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Identifying available resources and agricultural practices useful in soil fertility management to support orange-fleshed sweet potato cultivation on smallholder farms in Mozambique

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Orange-fleshed sweet potato is an important source of macro-and micronutrients for humans, particularly in resource-poor rural communities. However, sweet potato cultivation removes large amounts of nutrients from the soil. Hence, soil fertility replenishment is vital to secure long-term food production. The lack of access to fertilizers hinders the ability of farmers to supply and replenish soil nutrients, intensifying food insecurity. This study aimed at identifying locally available organic residues and agricultural practices with potential application in soil fertility management to prevent soil degradation in southern Mozambique. We conducted a survey to gather information on the farmers' demographics and farming systems of 107 orange-fleshed sweet potato farmers. Results show that more than 70% of farmers use agroecological practices such as intercropping and crop rotation, and more than 90% indicated having residual crop biomass after harvest. Most cultivated crops, such as lettuce, beans, etc., are harvested in July-August, before the start of orange-fleshed sweet potato cultivation. Thus, there is potential for the application of crop residues as an organic amendment for orange-fleshed sweet potato cultivation. Nevertheless, farmers need support to adopt soil fertility management based on locally accessible resources, therefore ensuring extension services focused on the long-term benefits of sustainable practices are vital.

Key words: Crop residue, organic agriculture, smallholder, survey.

INTRODUCTION

The dissemination of orange-fleshed sweet potato as a food-based approach, rather than a pill supplement, has

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successfully increased the vitamin A intake in the participating communities. Hence, orange-fleshed sweet potato can be an important staple crop improving the diet quality of many Mozambican families (Low et al., 2007, 2017). Malnutrition due to low intake of vitamin A affects more than 70% of children of 6 to 59 months old in Mozambique (Aguayo et al., 2005). Unfortunately, the crop draws heavily on soil nutrients that are removed at the harvest of the storage roots, with potential extraction reaching up to 100, 40 and 320 kg ha^{-1} yr^{-1} of N, P and K, respectively (Grüneberg et al., 2015; Nedunchezhiyan et al., 2012). Thus, Orange-Fleshed Sweet Potato (OFSP) cultivated without nutrient replenishment would greatly exacerbate soil degradation placing the long-term success of this food-based strategy in peril. Therefore, OFSP introduction should also promote soil fertility management to ensure nutrient replenishment and secure adequate supply for sustainable food production.

In Mozambican small scale rainfed systems, soil nutrient budgets deficit averaged -32, -6 and -25 kg ha^{-1} $year^{-1}$, however, the highest depletion was observed with root crops, such as cassava, depleting an additional 10 kg ha^{-1} $year^{-1}$ (Folmer et al., 1998). In the long-term, soil degradation hampers food production and particularly challenges resource-limited rural communities already exposed to nutritional insecurity (Tittonell and Giller, 2013). In Mozambique, smallholder farmers have limited options to replenish soil nutrients due to a lack of access to fertilizer markets and low purchasing power, forsaking land to deterioration (Cunguara and Garrett, 2011; Mazuze, 1999). Additionally, in the region, extreme climatic events such as extended drought periods or floods disrupt agricultural production causing great losses of crops and soil. The fragility of agricultural systems, caused by the low capacity of farmers to adapt in the occurrence of extreme events, extends problems such as malnutrition and poverty (Ehrhart and Twena, 2006; Leichenko and O'Brien, 2002).

For the resource limited farmer, locally accessible organic amendments incorporated within agroecological and conservational practices can advance sustainable agriculture for securing soil nutrient replenishment adequately. For instance, the adoption of practices such as intercropping and crop rotation using maize and leguminous crops on smallholding farms in central Mozambique enhanced food security by improving crop productivity and diversifying agricultural production (Rusinamhodzi et al., 2012). In a study performed in northern Mozambique, the conservational practice of retaining crop residues on the soil surface resulted in higher maize yields consistently over four seasons when compared to traditional cultivation involving soil-disturbing residue removal (Thierfelder et al., 2015). Nevertheless, the use of crop residue as mulch on the soil surface competes with other applications, such as the common practice of animal foraging, particularly in crop-livestock farming systems. Additionally, the lack of a sufficient labour force required to efficiently control weeds while retaining crop residue is a barrier to this method of improving crop yield (Rusinamhodzi et al., 2016a). The decision to apply crop residues depends on the farmer's own preferences, availability of alternative resources, the external demand for crop residues, and the availability of sufficient biomass produced in agricultural systems (Valbuena et al., 2015; Corbeels et al., 2014; Valbuena et al., 2012).

Specific factors related to the farmers' socio-economic and biophysical characteristics and context must be considered to ensure successful adoption and the optimal performance of soil fertility management (Ajayi et al., 2007). In the present study, we conducted a survey in rural communities located within the OFSP dissemination area in the Manhiça district in southern Mozambique. The survey aimed at identifying (i) locally accessible resources and known agroecological practices performed by interviewed farmers and (ii) main constraints for farmers to achieve desirable OFSP production. The survey results examined whether crop biomass residues from farming activities depend on farms' and farmers' characteristics. Findings from this work will support the development of tailored soil fertility management for sustainable OFSP cultivation based on local conditions and the resources available to the OFSP farmer.

MATERIALS AND METHODS

Study area

The survey encompassed Manhiça, which is the major sweet potato production district of Maputo province in southern Mozambique. The farming areas lie at altitudes of 15 m and experience a seasonal warm/wet and cool/dry climate during October to April and May to September, respectively. The annual temperature averages 23°C with a mean precipitation of 807 mm. The Incomati river serves the region and its banks serve for agricultural production. The soil in Manhiça comprises sandy sediments with coastal dunes and alluvial flatlands along the Incomati River. Manhiça hosts a population of about 190,000 inhabitants in an area of 2373 km^2. Although only 20% of the land serves agricultural purposes, agriculture represents the dominant economic activity in the municipality (Mozambican Ministry of State Administration-MMSA, 2005).

Smallholder farms receive public extension work performed by the District Services of Economic Activities (SDAE) – division of the Mozambican Ministry of Agriculture and Rural Development. The SDAE administers technical support, farming supplies such as seeds and fertilizers to local farmers' associations (MMSA, 2005). The SDAE also participates in dissemination campaigns of OFSP vines sponsored by the International Potato Center (CIP) (Matale and Munda, 2012).

Survey development

This study interviewed a total of 107 households in rural Manhiça (Figure 1). Participation in the questionnaire was optional and all interviewed farmers were informed that these findings would be published and the answers could not be traced back to individual

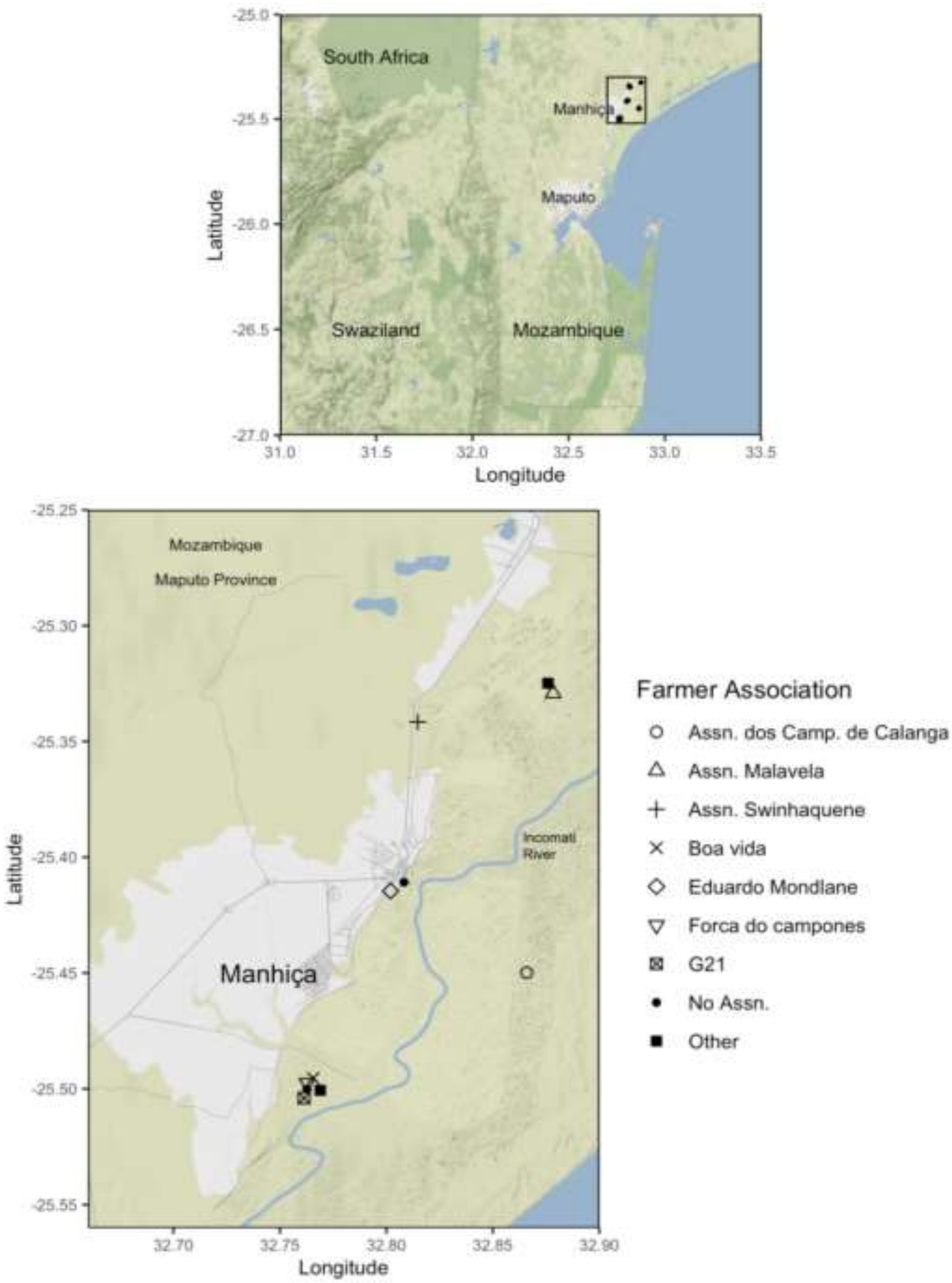

Figure 1. Map of southern Mozambique with details of the communities surveyed.

farmers. During the interview, farmers could cease to participate at any time.

To identify soil and crop management as well as production constraints involved in sweet potato farming, the questionnaire featured 22 questions (Supplementary Material 2) divided into five subtopics: (i) demographics, (ii) farm characterization, (iii) fertilization and cropping systems, (iv) OFSP cultivation, as well as (v) organic resources availability. The term 'synthetic fertilizer' refers to synthetic forms applied to cash crops, such as maize and garden crops. 'Organic fertilizer' refers to any kind of organic waste or residue, produced from farming practices, composted or not, divided into animal manure or vegetable residues.

Using the five subtopics, SDAE extension agents performed the surveys in the local language 'Changana'. All the farming associations selected for this survey participate in the OFSP dissemination campaigns administered by CIP and SDAE. Each association assisted by the SDAE resides along the Incomati river in Manhiça (Figure 1). The results are presented as a percentage of

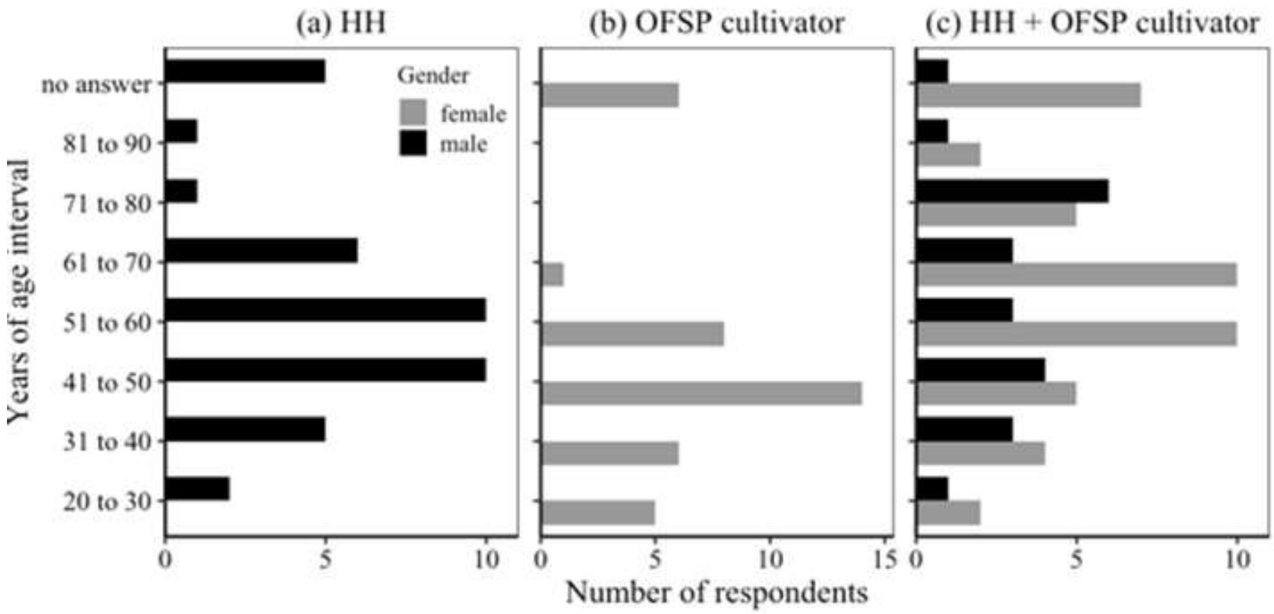

Figure 2. Number of respondents according to age interval and gender in each household, distributed by role in farm, (a) HH=head of household, (b) OFSP cultivator=orange-fleshed sweet potato cultivator, and (c) both HH and OFSP cultivator.

the respondents, followed by the number of respondents according to the answer for each of the questions. An independent $\chi 2$ test was used to determine if the production of organic fertilizer was dependent on the demographic characteristics of respondents as well as the farming system.

RESULTS

Demographics

Of the total 107 households surveyed, 62 are headed by men, and 45 by women. Women predominantly perform the OFSP cultivation (79%). Of the interviewed farmers, 40 women are exclusively OFSP cultivators, and 40 men are exclusively the head of the household; whereas 45 women and 22 men assume both roles (Figure 2). A $\chi 2$ test of independence shows a significant relationship between the age group and gender of the OFSP cultivator and/or head of the household ($\chi 2$= 34.656, df = 21, p-value = 0.03079). This means that when having exclusive roles in the household, the majority of respondents both women and men are younger (between 41 and 60 years of age) (Figure 2a and b). In contrast, in the households where the respondents accumulate both roles of head of household and OFSP cultivator, the majority of women were between 51 and 70 years of age and the majority of men were even older, between 71 to 80 years of age (Figure 2c). In other words, older respondents were more likely to be the head of the household and the OFSP cultivator, while younger respondents conserve their exclusive role in the household (Figure 2).

Of the interviewed farmers, 30% started their farming activities between 1950 and 1980, 40% started between 1980 and 2000, and the rest 30% started after 2000. Crop production is the main activity for income generation (92%), only 1 farmer indicated relying mainly on animal production and 2 farmers use both activities as their main income source.

Farm characterization

The area surveyed included 7 different farmers associations, distributed in sub-regions depending on the location of the farm (Figure 1). Farm size varied from 50 to 70000 m^2. A portion of respondents did not respond to the question about the size of their farm (39%). The majority of farmland is smaller than 10000 m^2, as 44% of farmers indicated having farms from 50 to 10000 m^2, and only 17% have farms larger than 10000 m^2. Only 3% of respondents have farm areas of 50000 to 70000 m^2.

Farmers are assisted by more than one organization. Only 13% of farmers do not receive any agricultural extension support, and half of these were not part of any association. A majority of farmers (85%) indicated they are assisted by SDAE and 30% are assisted by NGOs. Farmers obtain seeds from a variety of suppliers; mainly they purchase seeds to be used in the following season (82%) in addition to storing seeds for future use (50%) and donations from the local government appeared to be common (42%). Sharing amongst neighbors and other sources of seed supply are less common (10% and 7%,

Table 1. Duration of seasons according to the crop and number of respondents, in % that cultivate each crop.

Crop	Months												Respondents %
	J	F	M	A	M	J	J	A	S	O	N	D	
Sweet potato	h	p					h		p				83
Maize	h	p					h		p				76
Cassava							h		p				33
Potato	h	p					h		p				5
Cowpea			p			h	p		h				7
Kale				p		h							21
Onions				p			h						14
Tomato				p			h						11
Lettuce			p		h								14
Cabbage			p		h								10
Garlic			p		h								8
Beans			p				h						7
Pumpkin	p				h								15
Okra	p					h							4
Peanuts	p								h				11
Carrots	h								p				4
Banana													5
Sugar cane							h	p					4

(p = planting, h = harvesting).

respectively).

Agricultural practices

The most commonly cultivated crops are sweet potatoes, maize, and cassava (Table 1). Sweet potatoes include the white and orange-fleshed varieties, given that they are cultivated in the same area, under the same management. The cassava season starts in September with harvest 1.5 years later, during April and May. Sweet potato and maize can be cultivated twice a year, with the first planting during the warm/wet season Sep-Feb and a second in the cool/dry Feb-Jul season. Garden crops, such as lettuce, tomatoes, kale, etc. have faster maturity and are commonly cultivated during the cool/dry season between March and July (Table 1). The majority of farmers (70%) cultivate 1 to 3 plant species in the same season on their farm and only 24% cultivate between 4 to 7 plant species (Supplementary Table 1).

According to farmers' responses, more than one cropping system is practiced by the same household during the season. Intercropping is the most common agroecological management (84%), usually consisting of legumes planted with maize or okra. Crop rotation is the second most common farming system amongst the interviewed farmers (74%). Fallow periods are less used by farmers, as 36% of respondents leave their land fallow, and only 8% of the respondents mentioned they use fire to 'clean' the area left fallow. Monoculture is practiced by 41% of the farmers, mainly in areas with sugarcane, maize and sweet potato.

As animal production does not contribute to income generation for the majority of farmers, 36% of the respondents do not raise farm animals; nevertheless, more than half of farmers have poultry (52%). Less common are duck (34%), goat (21%), swine (11%), and cattle (9%) production. For farmers indicating more than one animal species on their farm, 38% mentioned raising between 2 and 3 animal species (Supplementary Table 1).

OFSP cultivation

The majority of interviewed farmers began to cultivate OFSP between the years 2012 and 2016 (73%). Most of the planting material originated directly from the International Potato Center (CIP) (45%), or from exchanging with neighbors (47%). None of the interviewed farmers indicated applying any type of fertilizer in OFSP cultivation. According to the respondents, the most common constraint to OFSP cultivation and cause of lower productivity is drought (79%) followed by pest incidence (64%). The estimated OFSP productivity varied amongst farmers from 0.12 t ha^{-1} to 100 t ha^{-1}, fresh weight basis (FWB), only 37 out of the 107 interviewed farmers informed us about their

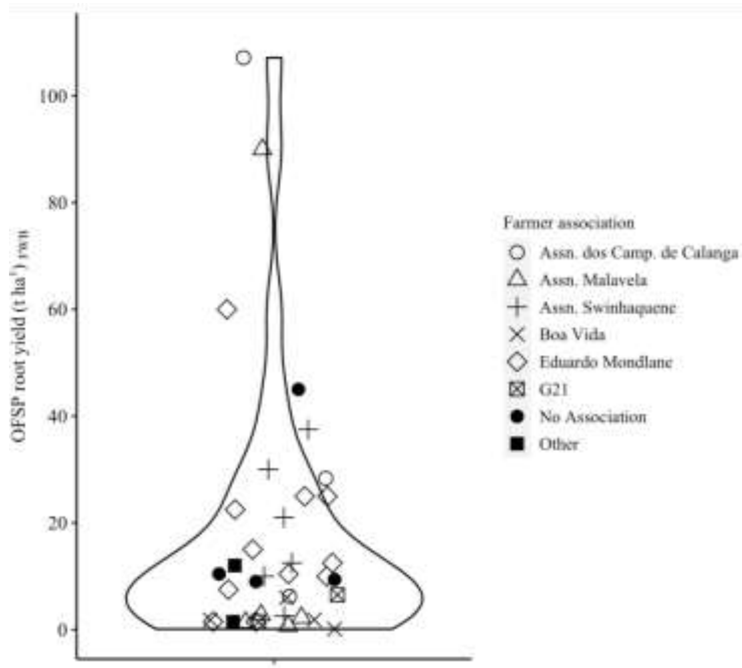

Figure 3. OFSP storage root yield on a fresh weight basis (FWB), according to farmers interviewed by each farmer association in this survey.

OFSP root yield (Figure 3).

Residual biomass from farming

The majority of farmers interviewed produce crop residue in their agricultural systems (85%, n=91). Of the farmers that produce residues, one farmer indicated having only animal manure as a residue on his farm, and six other farmers answered that they produce both animal and crop residues on their farm. Nevertheless, 8% of farmers did not specify any residual material from their farming activities. Most farmers use these residues as fertilizer (82%), and only 3% sell their residue. Of all the farmers interviewed, 6% burn the crop residues produced on their farms. A $\chi 2$ test of independence shows that the production of organic fertilizer or type of residue produced is not statistically related in any significant way to farmers' demographics, nor the farming system (Supplementary Table 1).

DISCUSSION

Identifying locally accessible resources and their potential use as fertilizer

Based on the survey performed, most of the annual crops (that is, lettuce, kale, pumpkin, etc.) are cultivated during the dry season and harvested before the start of the OFSP season (July-September, Table 1). Hence, the residues from these crops are potential accessible resources that can be used as organic fertilizer in subsequent OFSP cultivation. For instance, considering 20% residual biomass left after harvest, kale cultivation represents an addition of 10, 7.5 and 18 kg ha^{-1} of N, P and K, respectively (Ayaz et al., 2006; Chakwizira et al., 2015) and lettuce can add 47, 16 and 116 kg ha^{-1} of N, P and K, respectively (Hoque et al., 2010). Additionally, residual biomass from leguminous crops such as cowpea and groundnuts are viable sources of nutrients because these crops are able to supply 10 to 75 kg ha^{-1} of N, 1.5 kg ha^{-1} of P and 25 kg ha^{-1} of K (Randall et al., 2006; Gascho and Davis, 1994). Moreover, the incorporation of organic fertilizers increases soil organic matter and improves soil properties that benefit plant growth in the long term (Mangalassery et al., 2019). As it stands farmers take advantage of crop residue production as 82% of them indicated using crop residue as fertilizer. Thus, this survey asserts that farmers commonly use crop residues to fertilize the cropping systems; however, not on OFSP but mainly on cash crops.

Other authors reported the use of crop residues as animal feed to improve the quantity and quality of the animal manure for later use as a high-quality fertilizer (Rusinamhodzi et al., 2016a). Nevertheless, the competition to use crop residue as animal feed instead of directly as a fertilizer depends on the presence of cattle in the farming systems among other factors (Rusinamhodzi et al., 2016a; Corbeels et al., 2014). In Mozambique, the infestation of tsetse (*Bovine trypanosomosis*) limits cattle production in the country (Specht, 2008), which explains the low percentage of farmers surveyed employing cattle production in their farming systems. The national census further corroborates this data, reporting that only 5% of smallholder farms produce cattle in Mozambique (Amade et al., 2010). This indicates that the crop residue used as fertilizer does not compete with using it as cattle feed. Thus, the possibility of using crop residues to fertilize OFSP cultivation would compete with the current destination of these amendments, which are used as cash crop fertilizer.

Moreover, although most farmers generate crop residues from agricultural activities, a few cases produce no residual material from farming due to poor crop performance and consequent lower food availability (Ehrhart and Twena, 2006). Drier and warmer weather in southern Africa attributed to climate change increasingly damages limited-resource rural communities, increasing the risk for agricultural production and endangering food security (Cairns et al., 2013). In southern Mozambique, water scarcity drives crop failure (Ehrhart and Twena, 2006), thus, in low crop yield scenarios, the trade-offs and pressure to use crop residues as inputs in agricultural systems become higher (Valbuena et al., 2015).

Animal production remains a potential system for sourcing organic amendments because almost half of the farmers raise poultry and other animals. Overall in Mozambique, 60% of farms raise poultry (Amade et al., 2010). Poultry manure is established as a high-quality organic fertilizer; for example, Agbede (2010) found poultry manure to increase soil organic carbon by 13% and nutrient concentration, particularly soil N and P, with 40 and 30%, respectively in contrast to non-fertilized soil. When compared to legume plant residue incorporation, poultry manure increased soil N and P concentration by 65 and 23% (Amusan et al., 2011). Better sweet potato performance was observed with poultry manure fertilization, with 35% higher storage root yield compared to non-fertilized cultivation (Agbede, 2010). However, even with a significant number of farmers raising animals, the majority did not mention having animal manure on their farms. As observed during visits, the surveyed farms often had poultry, goats, or other animals ranging freely, which hinders manure accumulation and collection. Poultry systems are characterized by low animal density and scavenging poultry raised for subsistence in low-input/low-output systems (Goromela et al., 2006). Limited-resource farmers have no means to invest in improvements to intensify animal production (Lobo et al., 2006); therefore, targeted governmental policies should support farmers to improve their facilities for poultry production enabling the development of integrated agriculture based on internal cycling, that is, recycling of waste.

Identifying locally known sustainable agricultural practices

Relying on internal cycles to exploit soil resources more efficiently than monocultures, agroecological practices can offer adequate alternatives for resource-limited farmers to secure long-term sustainable food production systems (Dubey et al., 2020). Conservation agricultural practices are highly adopted in Mozambique with 79% of small and medium size farmers practicing intercropping; nevertheless, only 27% practice crop rotation (Amade et al., 2010). A larger number of smallholder farmers adopt maize-legume intercropping instead of maize-legume rotation due to higher risks and unreliable yield when legumes are planted in monoculture after the maize. Instead, rotations are commonly performed with maize followed by other crops, such as potatoes (Grabowski and Kerr, 2014). The surveyed communities commonly used maize-leguminous intercropping and maize rotations with a staple crop.

Intercropping has the potential to increase soil organic carbon and plant performance while diversifying produce, hence, can benefit smallholder farmers with limited access to resources (Rusinamhodzi et al., 2016b). Both intercrop and crop rotation systems using maize and leguminous plants have been shown to improve production. In a study performed in central Mozambique, maize-cowpea intercropping and maize in rotation with cowpea increased maize grain yield by more than 80% compared to monoculture after three growing seasons (Rusinamhodzi et al., 2012). Other authors reported a 38% increase in maize grain yield when intercropped with cowpea, in the same region (Nyagumbo et al., 2016). In OFSP systems intercropped with groundnuts, storage root yield was 38% higher in southern Mozambique when compared to OFSP monoculture (Munda et al., 2019).

In addition to the beneficial impacts on crop performance, maize-leguminous intercropping alternatives alleviate biophysical and socio-economic constraints faced by diversifying produce (Rusinamhodzi et al., 2012; Nyagumbo et al., 2016). However, the adoption of such agroecological practices is constrained by cultural and socio-economic factors such as the inclusion of leguminous plants and preference for maize as a food staple (Grabowski and Kerr, 2014; Thierfelder et al., 2014). From personal observation in the field, we observed that intercropping and crop rotations employed limited-resource adaptations, such as larger spacing between plants, reflecting the farmer’s knowledge and means (Supplementary Material 3). Thus, the management performed *in situ* requires investigation and the impacts on the agricultural systems should be quantified with respect to local conditions.

Thirty-six percentage of farmers used fallow periods to recover the soil fertility after continuous cultivation. At the end of fallow, 6% responded they burn weeds and residues accumulated to prepare for the subsequent cropping system. Other authors reported that farmers choose to burn residual biomass from fallow as a low-cost and less time-consuming alternative compared to leaving mulch on the soil surface (Adjei-Nsiah et al., 2007). For the sweet potato, the cultivation after a 2-year fallow period led to a 40% higher root yield than in a continuous monocropping system, demonstrating that nutrient input from plants biomass grown during the fallow can serve to increase yield (Hartemink, 2003). Moreover, the use of improved fallow systems, with the incorporation of leguminous plants can increase N supply and have a beneficial impact on yield (Akanvou, et al., 2000). However, the success of this procedure in recovering soil fertility depends on the climate, vegetation and management of the area, particularly fallow length (Nhantumbo, 2008). With rising population density intensifying pressures for land use, farmers increasingly shorten or skip fallow periods (Cunguara and Garrett, 2011). While burning weed biomass is used to clean the vegetated area before planting a new crop; the use of controlled fires has been discouraged by the governmental extension service to reduce and avoid accidents (Shaffer, 2010). As current practices diverge from the traditional system, new methods will be needed to manage resources efficiently, maintaining productivity and environmental sustainability.

Main constraints for OFSP production

Although OFSP root yield varies highly between farmers and complicates benchmarks (Figure 2), potential root productivity can surpass the current average production (Grüneberg et al., 2015). The long drought period most severely limits the achievement of desired OFSP performance. The occurrence of droughts challenges many countries in sub-Saharan Africa, and severely affects sweet potato yield as well as nutritional security in Mozambique. Hope lies in breeding programs targeting the development of drought-tolerant varieties (Parker et al., 2019). Pest incidence also imposes a great challenge. Weevil infestation, in particular, hinders the production and accumulation of root biomass and the effects can be more destructive during the dry season (Matale and Munda, 2012).

Soil fertility was not indicated as a limiting factor for OFSP productivity among the farmers located along the Umbeluzi River (Figure 1). Their farming on Fluvisol soil leverages natural moderate fertility and represents 6% of the area in Mozambique (Mazuze, 1999). These resource-limited communities traditionally cultivate staple crops without managing soil fertility, but the continuous removal of nutrients, particularly from root and tuberous crops, deplete the soil (Cunguara and Garrett, 2011; Lal, 1997). Care must be taken in advocating these more intense nutrient-demanding crops to supplement the soil fertility requirements before overdrawing the natural replenishment rates.

Conclusion

In conclusion, our results suggest that crop residues are a common local resource capable of improving soil fertility. Although more than half of respondents produce poultry, these are mainly characterized by free-range scavenging production systems, which limits the access to a sufficient amount of manure, as collection and accumulation of manure are difficult.

The survey results suggest that farmers do not use crop residue for animal feed but recognize them as potential fertilizer in their cash crop systems, that is, 82% indicated to use crop residue as fertilizer on cash crops, yet, no soil fertility management is performed in OFSP systems. The surveyed farms are located in a region with natural moderate soil fertility, hence, OFSP yield is not heavily constrained by the lack of soil nutrients and OFSP is not a cash crop; thus, the application of crop residue on OFSP is not considered by farmers. Nevertheless, strategies to ensure soil fertility replenishment should be prioritized in governmental extension services to avoid continuous nutrient removal.

Moreover, the incorporation of crop residues in agricultural systems have beneficial impacts that go beyond soil nutrient maintenance, as this material enhances soil organic matter, improving soil biological and physical properties that allow long lasting benefits on soil potential to provide conducive conditions for plant growth. This survey indicates that integrating local resources, (that is, crop residues) with known agroecological practices, (that is, intercropping and crop rotation) is a viable option that can be applied as soil fertility management in OFSP systems. Thus, extension assistance should focus in supporting farmers to adopt these practices to secure soil fertility and ensure OFSP production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Supplementary Table 1. Farmers' demographics and farming systems according to the total number of respondents and in relation to the residual biomass production. An independent χ2 test was calculated to determine if the production and the type of residue was dependent on demographics or farming systems responses.

Parameter	Total No. of respondents	No. residue	Green residue	Animal residue	Both residue	χ2
Total	107	9	91	1	6	
Sex head of household						
Male	62	8	50	1	3	χ2= 4.7536, df = 3, p-value = 0.1908
Female	45	1	41	0	3	
Farm size						
0-500 m^2	8	0	8	0	0	
500-1000 m^2	3	1	2	0	0	
1000-2500 m^2	9	1	8	0	0	
2500-5000 m^2	19	1	16	0	2	χ2= 19.074, df = 14, p-value = 0.1621
0.5-0.75 ha	3	0	2	0	1	
0.75-1 ha	6	0	6	0	0	
1-5 ha	15	1	14	0	0	
5-7 ha	2	0	1	0	1	
Experience (year started farming)						
1950 - 1960	2	0	2	0	0	
1961 - 1970	11	0	10	0	1	
1971 - 1980	11	1	9	0	1	
1981 - 1990	15	0	15	0	0	χ2= 17.339, df = 18, p-value = 0.4999
1991 - 2000	28	4	23	0	1	
2001 - 2010	22	3	17	0	2	
After 2010	9	1	7	1	0	
Age-head of household						
20 - 30	6	1	5	0	0	
31 - 40	13	2	10	1	0	
41 - 50	18	3	13	0	2	
51 - 60	25	1	22	0	2	χ2= 17.421, df = 18, p-value = 0.4944
61 - 70	18	2	16	0	0	
71 - 80	11	0	10	0	1	
81 - 90	3	0	2	0	1	
Farmer association						
Malavela	9	0	9	0	0	
Camp. de Munhanque	5	0	5	0	0	
Swinhaquene	21	2	19	0	0	
Boa Vida	18	4	14	0	0	
Eduardo Mondlane	25	0	20	1	4	χ2= 31.933, df = 24, p-value = 0.1287
Forca do Campones	4	0	4	0	0	
G21	5	1	4	0	0	
No association	13	1	10	0	2	
Other	7	1	6	0	0	
No. of crop species cultivated in the last year						
1	13	2	11	0	0	
2	26	2	24	0	0	χ2= 15.218, df = 21, p-value = 0.8119
3	36	5	26	1	4	
4	11	0	11	0	0	

Supplementary Table 1. Contd.

5	7	0	6	0	1	
6	5	0	4	0	1	
7	3	0	3	0	0	
8	0	0	0	0	0	
9	3	0	3	0	0	
>10	1	0	1	0	0	
No. of animal species raised in the last year						
0	38	3	34	0	1	
1	25	1	21	0	3	
2	23	2	18	1	2	χ2= 24.037, df = 15,
3	18	1	17	0	0	p-value = 0.06446
4	2	1	1	0	0	
5	1	1	0	0	0	
Extension assistance-Governmental						
No	16	3	13	0	0	χ2= 3.6535, df = 3,
Yes	91	6	78	1	6	p-value = 0.3014
NGO						
No	75	8	63	1	3	χ2= 3.1313, df = 3,
Yes	32	1	28	0	3	p-value = 0.3718
No assistance						
No	94	7	80	1	6	χ2= 1.8239, df = 3,
Yes	13	2	11	0	0	p-value = 0.6097
Other						
No	103	8	88	1	6	χ2= 1.6807, df = 3,
Yes	4	1	3	0	0	p-value = 0.6412
Agricultural practice-Monoculture						
No	63	6	55	0	2	χ2= 3.366, df = 3,
Yes	44	3	36	1	4	p-value = 0.3386
Crop rotation						
No	28	3	23	1	1	χ2= 3.3785, df = 3,
Yes	79	6	68	0	5	p-value = 0.3369
Intercropping						
No	17	2	14	1	0	χ2= 6.7149, df = 3,
Yes	90	7	77	0	6	p-value = 0.08156
Fire						
No	98	6	85	1	6	χ2= 8.2894, df = 3,
Yes	9	3	6	0	0	p-value = 0.04039
Fallow						
no	68	6	57	1	4	χ2= 0.6692, df = 3,
yes	39	3	34	0	2	p-value = 0.8804
Other						
No	105	9	89	1	6	χ2= 0.35835, df = 3,
Yes	2	0	2	0	0	p-value = 0.9487

Supplementary Table 1. Contd.

Residue use-Fertilizer						
No	19	9	8	1	1	$\chi 2$= 51.33, df = 3,
Yes	88	0	83	0	5	p-value <0.001
Sold						
No	104	9	90	1	4	$\chi 2$= 21.78, df = 3,
Yes	3	0	1	0	2	p-value < 0.001
No use						
No	97	0	91	0	6	$\chi 2$= 107, df = 3,
Yes	10	9	0	1	0	p-value < 0.001
Burnt						
No	101	9	85	1	6	$\chi 2$= 1.1176, df = 3,
Yes	6	0	6	0	0	p-value = 0.7728

Supplementary Material 1.

Questionnaire, translated from Portuguese to English, used to survey smallholder farmers.

Interviewed Demographics

1) Household head age: ___ years, gender: f / m
2) Responsible for OFSP cultivation age: ___ years, gender: f / m
3) Which year started agricultural activities (or How many years have been involved in agriculture)?
4) Are you a part of any association? Y/N, which one: _______________

Farm Characterization

5) Do you receive any kind of technical assistance? Y/N
6) If yes, technical assistance provided by: NGO / Government / Other:_________
7) Where do your seeds come from: Extension agents (Governmental) / Self-production / Purchased / other: ___________
8) Size of the property: _______________ (m^2 or ha)

Soil fertility and cropping systems

9) Fill in the table with the crops cultivated in the last year. Provide information concerning when specific crop was harvest and inputs used in cultivation

Crop	Planting month	Harvesting month	Irrigation Y/N	Pesticides Y/N	Fertilizers Y/N	Dose of fertilizer	Weed control method

10) Animal production in your farm (multiple choices are possible): cattle / goat / chicken / milk cattle / swine / duck / other: __________
11) Indicate which activity is the main income for the household: animal production / crop production / neither
12) Which of the following agricultural practices are performed in your farm: monoculture / crop rotation / intercropping / fallow / neither / other: _______

OFSP cultivation

13) Which year did you start with OFSP cultivation?
14) Area used for planting OFSP in the last year: ___________ m^2 or ha
15) How much do you produce of OFSP in the area mentioned on question 14? _____kg
16) Who provided OFSP vines in the last season? neighbors / self-production / SDAE / CIP / other: ________
17) Which OFSP variety do you plant?
18) If you use fertilizer on OFSP cultivation, please answer the following:
a. Dose of fertilizer
b. Which fertilizers?
c. When do you fertilize? Before planting / ___ days after planting / on planting day / other:_______
19) What would you say are the constraints for OFSP productivity: No constraints / pests, diseases / drought / weed infestation / poor soil fertility / flooding / other:______

Organic fertilizer availability

20) Identify if there is residues produced from agricultural practices performed in your farm: No / Yes, indicate: vegetable residues / animal manure / other:________
21) If you produce residues, how are they used: Do not produce any residue / use as fertilizer / commercialized / no use / other:_______
22) Identify if there is production of other organic residues that could be used in your farm as fertilizer: food residues / no other residue is produced / other:________
23) General comments from interviewer and interviewed:

Supplementary Material 2.

C

Figure 3. (A) Maize intercropped with cowpea; leguminous plants are scattered in the field; (B) Maize intercropped with okra. We see the neighbor area planted with banana monoculture in the distance; (C) Maize-cowpea intercropping; with fewer leguminous plants compared to maize.