sustainability

MDPI

Article

Crop Pollination in Small-Scale Agriculture in Tanzania: Household Dependence, Awareness and Conservation

Thomas Sawe [1,*], **Anders Nielsen** [2,3] **and Katrine Eldegard** [1]

[1] Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences (NMBU), P.O.BOX 5003, NO-1432 Ås, Norway; katrine.eldegard@nmbu.no
[2] Department of Landscape and Biodiversity, NIBIO—Norwegian Institute of Bioeconomy Research, P.O. Box. 115, 1431 Ås, Norway; anders.nielsen@nibio.no
[3] Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo, P.O. Box 1066, Blindern, 0316 Oslo, Norway
* Correspondence: thomas.sawe@nmbu.no

Received: 8 February 2020; Accepted: 9 March 2020; Published: 12 March 2020

check for updates

Abstract: Global economic value of agriculture production resulting from animal pollination services has been estimated to be $235–$577 billion. This estimate is based on quantification of crops that are available at the global markets, and mainly originates from countries with precise information about quantities of agriculture production, exports, and imports. In contrast, knowledge about the contribution of pollinators to household food and income in small-scale farming at local and regional scales is still lacking, especially for developing countries where the availability of agricultural statistics is limited. Although the global decline in pollinator diversity and abundance has received much attention, relatively little effort has been directed towards understanding the role of pollinators in small-scale farming systems, which feed a substantial part of the world's population. Here, we have assessed how local farmers in northern Tanzania depend on insect-pollinated crops for household food and income, and to what extent farmers are aware of the importance of insect pollinators and how they can conserve them. Our results show that local farmers in northern Tanzania derived their food and income from a wide range of crop plants, and that 67% of these crops depend on animal pollination to a moderate to essential degree. We also found that watermelon—for which pollination by insects is essential for yield—on average contributed nearly 25% of household income, and that watermelons were grown by 63% of the farmers. Our findings indicate that local farmers can increase their yields from animal pollinated crops by adopting more pollinator-friendly farming practices. Yet, we found that local farmers' awareness of pollinators, and the ecosystem service they provide, was extremely low, and intentional actions to conserve or manage them were generally lacking. We therefore urge agriculture authorities in Tanzania to act to ensure that local farmers become aware of insect pollinators and their important role in agriculture production.

Keywords: ecosystem services; Small-scale farming; insect pollinators; pollinator conservation; agricultural intensification

1. Introduction

Small-scale farming is a major source of food production and income in many countries [1] and employs about 2.1–2.5 billion people globally, of which the majority live in developing countries [2]. The importance of small-scale farming in maintaining food security, as well as the environmental benefits stemming from this farming practice, have been realized and advocated by different scientists [3]. One of the benefits of small-scale farming systems is that they constitute highly diverse semi-natural ecosystems through a combination of wild and domesticated species [4]. This practice can therefore conserve biodiversity and sustain agriculture production over long periods of time [5]. Yet, balancing biodiversity conservation and agriculture production is becoming increasingly difficult for a number of reasons, including destruction of natural habitats and agriculture intensification [6–9]. This has raised concerns about the sustainability of small-scale farmers' livelihoods, which depend on ecosystem services for agriculture production [10,11].

Animal pollination of crops is a threatened ecosystem service known to affect agriculture production in small-scale agro-ecosystems [12]. As much as 35% of the total global agricultural production depends on animal pollination, and thus this ecosystem service contributes significantly to global food security and the socio-economic status of the small-scale household farmers [13]. However, the total effects associated with animal pollination for local livelihoods; i.e., food availability and nutritional value, and farmers income, are poorly understood, as the main emphasis has been on the global monetary economic benefits [14,15]. According to Chaplin-Kramer et al. [16], a more holistic assessment—which also includes the value of insect pollination to human health through a varied diet—would provide better estimates of the total value of pollination services. Considering this, estimates of monetary values, based solely on global food market prices, most likely underestimate the value of pollination services to humans. This is because—across the globe—there is a great variety of crops that depend on animal pollination, that are not available at global markets, and their monetary value may vary substantially among regions [13]. It is therefore important to estimate the economic value of these crops on local or regional scales to understand their direct economic benefits to local farmers. In addition, the nutritional value of a crop can be hard to translate to monetary value, while at the same time nutritional security can be a bigger threat to human livelihoods than food security per se [17,18].

The conflict between increased food production and conservation of natural habitats that threatens sustainability of ecosystem services including insect pollination has received a lot of attention by scientists [19]. Díaz et al. [20] and Barbir et al. [21] show that small-scale farming by indigenous and local communities are resilient to global declines in pollination services because they have always used agricultural practices that maintain local pollinators on and around their agriculture lands (e.g., agroforestry systems). However, these practices seem to be a bet-hedging strategy for diversifying food and sources of income stemming from limited access agricultural inputs, like fertilizers and pesticides, rather than deliberate actions to protect or conserve pollinators or practice sustainable agriculture [22–25]. Consequently, local farmers will most likely trade their traditional agricultural systems if they are exposed to different farming systems with higher short-term returns. Such changes in practices will most likely lead to changes in land use and potentially pose a threat to local pollinators and, ultimately, the agricultural production itself [23].

In Tanzania, about 80% of the population live in rural areas and depend on small-scale agriculture for their livelihoods [24,25], characterized by low inputs and low yields per area [26]. Despite a high number of people involved in, and depending on, agriculture, government development strategies have focused more on the communication and infrastructure sectors than on the agricultural sector [27]. Most local farmers strive to increase their production by use of fertilizers, watering, and the use of quality seeds, i.e., purchasing improved seeds instead of sawing seeds from previous harvest. Local experience and knowledge shared among the farmers is the main source of information in pest management, as the farmers receive no or little help or advice from the agriculture authorities. For example, Laizer et al. [28] found that local farmers in Arusha use kerosene—a flammable hydrocarbon liquid commonly used as a fuel—mixed with several other pesticides for eliminating pests. Apparently, these practices show that local knowledge in addressing particular problems is usually based on traditions or trial and error procedures, due to lack of training from the responsible agriculture authorities. Moreover, the benefits of insect pollination in these regions have received little attention, most likely due to lack of awareness or as it has been considered a common good that is taken for granted [29]. We thus hypothesized that knowledge about the importance and economic benefits of animal pollination for food production is low among local farmers in our focal regions (Arusha and Kilimanjaro, northern Tanzania). In this study, we therefore carried out interviews with local farmers to get a better understanding as to what degree their farming system, local household income and food production was depending on insect pollinators. In addition, we acquired information about the farmers' awareness of pollinators and pollination services, and their intended actions to protect them.

2. Methods

2.1. Study Area and Respondents

We interviewed 147 local farmers in the Kilimanjaro and Arusha regions in northeast Tanzania. Most local famers in these regions are small-scale farmers growing different crops through the year, including vegetables, fruits, and ornamental flowers. With the help from a local agriculture officer, we randomly selected candidate farmers for the interviews. The farmers selected for an interview had to be engaged in several economic activities and willing to share their information for research purposes. We conducted the survey with help from three life science graduates (field assistants) well acquainted with Swahili (the local language) to facilitate conversation. The field assistants were trained to familiarize with data collection too. Moreover, before data collection, we tested our questionnaire to few farmers to ensure commonality among the field assistants. The questionnaire had two sets of questions; the first aimed to acquire demographic information such as education, age, and household income (see Questionnaire in Appendix A). The second aimed at collecting data on farming practices and awareness of pollination services (see Appendix A). The questionnaire contained open ended questions, except the last question. This was important to ensure that the farmers are not limited to specific possible answers. During the interview, all the information from the farmers were recorded in the notebook, and relevant information was extracted later during data analysis.

The composition of the natural pollinator community in the study area is poorly known. However, Sawe et al. [30] quantified flower visitation rates to watermelon flowers in 23 watermelon gardens in the Arusha and Kilimanjaro area in 2018, and found that the main groups of visitors were wild honeybees (*Apis mellifera*; (87.8%), followed by hoverflies (Syrphidae; 8.5%) and other Hymenoptera (3.7%). The honeybees are native in this region [31,32], mainly nesting in natural cavities in tree trunks in the bush/woodlots/forests surrounding–or scattered throughout–the agricultural landscape. In recent years, in order to stop people from encroaching the bushes/forest and chopping tree or burning them for honey collection, there has been efforts by Tanzania Forest Services (TFS) to introduce modern–empty–hives to local people around the forest. There is no domestication/management of the bees apart from deploying empty hives and collecting honey.

2.2. Farming Practices, Agriculture Revenue, and Operation Cost

We interviewed all the farmers about their fields separately to acquire information about farming practices in the previous year (2018). For every farmer, we obtained information about farming system including: Type of crops grown, amount of land used per crop (field size), yield decline experiences and presumed causes, cropping system, costs and revenues associated with growing each type of crop, awareness of pollinating insects and intended activities to conserve them (Questionnaire in Appendix A).

2.3. Classification of Crop Pollination Dependency

To estimate to what extent the small-scale farming, i.e., the crops the farmers had grown in the previous year, depended on animal pollination, we used the five categories of crop pollinator dependency developed by Klein et al. [33] (Table A1). The category "no" refers to crops with no yield reduction following pollinator exclusion, "little" are crops with up to 10% yield reduction, "modest" are crops with >10−40% yield reduction, "great" are crops with >40–90% yield reduction, and "essential" are crops with more than 90% reduction. These categories, however, do not consider the variation in pollinator dependence among crop varieties.

2.4. Data Analysis

Before data analysis, we summarized the responses to variables that can be measured to every individual farmer. In addition, for multiple response questions we summarized each response and categorized them into simple variables that best fit information from the farmer. To test whether farmers allocated contrasting amounts of their land (field size) to crops of different levels of pollinator dependency, and whether level of pollinator dependency affected the contribution of crops to household income, we used analysis of variance (ANOVA). To estimate number of local farmers that grow crops with different pollinator dependence level, we fitted a generalized linear mixed model (GLMM) with Poisson distributed errors and log link. The same type of statistical model was fitted to test if the number of farmers—reporting reasons for yield decline—differed between types of perceived reasons. All data analyses were carried out in the statistical software R version 3.6.1.

3. Results

3.1. Farming System

Average age of our respondents was 42 (SD = 7) years, and most of the respondents were male (91.8%) and had basic primary education 77.6%; (n = 114). Size of the household, i.e., average number of people per household was 8 (SD = 3), however, it was often mentioned to vary at different times of the year. On average, respondents owned small farms (1.4 ha ± 0.89 SD), fragmented into small fields around their residence areas. The majority (89%, n = 131) did not have enough agricultural land and therefore borrowed or rented land (3.1 ha on average), which was usually located farther away from their home. The borrowed land was mainly used for growing maize, on average the total amount of land used for maize was 3 ha (SD = 1.1), which is almost three times bigger than for other grown crops. Maize was mentioned as the main staple food and as a source of income by most of the farmers. In total, we found 31 different crop types to be grown by the group of respondents, whereby on average every farmer grew a combination of two to four crops per year through intercropping or crop rotation, and whereby maize was grown by 97% (n = 143) of all the farmers (see Appendix B, Table A1). We also found that all main types of crops contributed equally to household income irrespective of their dependence on animal pollination. However, considering individual crops, maize contributed more to household income than the rest of the crops, followed by watermelon and tomatoes.

We found that all farmers practiced monoculture and mixed cropping at different times during the season. Monoculture cropping was most common in maize fields (borrowed/rented land). After harvesting the maize, the field was usually (89%) abandoned until the next season, or replaced with another crop, often beans. There was no statistically significant difference in the average field size used for crops in the different pollination dependency categories (F4,26, Z = 0.42, p = 0. 79; Figure 1A).

3.2. Pollinator Dependency for Food Production and Household Income

We found that 20 out of 31 crops grown by the local farmers in our study areas to some extent benefit from insect pollination (see Appendix B, Table A1). The number of farmers growing crops of different degrees of pollinator dependence was not evenly distributed (χ^2 = 57.9, df = 4, $p \leq 0.01$; Figure 1B). A higher number of farmers than expected by chance grew crops with "modest" pollinator dependency, such as eggplant and bitter tomatoes, whereas fewer farmers than expected by chance grew crops with "great" dependency on pollinators, such as mangoes and avocado (See, Table A1, Figure 1B). Notably, 93 of 147 (63%) of the farmers reported that they were growing watermelons, which is a crop categorized as "essential" in terms of dependency of insect pollination.

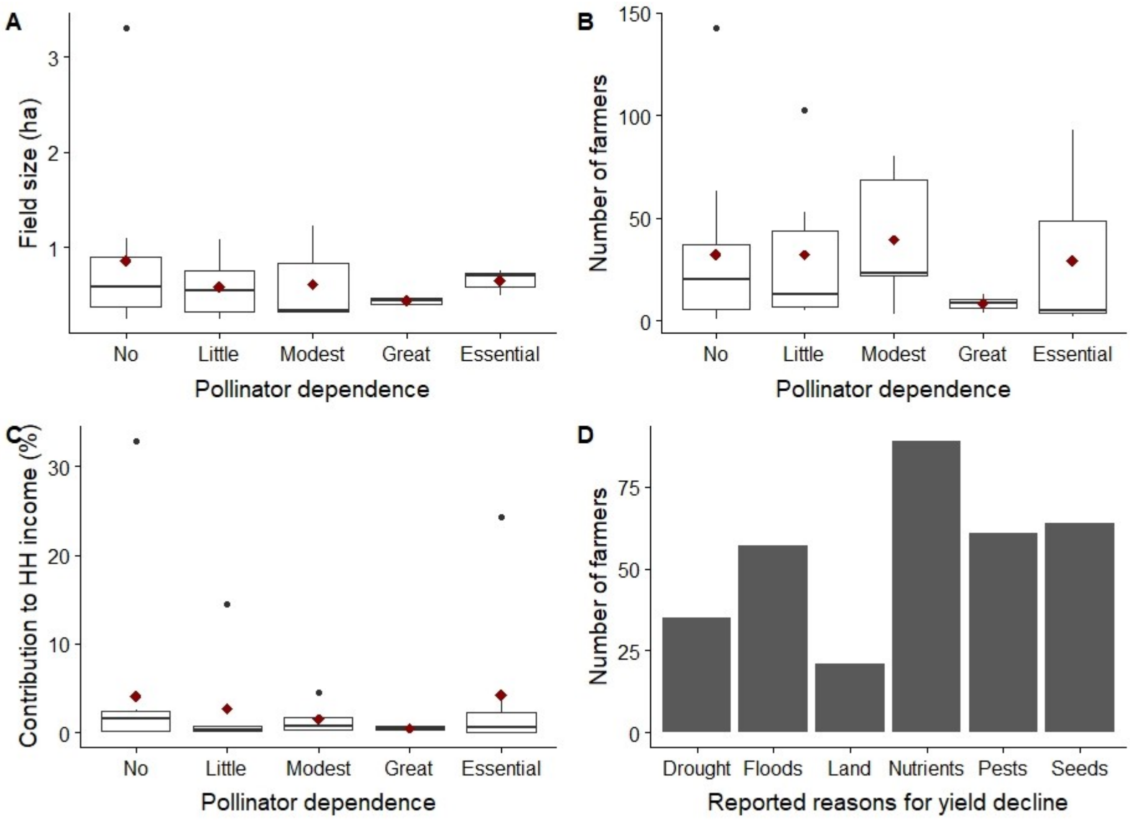

Figure 1. (**A**) Field size used for crops of different levels of dependency on animal pollination. (**B**) Number of farmers growing crops of different dependencies on animal pollination. (**C**) Contribution to household (HH) income from crops of different dependencies on animal pollination. (**A**–**C**) Boxplots showing observed averages (diamonds), medians (midline), and 75th and 25th percentiles (upper and lower limits of the box). The whiskers extend up to 1.5 times the interquartile range; data beyond that distance are represented as points. (**D**) Reported reasons for yield decline, and the number of farmers reporting each type of reason.

Contribution to the household income did not differ among the crops based on their pollinator dependency (F4,26, Z = 0.82, $p = 0.52$; Figure 1C). However, at the individual crop level, three crops grown by the majority of farmers, i.e., maize ("no" pollinator dependency), tomatoes ("little" pollinator dependency), and watermelon ("essential" pollinator dependency) contributed more than half of all agriculture revenue respectively, i.e., 32%, 14.4%, and 24.3% (see Appendix B, Table A1). The farmers reported that they derive their food from all crops belonging to all categories of pollination dependency. Crops grown only for household food production, which did not contribute directly to household income, were distributed across the pollinator dependency categories as follows: 36.7% "no", 20% "little", 20.1% "modest", 2% "great", and 21.2% "essential ". Thus, about three-quarters of the crop plants used for producing food for the households had dependence on animal pollination at the level of "little" or above.

3.3. *Knowledge of Insect Pollinators and Pollination*

Only 7.4% (n = 11) of the interviewed farmers were aware of pollinators and they considered them as useful insects, but they did not know exactly how pollinators benefit the crops. Honeybees and butterflies were mentioned to be useful insects, but butterflies were also mentioned as crop pests. When asked about their strategy to conserve pollinators, only one farmer among the 11 who were aware of pollinators had an intentional strategy, i.e., to avoid spraying pesticides in the morning. None of the farmers practiced bee keeping. We did not find pollinator awareness to relate with either type of crops grown, level of education, nor household income.

3.4. Experiences in Yield Decline within Ten Years and Reasons

All farmers had experienced declines in their agriculture production due to various reasons. However, none of the farmers listed pollination deficiency among the factors contributing to yield decline. The major causes of decline in agriculture production (crop yield), were perceived by local farmers to be declining soil nutrients 60% (n = 89), poor seeds obtained from the harvest 44% (n = 64), and pests 41% (n = 61) (see Table 1, Figure 1D).

Table 1. Factors causing yield decline, according to farmers, and their significance, relative to reductions in field size (reference level). Results from a generalized linear mixed model (GLMM) with Poisson distributed errors.

	β	SE	z	*p*
Intercept	−3.56	0.22	−16.29	<0.01
Drought	0.51	0.28	1.85	0.06
Floods	0.98	0.26	3.83	<0.01
Pests	1.07	0.25	4.21	<0.01
Seeds	1.11	0.25	4.43	<0.01
Nutrients	1.43	0.24	5.90	<0.01

4. Discussion

The present study has revealed that crops that have some dependence to animal pollination are crucial for small-scale farmers in northern Tanzania, both for income and food for home consumption. Despite the prominence of maize cultivation, i.e., a crop that is wind-pollinated, there is potential for small-scale farmers to increase their income from insect-pollinated crops, such as watermelon, which are grown on their own small fields, in proximity to their own homes. Importantly, we have documented that a large majority of local farmers are not aware of insect pollinators and their important roles in crop production. This lack of awareness poses a threat to existing pollinator communities because current farm management practices are likely to change if farmers are introduced to new practices that offer quick increase in agriculture production.

4.1. Local Farmers and Farming Systems

In general, the characteristics of the small-scale local farmers interviewed in our study area were similar to those reported by other scientists in Tanzania [24] and other Sub-Saharan countries [34]. Majority of the respondents were male, who are considered head of the families. This might have some implications in our results, as most often women are also involved in farming and marketing of agriculture products. The amount of land owned by local farmers in our study area was low compared to other parts of Tanzania, as most of the productive land in the Arusha and Kilimanjaro regions is under conservation, i.e., national parks, and a significant portion of the land is semi-arid [35,36]. The great majority of the farmers that we interviewed grew maize, both for food and for income. However, we found out that maize growers typically did not use their own land for this purpose, because maize often requires larger fields for higher production [37]. Due to field size limitation, the farmers usually rent or borrow land for maize production, and the compensation is most often through splitting the harvest or forming a partnership whereby one farmer provides land and the other provides labor. This sort of collaboration was also found by Adjognon et al. [38] as the main approach for local farmers in sub-Saharan Africa to access most of the applied agriculture inputs.

4.2. Household Income and Pollinator Dependency

Our results show that, despite farmers growing many different crops for household consumption, only three different crops, i.e., maize, watermelon, and tomatoes contributed substantially to average household income (32, 24, and 14%, respectively). These crops were also grown by a majority of the interviewed farmers. In contrast to several previous studies [39–41], which found coffee to be the most important crop for most of the local farmers in this area of Tanzania, our study reveals that other crops, especially watermelon, are crucial for the local farmers [39]. Perhaps declining global coffee price [42], pests [43], climate fluctuations [44], competition from giant producers [45], and lack of government support [46] have necessitated growing alternative crops. Replacement of coffee cultivation by annual fruit crops—such as watermelon, as observed by Katega et al. [47] in western Tanzania—suggests that the demand for insect pollination will actually increase; coffee yield is moderately dependent on pollination [48], whereas crops such as watermelon or vanilla (*Vanilla planifolia*) are essentially dependent on pollinators [49].

Apart from maize, watermelon, and tomatoes, most crop types contributed little to household income, and we found that average income derived from different categories of crop plants, grouped according to level of dependence of insect pollination, did not differ significantly. However, in our previous studies in these same regions, we have shown that watermelon yields are limited by available natural pollination services [50]. Therefore, results from our present study signify that household income resulting from agriculture activities can be increased if pollination services are improved.

Reliance on maize for both food and income by most of the local famers appears to emerge from traditional/conventional reasons rather than economic analysis. For example, watermelon grown on one-third of the land used to grow maize, produces almost equal economic benefits as maize grown on a borrowed land. Moreover, the cost associated with growing maize seems to be more than what farmers are aware. For example, since borrowed land for maize is far from home and the farmers have to move the distance back and forth or camp, extra financial resources is required, which increases investment costs. In addition, there is low efficiency and motivation in investing and utilizing borrowed land as reported by [51,52]. Both of the mentioned reasons increase cost of maize production, though local farmers seems to be more aware with direct cost such as seeds, fertilizer, and watering. In this study, we could not quantify all the costs associated with the crops from farm preparation to harvesting, as the majority of the farmers do not keep records. Some farmers who seem to be aware of various costs incurred during maize farming mentioned that they practice agriculture to save money rather than acquiring economic benefits. The reasoning here is that, since there is insufficient money to invest in agriculture, small investment is made each time a penny is acquired through other means, hoping for lumpsum during the harvest.

On the other hand, further results from this study show that animal-pollinated crops grown and managed in small land around home "for example watermelon and tomatoes" may generate higher incomes. This implies that local farmers can benefit from these crops, which are grown on small areas around their home. Sawe et al. [50] shows that, watermelon—which is grown by most of the local farmers and with substantial household income—yields can be increased, i.e., number of marketable fruits could be doubled, if sufficient pollination is provided under the current levels of irrigation and fertilization. Apparently, our current findings and mentioned previous studies suggest that local farmers can benefit economically by focusing on their own small farms and improving pollination services in these. This is also backed by Makuya et al. [53], who observed that smaller watermelon fields produced higher yields compared to bigger ones as a result of easy management and efficient use of agriculture inputs. Smaller field size and increased crop diversity may indeed contribute to conserving biodiversity while ensuring agricultural production. In a recent analysis of 435 European and North American agricultural landscapes along gradients of crop diversity and mean field size, Hass et al. [54] showed a clear positive effect of decreasing field size on multitrophic diversity, even stronger than increasing seminatural cover. They also found that increasing the number of crop types had a positive effect on multitrophic diversity, but the effect of increasing crop diversity depended on the amount of seminatural cover in the surrounding landscape [54,55].

4.3. Household Food Production and Pollinator Dependency

We found that 67% of the cultivated crop types used for household food production were to some extent insect-pollinated. We found that local farmers derive their food from all grown crops and that not all crops grown were meant for selling purposes. Most of the farmers who cultivated "modest" pollinator-dependent food crops used them for home consumption; these included egg-plants, bitter tomatoes, and okra; other crops cultivated for home consumption were also vegetables. Yields from these vegetable crops were mentioned to be low and considered as bonus, because they are largely integrated in mixed cultures with some other important cash crops, and they did not require additional caretaking. Low harvest of these crops was thought to be a function of sowing poor-quality seeds, stemming from the farmers' own harvest in the previous season. Previous studies have shown that poor quality of seed used by the majority of local farmers in sub-Saharan African countries is major bottleneck for agriculture productivity [56,57]. This implies that local farmers could improve the vigor of the produced seeds by improving pollination condition in their fields [58]. As the insects carry pollen across different plants of the same species, they contribute to increasing genetic variation among the plant individuals, and thus decrease inbreeding depression resulting from selfing [59,60].

4.4. Pollinators Awareness

Our study has documented that a large majority of the local farmers were not aware of pollination and pollinating insects. The few farmers who mentioned they were aware of pollinating insects (7%) did not know how the insects improve the yield, and only one among them deliberately sprayed pesticides in the evening to protect pollinating insects. When the farmers were asked about the beneficial insects visiting their crops, they mentioned honeybees and butterflies, though butterflies were mentioned as pests as well. Honeybee visits were considered beneficial because they collect raw materials for honey production. The lack of pollination awareness among farmers was confirmed by the fact that they all reported to have experienced yield decline, but none thought pollination deficit could contribute to yield decline. Pests, fertilizers, and lack of good quality seeds were reported as the main pressing problems leading to decline in agriculture production. The level of education or type of crops grown did not seem to play a role in pollination awareness as reported by other studies [61–63]. The few farmers aware of pollinators seemed to have acquired this information from agriculture training programs or from other farmers. Our results are similar to observations made by [29] in Kenya and by Munyuli [64] in Uganda. In contrast, Hordzi [65] found that majority of the local pigeon pea farmers in Ghana understood insect pollination and roles played by honeybees in cross-pollination.

4.5. Pollinators Conservation

Since most of the farmers were not aware of the role of pollinating insects, they did not make any attempt to protect or conserve them. Except for one farmer who mentioned spraying pesticide in the evening to reduce negative impacts on pollinating insects. A previous study by Sawe et al. [50] on the same regions found watermelon yield to be limited by existing level of natural pollination services. Lack of awareness on insect pollinators and their role in crop production documented in the current study reveals their increased vulnerability to unsustainable agriculture practices, such as misuse of pesticides.

4.6. Management Implications

We conclude that there is an urgent need to increase awareness of insect pollination as a vital factor for agricultural productivity in Northern Tanzania. We recommend that agricultural authorities endeavor to enhance local farmers' awareness of pollinators and their role as providers of important—and free—ecosystem services. This could be implemented by establishing special programs, aimed at increasing the farmers' understanding of the diversity and ecological functions of pollinators, both in agricultural and (semi)natural habitats. This could also be achieved through, for example, creating media coverage about the connections between agricultural productivity, food and nutritional security, and the conservation of biodiversity, which remain unknown to the majority local farmers.

Author Contributions: K.E. and A.N. conceived the ideas, and A.N., K.E., and T.S. designed methodology; T.S. collected the data; T.S. analyzed the data; T.S., A.N., and K.E. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We thank Ørjan Toland for valuable inputs on study design and data collection in an early phase of the study. The Norwegian Government through the Norwegian State Education Loan Fund supported this research. We thankfully acknowledge the field assistance of Erica Mmuru, Vicent Elisante, Jumanne Kway, Nassoro Kimaro and Stella Swai. We thank all farmers who allowed us to use their gardens for this study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Questionnaire used in interviews of 147 local farmers in the Kilimanjaro and Arusha regions in northeast Tanzania, after the 2018 crop growing season. The interviews were conducted by graduates acquainted with Swahili language.

Questionnaire

Enumerators name … … … … … … … … … … … …

Part I

I. Full Name: … … … … … … Date: … … … … … … … … … … … … …
II. Village name: … … … … … … … … Ward … … … … … … … … District: … … … … … …
III. Age: … … … … … … … … … … … … … … Sex: … … … … … … … … … … …
IV. Education: … … … … … … … … … … … … …
V. Number of persons that lived in your house: … … … … … … … … … … … … … …

Part II

VI. Total income earned last year: … … … … … … … … … … … … … … … … … …
VII. Percentage of income coming from agricultural production (crop production) … … … … … … … … …
VIII. Further income sources besides agricultural production (crop production) … … … … … … … … … …
IX. Field size … … … … … … … … … … … … … … …
X. Which crops do you grow … … … … … … … … … … … … … … ?
XI. Cost for associated with each crop and the market price … … … … … … … … …
XII. Are you practicing Monoculture or mixed culture … … … … … … … … … … … … … … … … … ?
XIII. Percentage of production sold on the market in 2018 … … … … … … … … … … … … … … …
XIV. Is there any change in the yield in the crops you grow? … … … … … … … … … … … … … … … … … … …
XV. How do you know crops yields are changing? … … … … … … … … … … … … … … … … … …
XVI. Why are crop yields changing? …
XVII. Do you know pollinators or any beneficial insects visiting your plants? … … … … … … … … … …
XVIII. Do you know their roles? … … … … … … … … … … … … … … … … … …
XIX. Which crops do they visit? …

XX. What are the most insects visiting insects on your crops? . . . .
XXI. Do crops need pollination? . . . .
XXII. Why do you think crops need pollinators? . . . .
XXIII. How do you know? . . . .
XXIV. Would it be useful to have more pollinators? . . . .
XXV. In your opinion, how could their abundance be increased? . . . .
XXVI. What practice do you use to conserve pollinators? . . . .
XXVII. Do you practice conservation agriculture/pollinator management? . . . .

- Mixed farming/agroforestry
- Hedgerow farming
- Bee keeping

Appendix B

Table A1. A list of crops grown by 147 local farmers in surveyed areas, based on the farmers' response to the questionnaire in Appendix A. Categorization of dependency of animal pollination for different crops follows Klein et al. (2007). Numbers in the parentheses are standard deviations. HH = household.

Crop Name	Number of Farmers	Pollination Dependency	Average Field Size in Ha	Average % HH Income Contribution
Amaranthus *(Amaranthus. sp.)*	23	No	0.41 (0.20)	0.17
Avocado *(Perseaamericana)*	4	Great	0.38 (0.14)	1.02
Banana *(Musa sp.)*	35	No	0.74 (1.12)	0.13
Beans *(Phaseolu sp.)*	53	Little	1.08 (0.83)	0.46
Bitter tomatoes *(Solanum aethiopicum)*	69	Modest	0.33 (0.19)	4.55
Cabbage *(Brassica sp.)*	44	No	0.34 (0.15)	1.3
Cantaloupe *(Cucumis melo)*	5	Essential	0.60 (0.52)	0.7
Carrots *(Daucus carota)*	4	No	0.56 (0.13)	1.55
Cassava *(M.esculenta)*	1	No	0.25 (0.12)	0.04
Chilli (various chilli)	5	Little	0.25 (0.00)	0.13
Coffee *(Coffee arabica)*	3	Modest	0.83 (0.29)	0.35
Cucumber *(Cucumis sativus)*	62	Great	0.71 (0.26)	3.8
Eggplant *(Solanum melongena)*	80	Modest	0.32 (0.19)	0.79
Maize *(Zea mays)*	143	No	3.31 (1.10)	32.82
Mangoes *(Mangifera indica)*	13	Great	0.50 (0.35)	0.04
Okra *(Abelmoschus esculentus)*	22	Modest	0.34 (0.23)	0.22
Onions *(Allium cepa)*	31	No	0.80 (0.22)	2.49
Oranges *(Citrus sinensis)*	16	Little	0.42 (0.31)	0.01
Paprika *(Capsicum sp.)*	10	Little	0.30 (0.11)	0.29
Passion *(Passiflora edulis)*	3	Essential	0.75 (0.66)	0.02
Peas *(Pisum sativum)*	6	Little	0.79 (0.33)	0.81
Irish potatoes *(Solanum tuberosum)*	4	No	0.94 (0.77)	0.21
Pumpkin *(Cucurbita pepo)*	2	Essential	0.50 (0.01)	0.05
Rice *(Oryza sativa)*	20	No	0.86 (0.38)	2.4
Sorghum *(Sorghum bicolor)*	14	No	1.09 (0.52)	2.6
Spinach *(Lactuca sativa)*	63	No	0.33 (0.17)	1.85
Squash *(Cucurbita pepo)*	5	Essential	0.70 (0.45)	0.57
Sunflower *(Helianthus sp.)*	23	Modest	1.23 (0.64)	1.76
Sweet potatoes *(Ipomoea batatas)*	8	No	0.59 (0.30)	0.15
Tomatoes *(Solanum lycopersicum)*	103	Little	0.67 (0.25)	14.43
Watermelon *(Citrullus lanatus)*	93	Essential	0.57 (0.22)	24.29

References

1. Lowder, S.K.; Skoet, J.; Raney, T. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Dev.* **2016**, *87*, 16–29. [CrossRef]

2. Tscharntke, T.; Clough, Y.; Wanger, T.C.; Jackson, L.; Motzke, I.; Perfecto, I.; Vandermeer, J.; Whitbread, A. Global food security, biodiversity conservation and the future of agricultural intensification. *Biol. Conserv.* **2012**, *151*, 53–59. [CrossRef]
3. Bianchi, F.J.; Booij, C.; Tscharntke, T. Sustainable pest regulation in agricultural landscapes: A review on landscape composition, biodiversity and natural pest control. *Proc. R. Soc. B Biol. Sci.* **2006**, *273*, 1715–1727. [CrossRef] [PubMed]
4. Boyce, J.K. A future for small farms? Biodiversity and sustainable agriculture. In *Human Development in the Era of Globalization: Essays in Honor of Keith B. Griffin*; FAO: Rome, Italy, 2006; pp. 83–104.
5. Kok, M.T.; Kok, K.; Peterson, G.D.; Hill, R.; Agard, J.; Carpenter, S. Biodiversity and ecosystem services require IPBES to take novel approach to scenarios. *Sustain. Sci.* **2017**, *12*, 177–181. [CrossRef] [PubMed]
6. Emmerson, M.; Morales, M.B.; Oñate, J.J.; Batáry, P.; Berendse, F.; Liira, J.; Aavik, T.; Guerrero, I.; Bommarco, R.; Eggers, S.; et al. How agricultural intensification affects biodiversity and ecosystem services. *Adv. Ecol. Res.* **2016**, *55*, 43–97.
7. Quintana, C.; Girardello, M.; Balslev, H.J.P. Balancing plant conservation and agricultural production in the Ecuadorian Dry Inter-Andean Valleys. *PeerJ* **2019**, *7*, e6207. [CrossRef] [PubMed]
8. Simons, N.K.; Weisser, W.W. Agricultural intensification without biodiversity loss is possible in grassland landscapes. *Nat. Ecol. Evol.* **2017**, *1*, 1136. [CrossRef]
9. Weiser, M.D.; Michaletz, S.T.; Buzzard, V.; Deng, Y.; He, Z.; Shen, L.; Enquist, B.J.; Waide, R.B.; Zhou, J.; Kaspari, M. Toward a theory for diversity gradients: The abundance-adaptation hypothesis. *Ecography* **2018**, *41*, 255–264. [CrossRef]
10. Malmborg, K.; Sinare, H.; Enfors Kautsky, E.; Ouedraogo, I.; Gordon, L.J. Mapping regional livelihood benefits from local ecosystem services assessments in rural Sahel. *PLoS ONE* **2018**, *13*, e0192019. [CrossRef]
11. Wisely, S.M.; Alexander, K.; Cassidy, L. Linking ecosystem services to livelihoods in southern Africa. *Ecosyst. Serv.* **2018**, *30*, 339–341. [CrossRef]
12. Steward, P.R.; Shackelford, G.E.; Sait, S.M. Pollination and biological control research: Are we neglecting two billion smallholders. *Agric. Food Secur.* **2014**, *3*, 5. [CrossRef]
13. IPBES. Summary for Policymakers of the Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production. In *Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; Potts, S.G., Ngo, H.T., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J., Vanbergen, A.J., Eds.; IPBES: Bonn, Germany, 2016.
14. Eilers, E.J.; Kremen, C.; Smith Greenleaf, S.; Garber, A.K.; Klein, A.M. Contribution of pollinator-mediated crops to nutrients in the human food supply. *PLoS ONE* **2011**, *6*, e21363. [CrossRef] [PubMed]
15. Gallai, N.; Salles, J.; Settele, J.; Vaissièrea, B.E. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ.* **2009**, *68*, 810–821. [CrossRef]
16. Chaplin-Kramer, R.; Dombeck, E.; Gerber, J.; Knuth, K.A.; Mueller, N.D.; Mueller, M.; Ziv, G.; Klein, A. Global malnutrition overlaps with pollinator-dependent micronutrient production. *Proc. R. Soc. B* **2014**, *281*. [CrossRef] [PubMed]
17. Hwalla, N.; el Labban, S.; Bahn, R.A. Nutrition security is an integral component of food security. *Front. Life Sci.* **2016**, *9*, 167–172. [CrossRef]
18. Smith, M.R.; Singh, G.M.; Mozaffarian, D.; Myers, S.S. Effects of decreases of animal pollinators on human nutrition and global health: A modelling analysis. *Lancet* **2015**, *386*, 1964–1972. [CrossRef]
19. Marshman, J.; Blay-Palmer, A.; Landman, K. Anthropocene Crisis: Climate Change, Pollinators, and Food Security. *Environments* **2019**, *6*, 22. [CrossRef]
20. Díaz, S.; Demissew, S.; Carabias, J.; Joly, C.; Lonsdale, M.; Ash, N.; Larigauderie, A.; Adhikari, J.R.; Arico, S.; Báldi, A.; et al. The IPBES Conceptual Framework—Connecting nature and people. *Curr. Opin. Environ. Sustain.* **2015**, *14*, 1–16. [CrossRef]
21. Barbir, J. Managing Semi-natural Habitats of Pollinators within Agro-ecosystems. *Entomol. Ornithol. Herpetol.* **2016**, *5*, 171. [CrossRef]
22. Kassie, G.W. Agroforestry and farm income diversification: Synergy or trade-off? The case of Ethiopia. *Environ. Syst. Res.* **2018**, *6*, 8. [CrossRef]

23. Waha, K.; van Wijk, M.T.; Fritz, S.; See, L.; Thornton, P.K.; Wichern, J.; Herrero, M. Agricultural diversification as an important strategy for achieving food security in Africa. *Glob. Chang. Biol.* **2018**, *24*, 3390–3400. [CrossRef] [PubMed]
24. Anderson, J.; Marita, C.; Musiime, D. *National Survey and Segmentation of Smallholder Households in Tanzania*; CGAP: Washington, DC, USA, 2016.
25. FAO. *The United Republic of Tanzania Resilience Strategy 2019–2022*; FAO: Rome, Italy, 2019.
26. Bergius, M.; Benjaminsen, T.A.; Widgren, M. Green economy, Scandinavian investments and agricultural modernization in Tanzania. *J. Peasant Stud.* **2018**, *45*, 825–852. [CrossRef]
27. Pieterse, P.M. *Tech for Governance Programmes in Tanzania—(How) Can Tech Be Used to Promote Good Governance in the Magufuli Era?* IDS: Brighton, UK, 2017.
28. Laizer, H.C.; Chacha, M.N.; Ndakidemi, P.A. Farmers' Knowledge, Perceptions and Practices in Managing Weeds and Insect Pests of Common Bean in Northern Tanzania. *Sustainability* **2019**, *11*, 4076. [CrossRef]
29. Kasina, J.; Mburu, J.; Kraemer, M.; Holm-Mueller, K. Economic benefit of crop pollination by bees: A case of Kakamega small-holder farming in western Kenya. *J. Econ. Entomol.* **2009**, *102*, 467–473. [CrossRef]
30. Sawe, T.; Nielsen, A.; Sydenhman, M.; Venter, S.; Totland, O.; Samora, M.; Eledegard, K. Tree cover, wild floral resources and pesticide affect crop pollination and yiled in small-scale agroforestry system in Tanzania. *Ecosphere* **2020**, under review.
31. Huryn, V.M.B.J.T. Ecological impacts of introduced honey bees. *Q. Rev. Biol.* **1997**, *72*, 275–297.
32. Michener, C.D. *The Bees of the World*; JHU Press: Baltimore, MD, USA, 2007.
33. Klein, A.-M.; Vaissière, B.E.; Cane, J.H.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Tscharntke, T. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. Lond. B Biol. Sci.* **2007**, *274*, 303–313. [CrossRef]
34. Kuivanen, K.; Alvarez, S.; Michalscheck, M.; Adjei-Nsiah, S.; Descheemaeker, K.; Mellon-Bedi, S.; Groota, J.C.J. Characterising the diversity of smallholder farming systems and their constraints and opportunities for innovation: A case study from the Northern Region, Ghana. *NJAC* **2016**, *78*, 153–166. [CrossRef]
35. Mkonda, M.Y.; He, X.H. Climate variability and crop yields synergies in Tanzania's semiarid agroecological zone. *Ecosyst. Health Sustain.* **2018**, *4*, 59–72. [CrossRef]
36. Riggio, J.; Jacobson, A.P.; Hijmans, R.J.; Caroa, T. How effective are the protected areas of East Africa? *Glob. Ecol. Conserv.* **2019**, *17*, e00573. [CrossRef]
37. Cairns, J.E.; Hellin, J.; Sonder, K.; Araus, J.L.; MacRobert, J.F.; Thierfelder, C.; Prasanna, B.M. Adapting maize production to climate change in sub-Saharan Africa. *Food Secur.* **2013**, *5*, 345–360. [CrossRef]
38. Adjognon, S.G.; Liverpool-Tasie, L.S.O.; Reardon, T.A. Agricultural input credit in Sub-Saharan Africa: Telling myth from facts. *Food Policy* **2017**, *67*, 93–105. [CrossRef] [PubMed]
39. Rogers, S.G. The Kilimanjaro Native Planters Association: Administrative Responses to Chagga Initiatives in the 1920's. *Trans. J. Hist.* **1974**, *4*, 94.
40. Mhando, D.G.; Mbeyale, G. *An Analysis of the Coffee Value Chain in the Kilimanjaro Region, Tanzania*; NCCR: Bern, Switzerland, 2010.
41. Ruoja, C.S. The contribution of coffee exportation on poverty reduction in Tanzania. *Int. J. Econ. Commer. Manag.* **2016**, *IV*, 551–559.
42. Segerstrom, T.M. Global Climate Change, Fair Trade, and Coffee Price Volatility. *Gettysbg. Econ. Rev.* **2016**, *9*, 6.
43. Magina, F.; Makundi, R.H.; Maerere, A.P.; Maro, G.P.; Teri, J.M. Temporal Variations in the Abundance of Three Important Insect Pests of Coffee in Kilimanjaro Region, Tanzania. Master's Thesis, Sokoine University of Agriculture, Morogoro, Tanzania, 2009.
44. DaMatta, F.M.; Rahn, E.; Läderach, P.; Ghini, R.; Ramalho, J.C. Why could the coffee crop endure climate change and global warming to a greater extent than previously estimated? *Clim. Chang.* **2019**, *152*, 167–178. [CrossRef]
45. Lenzen, M.; Moran, D.; Kanemoto, K.; Foran, B.; Lobefaro, L.; Geschke, A. International trade drives biodiversity threats in developing nations. *Nature* **2012**, *486*, 109. [CrossRef]
46. Sambuoa, D.; Mbwagab, A. Challenges of Coffee Price Fluctuations and Sustainability of Agricultural Marketing Co-Operatives in Tanzania: Experience from Mbozi and Rombo Districts. *Noble Int. J. Econ. Financ. Res.* **2017**, *2*, 140–151.

47. Katega, I.; Hyandye, C.; Miyonga, M. Contributing factors to decline of coffee production in Muleba district: A case of Makarwe village in Buleza ward. *IJRCE* **2014**, *4*, 85–89.
48. Delaplane, K.S.; Mayer, D.R.; Mayer, D.F. *Crop Pollination by Bees*; Cabi: Warringford, UK, 2000.
49. Lubinsky, P.; van Dam, M.; van Dam, A.J.L. Pollination of Vanilla and evolution in Orchidaceae. *Lindleyana* **2006**, *75*, 926–929.
50. Sawe, T.; Nielsen, A.; Totland, Ø.; Macrice, S.; Eldegard, K. Inadequate pollination services limit watermelon yields in northern Tanzania. *Basic Appl. Ecol.* **2020**, *44*, 35–45. [CrossRef]
51. Chand, R.; Prasanna, P.L.; Singh, A.J.E.; Weekly, P. Farm size and productivity: Understanding the strengths of smallholders and improving their livelihoods. *Econ. Political Wkly.* **2011**, *46*, 5–11.
52. Myeni, L.M.; Thavhana, M.; Randela, M.; Mokoena, L. Barriers Affecting Sustainable Agricultural Productivity of Smallholder Farmers in the Eastern Free State of South Africa. *Sustainability* **2019**, *11*, 3003. [CrossRef]
53. Makuya, V.; Ndyetabula, D.; Mpenda, Z. Cost efficiency of watermelon production in Tanzania. *Int. Assoc. Agric. Econ.* **2018**. [CrossRef]
54. Hass, A.L.; Kormann, U.G.; Tscharntke, T.; Clough, Y.; Baillod, A.B.; Sirami, C.; Fahrig, L.; Martin, J.L.; Baudry, J.; Bertrand, C.; et al. Landscape configurational heterogeneity by small-scale agriculture, not crop diversity, maintains pollinators and plant reproduction in western Europe. *Proc. Biol. Sci.* **2018**, *285*, 1872. [CrossRef]
55. Sirami, C.; Gross, N.; Baillod, A.B.; Bertrand, C.; Carrié, R.; Hass, A.; Henckel, L.; Miguet, P.; Vuillot, C.; Alignier, A.; et al. Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 16442–16447. [CrossRef]
56. Minot, N. *Promoting a Strong Seed Sector in Sub-Saharan Africa*; IFPRI: Washington, WD, USA, 2008.
57. Lynam, J.; Gilbert, E.; Elliot, H. *Evolving a Plant Breeding and Seed System in Sub-Saharan Africa in an Era of Donor Dependence: A Report for the Global Initiative on Plant Breeding*; FAO: Rome, Italy, 2010.
58. Fijen, T.P.; Scheper, J.A.; Boom, T.M.; Janssen, N.; Raemakers, I.; Kleijn, D. Insect pollination is at least as important for marketable crop yield as plant quality in a seed crop. *Ecol. Lett.* **2018**, *21*, 1704–1713. [CrossRef]
59. Jones, J.S.; Bingham, E.T. *Inbreeding Depression in Alfalfa and Cross-Pollinated Crops*; FAO: Rome, Italy, 1995; Volume 13, pp. 209–233.
60. Cardoso, A.I.I. Depression by inbreeding after four sucessive self-pollination squash generations. *Sci. Agric.* **2004**, *61*, 224–227. [CrossRef]
61. Bhattacharyya, M.; Acharya, S.K.; Chakraborty, S.K. Pollinators Unknown: People's perception of native bees in an agrarian district of West Bengal, India, and its implication in conservation. *Trop. Conserv. Sci.* **2017**, 10. [CrossRef]
62. Schönfelder, M.L.; Bogner, F.X. Individual perception of bees: Between perceived danger and willingness to protect. *PLoS ONE* **2017**, *12*, e0180168. [CrossRef]
63. Sieg, A.-K.; Teibtner, R.; Dreesmann, D.J.I. Don't Know Much about Bumblebees?—A Study about Secondary School Students' Knowledge and Attitude Shows Educational Demand. *Insects* **2018**, *9*, 40. [CrossRef] [PubMed]
64. Munyuli, T. Pollinator biodiversity in Uganda and in Sub-Sahara Africa: Landscape and habitat management strategies for its conservation. *Int. J. Biodivers. Conserv.* **2011**, *3*, 551–609.
65. Hordzi, W.H.K. Knowledge of the Roles of Cowpea Insect Flower Visitors and Effects of Pesticide Control Measures on them by Farmers in Three Districts in the Central Region of Ghana. *Int. J. Res. Stud. Biosci.* **2004**, *2*, 30–55.