and dry) are important to farmers. The climate is sub-tropical with regular rainfalls, which favor intensive cropping of rain fed or irrigation based vegetables which are combined with livestock especially dairy and meat goats, pigs and poultry, and aquaculture.

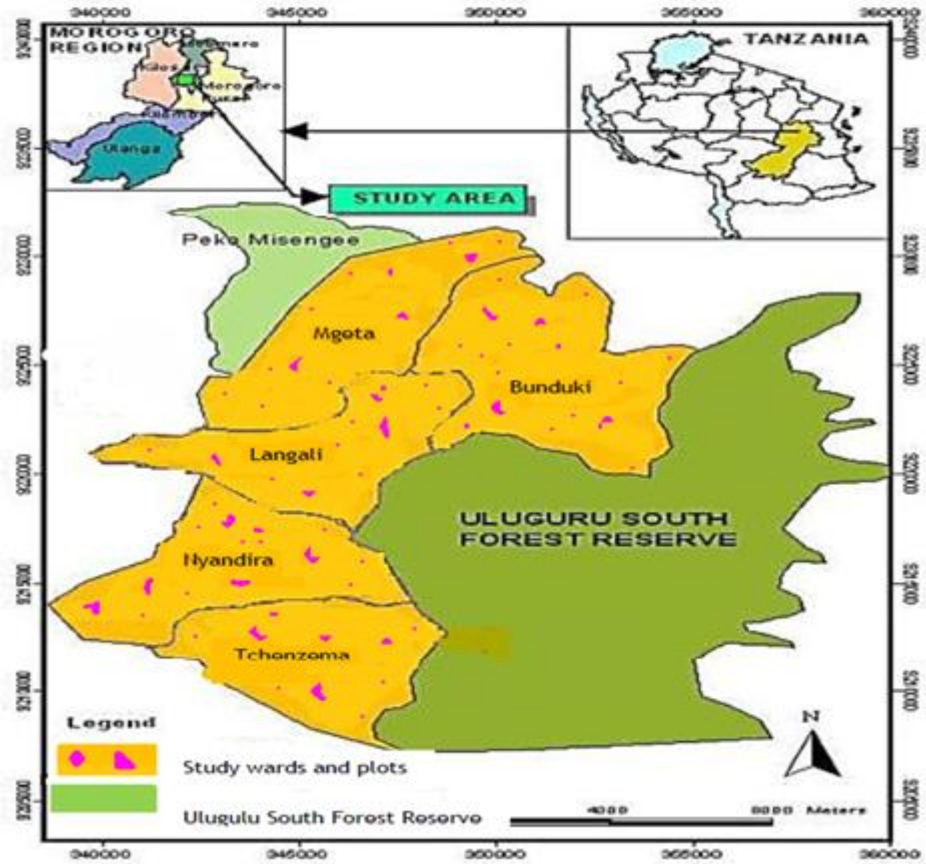

Figure1: Map of the Mgeta study area

The purposive sampling technique was used to sample farmers in both wards and villages in the study area. A total of 60 farmers within five out of the seven wards of the Mgeta division namely: Tchenzema, Nyandira, Mgeta, Langali and Bunduki (Figure 1), were interviewed. In each ward three villages, each with four households, were selected. Interviews with farmers, guided by a pretested structured questionnaire were conducted in July and August 2012. The data collected included general household information, parcel characteristics, crop and livestock production characteristics and their respective assumed labor requirements. In addition, characteristics regarding grass, multipurpose trees (MPTs) and fruit trees were quantified. The data were summarized and analyzed

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using SPSS to calculate standardized values (z scores) including sample size, means and standard deviations (SDs).

The LP model

The results and values obtained from the questionnaire were used to develop and parameterize a general linear programming farm model encompassing dairy goats, EA-goats, pigs and different kinds of vegetables in the two seasons (rainy and dry). The LP technique is based on constrained optimization that can be said to reproduce the reality of farmers who strive to maximize their income while facing several constraints. In farm, LP models [7] several activities, restrictions and production techniques are considered simultaneously and the effects of changing technical specifications and biological responses or right hand side parameters can easily be assessed. The mathematical model of a primal LP problem [8]:

Max $Z = c'x$, subject to $Ax < b$, $x \geq 0$,
where: Z= objective function, farm gross margin (GM),
c'= a vector of marginal activity GMs,
x = a vector of activity levels,
A= a matrix of activity resource requirements, and
b = a vector of resources such as land, work hours.

Based on the questionnaire model, activities for tomatoes, potatoes and cabbage as well as the N-fixing crops beans and green peas, were developed on land close to the farm homestead. Two complete crop production seasons, the rainy period of approximately 270 days from September to May and the dry period, 95 days from June to August, were considered. The vegetable crops were grown under fruit trees, which were limited to one fruit tree per $100m^2$. In the model plums, which give yield only in the rainy season were assumed. On distant higher lying farmland, beans and maize can be grown in both seasons. Intercropping was assumed in both seasons for potatoes and green peas on homestead area and for maize and beans in higher lying farmland area. Estimated area of tomatoes may constitute a maximum of 30% of the homestead area in either season due to need for crop rotation. Moreover, it was assumed, based on the size of the farming households, that the family's own needs will require 10% of the homestead area for tomatoes and potatoes and another 5% for cabbage. Farmers used urea and manure to increase soil nutrients and separate model constraints balance the supplies and use of fertilizers and manure with purchased fertilizers and farm produced manure.

The gross margins were calculated by multiplying expected yields and prices and subtracting the crop specific variable costs for each crop in the 2012 price level. The expected normal yields in the area were derived from the questionnaire and the feeding values were based on Solaiman [9]. As for the grass and MPTs, 192 MJ of energy from $10m^2$ were applied. There were no purchased inputs for this process but there may be some work to maintain the grass sward.

The variation in annual rainfalls in the area was considered as the best proxy for long-term crop yield variation. Data for annual rainfalls in Mgeta were not available. However, in a study of rainfall trends and variability in Tanzania [10], standard deviation (SD) for

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Morogoro was estimated to constitute 21.4% of average annual rainfall for the 30 years period from 1982 to 2012. The annual rainfalls in the high altitude Mgeta part of the Mvomero District were assumed to be somewhat more stable than in the lowland Morogoro town nearby. Moreover, the extensive use of irrigation in Mgeta agriculture will moderate the effects of droughts on crop yields that presumably will vary less in Mgeta than in Morogoro. In a basic scenario, all yields were assumed to be normally distributed with SD of 10% which was reasonably in line with those data and considerations. In general, climate change was assumed to have two effects on crop yields: a lower yield level and more yield variation. However, the effects were assumed to be dependent on the crop in question with open field vegetables being especially exposed to drought due to higher temperatures. In a climate change scenario the expected normal crop yields were assumed to be lowered by 10% for all vegetable crops and by 5% for the grass and MPTs yields. Regarding the effects of climate change on yield variation, it was assumed that the SDs would increase to 20% on vegetable crop yields and to 15% on grass and MPTs.

The animal activities consisted of dairy and EA-goats and pig keeping. Separate processes provided replacements for the goats. The replacement rate was 0.4 for both dairy and EA-goats. The piglets were assumed to be purchased and the cost of one piglet was subtracted from the objective function of pig production. East African-goats were free roaming, while dairy goats were assumed to be tethered or fed indoors. The pigs used crop leftovers including some of the yields from tomatoes, potatoes and fruits while other crops leftovers were assumed to be used by the goats. Maize bran can be purchased for supplementary feeding. The work requirements for crops and livestock were developed according to season and farmers could hire labor if the family workforce was insufficient.

The goats utilize grass, leaves and branches of multipurpose trees (MPTs), particularly Mulberry and *Leucaena leucocephala*, grown on their own land or on communal land. The feeding of dairy goats was taken care of in five constraints, energy and protein requirements for milk production in the two seasons and a constraint for maintenance feed which was assumed to be provided by grass and MPTs in both seasons. Based on maintenance feed requirement for dairy goats was calculated to 9.4 MJ of energy per day and production feed for milk to be 19.9MJ of energy and 130 gram of protein per day [9]. For replacement kids, values at 50% of adult animals were assumed. For EA-goats, the values for maintenance and growth equal were set to 70% of the maintenance feed of dairy goats and no production feed, as they were not milked. For pigs, 35.2 MJ of energy and 155 gram of protein per day for maintenance and growth were applied in both seasons.

The vector “b” of right-hand side values constraints the activities to the available fixed assets of the two categories of farmland, either near the homestead (2093 m^2) or more distant (3475 m^2), based on the questionnaire. The land can be used in both seasons but may be left idle in either season. Usable communal land was assumed to constitute 20% of the homestead land or 418 m^2, which limited the amount of grass and MPTs from communal land. The model, consisting of 31 activities and 35 constraints, was specified

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and solved in an Excel spreadsheet supported with Simetar to undertake a risk analysis [11].

RESULTS

The model was run both with and without dairy goats in the two scenarios. The main results are summarized in Table 1.

The results demonstrate that farmers would choose rather extensive vegetable cropping in a basic scenario when dairy goats were not an option. The EA-goats were less profitable, utilized only communal land and farmers will rather have pigs to utilize crop leftovers. However, the number of pigs kept depended on the available amount of crop leftovers (the calculations resulted in less than 0.5 pigs). When dairy goats were permitted in the model the amounts of grass and MPTs increased, and farmers started to purchase considerable amounts of maize bran for feeding the goats. Due to the need for land to produce goat feed, the cultivation of vegetable crops declined to the minimum, which were the amounts considered necessary to provide for the need of the farming household. Evidently, alternatives with dairy goats, MPTs and grass production did better in both scenarios, considering climate change impacts. Under the climate change scenario, the results suggested that alternatives with dairy goats would do 21.4% better than unilateral vegetable production compared to 13.8% under the basic scenario. The probability density functions (PDF) of the farm GM for the alternatives with and without dairy goats in the basic scenario (Figure 2) and in the climate change scenario (Figure 3) are shown below.

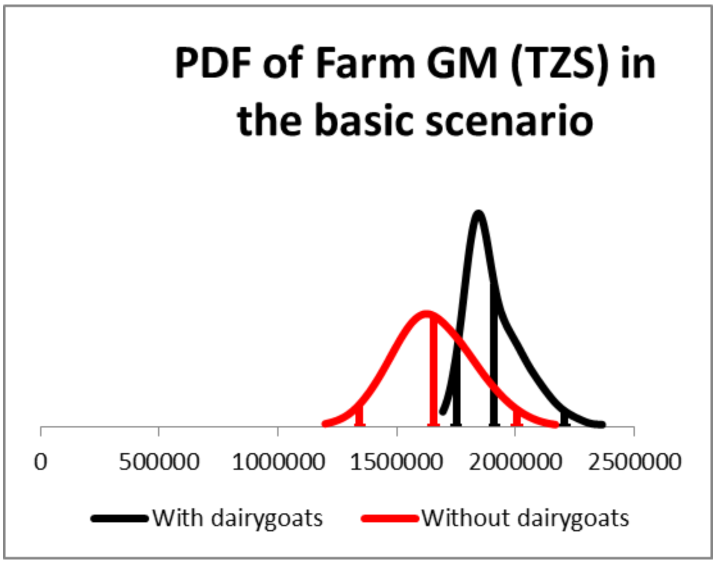

Figure 2: Probability density functions of farm gross margin (TZS) in the basic scenario with and without dairy goats

A comparison of the model results in the figures 2 and 3 reveals that in addition to the better results achieved with dairy goats, the farming results should be expected to be more stable over time when dairy goats were an option since the dependence on the stochastic crop yields was lowered in the scenarios with dairy goats.

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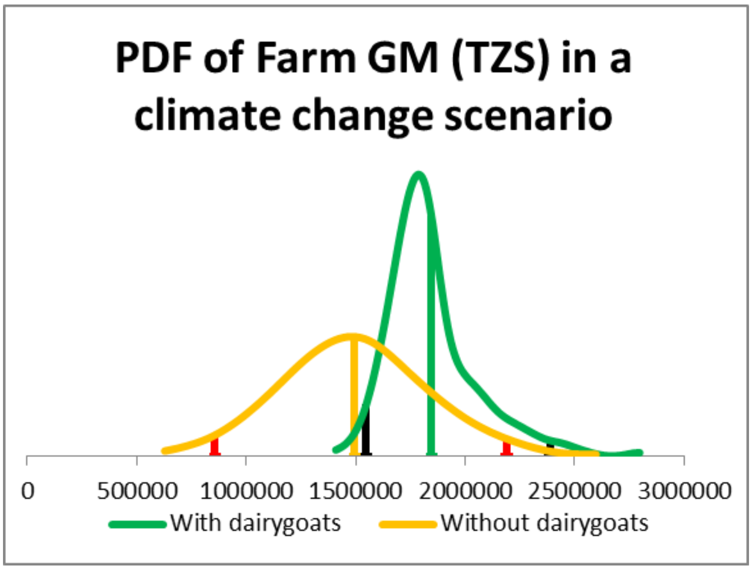

Figure 3: Probability density functions of farm gross margin (TZS) in a climate change scenario with and without dairy goats

Farm policy measures to promote or enhance more dairy goats have not been examined but could include such measures as (a) subsidies for increased concentrate feed purchase, (b) investment support and other measures for developing yoghurt production or other goat milk processing industries or (c) introducing subsidy payment for permanent grassland and MPTs.

DISCUSSION

Livestock and vegetables are both components of the agricultural production systems and crucial trade-off commodities for livelihood and environment in Mgeta. In Mgeta, land degradation has been widely reported [3]. The situation is threatening the livelihoods of the local communities. As time passes, competing demands and the need for sustainable use of natural resources will definitely continue to increase [12]. Capitalizing on the sustainable utilization of the local resources might help to attain the goals of supporting both livelihood and the environment in these vulnerable areas. Keeping dairy goats might be an important strategy to improve food security and livelihoods in vulnerable communities like Mgeta [13]. Likewise, dairy goats under certain constraints regarding grazing and browsing behavior may provide opportunities for a more environmentally friendly use of the farmland compared to vegetable cultivation or browsing EA-goats. Many studies suggest that in the course of climate change, demand for sustainable food security to support livelihoods in the study area will increase tremendously. For instance, according to Thornton & Herrero and Steinfeld *et al.* [14, 15], by 2050 annual per capita consumption of milk will increase by 28% in developing countries including Tanzania. The estimated probability function for farm gross margin revealed that one should expect considerably more income variations for vegetable production as compared to dairy goats. One reason the MPTs system was assumed to be less affected by climate change compared to vegetable crops was the tree cover, which will limit evaporation. Moreover, in the steep slopes of Mgeta, dried land was assumed to be more exposed to landslides

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when heavy rain follows a prolonged period of drought, assumed to be an effect of climate change. Perennial grasses under a tree canopy were considered likely to do better in such a case. Change in length of the growing season, extended drought, shortage of water for irrigation, and increase in crop diseases were some of the many suggested causes for the variation [16, 17].

Considering that Mgeta is located at a high altitude with steep land terrain and has the potential as a water catchment area, intensifying dairy goat keeping could be the best option to improve livelihood needs and sustainable use of natural resources. Such strategies may reduce pressure on the environmental resources such as land and water [13, 18, 19]. More importantly, farmers could increase productivity per unit of resource.

The model results suggest that under the climate change scenario, unlike vegetables, EA meat goats and pig production system, keeping dairy goats was a more worthwhile production system in both economic and environmental perspectives. Contrary to EA-goats, dairy goats can be partly stall-fed and still give more products of economic value. The model results were in line with the findings by Thornton and Herrero who reported on the productivity potential of dairy goats under smallholder farming systems [14]. In this regard, there are opportunities in the dairy agriculture sector with significant future contributions to the livelihoods of the poor communities like Mgeta.

In cognizant of the above, farmers in Mgeta should shift from crop-livestock integration to intensive dairy goat production. The shift would require improving management practices such as breeding, feeding and disease control, accompanied by fodder production and planting of multipurpose trees. In so doing productivity will likely increase, enabling the household purchasing power to improve. Adaptation of the transformation to a more market economy could be somehow difficult but gradually the system should stabilize at the micro level.

At the macro level, adaptation of such a production system is expected to restore the depleted water catchment areas along the Uluguru Mountains, ensure better community livelihoods, and more environmentally friendly area use. However, literature suggests that such a shift cannot happen automatically, as it will require different approaches, regarding both the technology dimensions and policy and market solutions that work for those involved in dairy goat production systems [13, 15]. Almost thirty years of research with dairy goats in Mgeta has developed several technology packages including breeding practices, yoghurt making and local capacity for milk processing [6].

Regarding policy issues, the implementation of the National Public Private Partnership Policy [18] opens up more opportunities for partnerships to invest along the milk value chain. In such a scenario, Shambani Graduates, a private milk processing company based in Morogoro stands a better chance to strengthen goat milk processing capacity and gain access to the milk market to capture the increase in supply. Further, adaptation of innovations by farmers would depend on whether the innovation fits their farming priorities, characteristics of household and available resources [19, 20]. Thus, it remains debatable whether the vulnerable and poor people in Mgeta will and can be interested in

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capitalizing their struggles to better livelihoods and sustainable use of scarce natural resources through improving the dairy goat production systems.

CONCLUSION

The current study in Mgeta indicates that a changeover from a seasonal vegetable crop system to a system with dairy goats and more permanent grass and multipurpose fodder trees would increase farm gross margin by roughly 14%. Moreover, this system also seems to do better under a climate change scenario in which average farm gross margin was found to decline by only 3.5% compared to 9.6% without dairy goats. The result was due to a smaller decline in yields and less increase in yield variation compared to seasonal vegetable crops since perennial grasses under a multipurpose tree canopy were likely to be less affected in this situation.

RECOMMENDATIONS

Based on the conclusions drawn, it is recommended that the community gradually improve dairy goat feeding and breeding management; and increase establishment of grass and fodder trees, particularly in the steep terrain and mostly erosion-vulnerable parts of the area to counter some of the expected effects of climate change. Also, there is need to develop different policy measures to promote this development.

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Table 1: Model solutions for farming in Mgeta with and without dairy goats in a basic scenario compared to a climate change scenario

Scenario	Land use*, m^2					Grass MPTs	Goats		Pigs	Feeds	FGM
	T	PGp	C	B	MB		Dairy	Meat		TZS	
Basic											
Without dairy goats	2512	1423	251	2412	3831	419	0	3	0	0	1644461
With dairy goats	502	1005	251	2119	2617	1633	8	0	0	15842861	1871378
Climate change											
Without dairy goats	1512	1423	251	968	2236	419	0	3	0	0	1487230
With dairy goats	502	1005	251	565	954	1633	8	0	0	15842861	1805026

T=Tomatoes, P=Potatoes & green peas, C=Cabbage, B=Beans, MB=Maize & Beans (distance land), MPT=Multipurpose trees, TZS=Tanzania Shillings, and FGM=Farm Gross Margin

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