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Developing pathways to improve smallholder agricultural productivity through ecological intensification technologies in semi-arid Limpopo, South Africa

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Abstract

Agricultural productivity in many rural areas in Sub Saharan Africa is low. This affects food security and rural livelihoods. Understanding farm diversity is essential to delineate recommendation domains for new technologies. Farm typologies are a useful tool to assist in unpacking and understanding the wide diversity among smallholder farms to improve targeting of agricultural intensification strategies. We studied a community of smallholder farmers in Ha Lambani, a village, Limpopo South Africa. In this study, agricultural experts identified farmer groupings through based on the crops grown, farm size and major the source in which gross maximum income was earned. A survey was then carried out to identify farming patterns, constraints and we linked these constraints and solutions to specific ecosystem services that appear to be currently important to the farming systems. This enabled us to explore the potential to enhance productivity through ecological intensification, and provides important information about which specific ecological intensification measures are likely to gain traction or appeal to a particular group of farmers in this community. We conclude that although expert based typologies enhance local relevance and reality, they need to be combined with statistical approaches for effective selection of farms, innovation targeting and out-scaling of technologies.

Key Words: farm types; smallholder agriculture; ecosystem services, ecological intensification

Contents

1.0 Introduction

In Southern Africa, smallholder farming is dominated by dryland crop production. The regional average grain yields ranged from 0.3 to 2.2 tha^{-1} during the period 2008–2012 (FAO, 2014). South Africa is generally considered as a food secure nation (De Cock et al., 2013), but many households in rural areas are food insecure (Pereira et al., 2014). About 35.2 % of the South African population live in rural areas and practice subsistence agriculture. They rely on agricultural activities for their livelihoods, and are amongst the poorest and most vulnerable in the country (Tibesigwa et al., 2014; Ncube et al., 2016). The rural farming households are particularly vulnerable to climate and other disaster risks because they are mostly dependent on rain fed traditional agriculture (Mwenge Kahinda & Taigbenu, 2011; Kong et al., 2014) and have a low adaptive capacity due to technical, financial and infrastructural constraints (Gbetibouo et al., 2010).

In South Africa and most surrounding countries in Southern Africa, agriculture and agricultural related activities contribute to most of the employment in rural areas (Dercon & Gollin, 2014). Smallholder agriculture has the potential to generate more employment, income and improve livelihood opportunities in rural areas of South Africa (Shisanya & Hendriks, 2011; Mpandeli & Maponya, 2014). Therefore, improving agriculture is considered as a viable and sustainable alternative in reducing rural poverty in South Africa and other Sub Saharan African (SSA) countries (Adekunle, 2014; Thamaga-Chitja & Morojele, 2014; Shisanya & Mafongoya, 2016). With proactive technical and policy support, smallholder farmers can realise their potential to become competitive in their agricultural production activities. Thus, improvement of smallholder farming is a high priority in South Africa's improvement of rural communities (Aliber & Hall, 2012; Kepe & Tessaro, 2014).

The manner in which agricultural technologies/innovations should be promoted in SSA to improve agricultural production and sustainable livelihoods through smallholder farming is largely debated (Wainaina, et al., 2016). Technologies on sustainable land use and improved agricultural productivity have been developed, promoted and scaled out in the past 30 years in SSA (Bidogeza, et al., 2009). However some of these technologies have only been partially adopted (Giller, et al 2009, 2015), indeed most have not been fully adopted (Wainaina et al., 2016). This is because most interventions are not reflective of smallholder farmer circumstances and fail to acknowledge the environmental realities of smallholder farmers, their social views, their perceptions of their own environmental realities and the strategies used to meet their food security needs (Nhantumbo et al., 2016). For example, Giller et al. (2009) argue that, despite CA being promoted heavily in SSA, they question its suitability and effectiveness, especially in smallholder agriculture in SSA, highlighting a possible mismatch between the conditions required for all CA principles to be adopted by farmers and the circumstances that characterize and constrain smallholder African farming systems. This disconnect undermines effective engagement between farmers, extension services and researchers for effective improvement of technologies for adoption. Therefore new pathways of fostering agricultural interventions in South Africa and SSA are needed before scaling up such interventions (Whitbread et al., 2010; Sanyang et al., 2016). Agricultural technologies/interventions aiming to enhance production, income and household livelihoods, must capture the contrasting biophysical circumstances within and across the heterogeneous agro ecologies in smallholder agriculture in SSA (Baudron, et al., 2015; Giller et al., 2015). This must include the differing socio-economic circumstances within the sector.

Effectively identifying and integrating major issues that guide smallholder farmers' decision making is therefore important to unlock current low adoption rates of practices such as conservation agriculture, in situ rain water harvesting among others (Nhantumbo et al., 2016). A practical way to understand smallholder farmers' decision making is to identify performance, efficiency levels, challenges/constraints and opportunities. Understanding the vulnerability of the farming systems to climate, social, economic and biophysical shocks and their impacts could also help. Different modelling frameworks can be used to achieve the above. However, a successful farming system analysis model requires the establishment of farm typologies.

Amongst farm households with similar production goals, biophysical and resource endowments, farm typologies effectively classify the heterogeneity of farmers' motivations and socio-economic circumstances related to their farming systems (Bidogeza et al., 2009; Chikowo et al., 2014; Chenoune et al., 2016). Two approaches could be used to identify farms heterogeneity in smallholder agriculture in SSA. The first is a bottom-up participatory approach where every farmer is consulted and engaged through field visits, discussions and interviews. The second is a top-down approach is where key informants are used to identify heterogeneity and generate typologies as shown by (Tittonell et al., 2005; Zingore et al., 2007). Whilst the first approach cannot be implemented on a large scale (lack of human and time resources), it allows for better description of farmer's anticipation, capacity and willingness to adopt new management strategies and agro-technologies. The second approach has the potential for large scale implementation in cases where time and other resources are limiting. The classification criteria depend on the goal of the typology and the kind of data available. Furthermore, agricultural scientists are being encouraged to develop farm typologies to support a more tailored approach to agricultural development and innovation (Kuivanen et al., 2016).

In SSA two models of fostering agricultural development and innovation to improve smallholder agriculture have gained momentum, namely sustainable and ecological intensification (Petersen & Snapp, 2015). The two are closely linked in terms of definitions, principles and practices thus creating some confusion in their meaning, interpretation and implications, although it is often argued that ecological intensification is more clearly defined, with a better theoretical basis (Petersen & Snapp, 2015; Wezel et al., 2015). The major difference between these two models is that for ecological intensification, agricultural systems are designed to benefit from ecological processes and functions, including biological control of biotic stressors and efficient use of available resources and ecological services (Bommarco et al., 2013; Tittonell, 2014; Kovács-Hostyánszki et al., 2017). Sustainable intensification, on the other hand, does not have a focus on ecological processes, although these can be incorporated if they contribute to reduced inputs, increased outputs or enhanced efficiency. In recent literature, sustainable intensification has tended to have more of a focus on technological innovation and increased production without environmental impacts (Loos et al., 2014; Kuyper & Struik, 2014; Godfray, 2015).

In this study, we focus on and explore ecological intensification, a means of increasing agricultural production and environmental services while reducing the need for external inputs and capitalising on ecological processes that support and regulate primary productivity in agro ecosystems (Tittonell, 2014). Ecological intensification seeks to ensure long term productivity and sustainability through restoration of biodiversity and a full array of ecosystem functions and services that support food production and human well-being aims to achieve a healthy environment that provides multiple ecosystem services (*i.e*., clean water, soil fertility, pest suppression, nutrient cycling, and climate regulation) (Bommarco et al., 2013; Geertsema et al., 2016). Ecosystem services and functions have particular relevance in Sub Saharan Africa (SSA), where the majority of the population live in rural areas and rely on ecosystem services and functions for their living through smallholder farming, pastoralism and fisheries (Egoh, et al., 2012). Despite the potential of ecological intensification to improve food production systems in smallholder agricultural systems in SSA (Rusere & Crespo, 2017), it has rarely been seriously addressed in the context of smallholder farming systems of rural Africa (Tittonell & Giller, 2013) and its research remains limited in SSA (Struik, 2017). In this paper, the objective was to explore the structure of the smallholder farming system, constraints, solutions and link the constraints and solutions to specific ecosystem services that appear important in developing pathways to ecological intensification in smallholder farms in rural South Africa.

2.0 Materials and methods

2.1 Study area

This study was conducted in Ha Lambani, a village in Vhembe District in Limpopo province South Africa. Limpopo province is the fourth largest province in South Africa (SSA, 2015). It has the highest population growth rate of 3.9 % per annum and 90 % of the population live in rural areas (De Cock et al., 2013). According to Mpandeli & Maponya, (2014) the main contributor to employment and livelihoods in the Vhembe District is agriculture. Smallholder agriculture accounts for 70 % of the farming activities in the district whilst the other 30 % is commercial agriculture. The district is situated in a semi-arid area and experiences water shortages from May to August. Most commercial farmers depend on irrigation systems for farming while the subsistence or smallholder farmers rely on seasonal rainfall which is normally received from November to March. The district average annual rainfall is approximately 820 mm. The smallholder farmers predominantly grow maize, legumes and some vegetables for their own consumption, with any surplus sold or loaned to neighbours or relatives. Rain fed crop yields are generally poor due to low and erratic rainfall.

2.2 Identifying different smallholder farm types in Ha Lambani

In the context of the project, to identify farm types, we used expert knowledge. An introductory meeting was held with the senior agricultural extension workers to request cooperation from the field based extension workers and to present the research objectives, which were (i) to classify farms and farmers in the study area, (ii) unravel and assess farming system performance and efficiency levels, (iii) identify challenges and constraints and (iv) identify opportunities to drive farming systems towards more sustainable ones through ecological intensification technologies in rural areas of South Africa. Five key informants, field based agricultural extension workers based in the study area were identified by the senior agricultural extension workers. Four of the agricultural extension workers specialised in crops and one specialised in livestock. The agricultural extension workers were informed that the objective was to classify smallholder farmers based on predominant socio-economic characteristics, resource endowments and production objectives. Thereafter, local experts (agricultural extension workers), based on their knowledge, in-depth experience and considering the structure of the farming system and landscape and by identifying the most important sources of variation among farms in the area, three farmer types were identified from the classification variables listed in table 1 below. According to Kuivanen, et al., (2016) the expert based approach of classifying farmers captures context specific aspects of farm complexity and has potential to enhance local relevance and socio-cultural sensitivity aspects of interventions. Nevertheless, the degree to which an expert based approach based on these variables can predict actual behaviour in a context of rural development has not been proven. The main limitation of the expert based approach in classifying farmers and farms is that the reliance on local experts as sources of information is not enough for comprehensive understanding and analysis of complex and diverse farming systems as it can be potentially misleading and biased. Therefore, the expert based approaches need to be combined with participatory and statistical approaches to retain objectivity and reproducibility Acknowledging this limitation, this work is only able to complete the initial steps of establishing a baseline to guide in exploring potential strategies to promote or foster ecological intensification.

2.3 Identifying challenges, constraints and opportunities for ecological intensification

We used a snowball sampling approach to identify farmers representing each of the three farm types, to take part in the face to face interviews. Snowball sampling is an approach for locating information-rich key informants to participate in the study (Duan & Hoagwood, 2015). Using this approach, agricultural extension officers identified potential farmer respondents to represent the three farm types. Face to face questionnaire based structured interviews were conducted with the help of the agricultural extension workers who assisted in the translation of the questions and farmer responses. The interviews sought information on the estimates of farm size, cropped area, types of crops grown, estimates of yields obtained, crop preferences and production objectives. Farmers were asked to identify major constraints and challenges to their current crop and livestock farming practices. Farmers' perceptions on their potential solutions to their production constraints and objectives were sought by means of open ended questions. Furthermore, through discussions with farmers, we could identify key ecosystem services important to different farm types in the study area. Owing to the small sample size of farmers interviewed in each class, descriptive statistical analysis was carried out on the survey data. The results of the survey are summarized in table 2

3.0 Results

3.1 Farm types and household characterisation

Field based agricultural extension workers identified three types of farms in Ha lambani. The farms were overlapping in many characteristics but differed in their main source of income. The farm types identified were namely (1) the cereal and livestock based, (2) the horticultural based and (3) the off-farm income dependent farms. The table1 shows the variables used to build the typology.

Type 1: Cereal and livestock based farms

The cereal and livestock based farms were large farms (averaging more than 2 ha), with elderly household heads (60 years old and more). Maize is the most cultivated crop whereas legumes and vegetables are minor crops in this category. Livestock is a determinant factor, with farms rearing mainly cattle and goats (10-15 cows and 5 goats on average). Cereal and livestock activities contribute most to the household income (75%), while social grants and remittances come as a complement (25%).

Type 2: Horticultural based farms

The horticulture based farms are small, often less than 1.5 ha. They comprise mainly young household heads ranging from 18 to 35 years of age. Vegetables are mostly grown and maize (green mealies) is cultivated as a minor crop. Most of the farmers in this category do not own livestock. Income from horticultural activities is the major source of household income.

Type 3: The off-farm income dependent farms

The off-farm income farms are average size farms often between 1.5-2 ha. The household heads are mainly farmers aged between 36 to 60 years. They mostly grow maize, vegetables and legume as minor crops. They own a small herd of livestock biased towards ruminants (5 cows and 5 goats own in average). The largest household income comes from salaries and part time jobs they engage into in their local communities, complemented in small portion by agricultural activities.

Table 1: Variables used to construct the farm types

Variable dependent	(1) Cereal and livestock based	(2) Horticultural based	(3) Off farm income
Household size	5	3	5
Average Number of Children	3	1	3
Age of household head	> 60	18-35	35-60
Level of education of household head	no education	matric grade 12	matric grade 12
Major source of income	farming	farming	salaries/ par time jobs
Other sources of income	grants/remittances	grants	farming
Average farm size	>2ha	<1.5ha	1.5-2ha
Average size of land cultivated	1.5 ha	1 ha	1ha
Major crops grown	maize	vegetables	maize
Minor crops grown	legumes, vegetables	green mealies	vegetables, legumes
Average maize yields	1 tonne/ha	0.25-0.5 tonnes/ha	> 0.5 tonnes/ha
Number of cattle	15	0	5
Number of goats	5	0	5
Use of chemical inputs	Low	Moderate	Low

3.2 Farm types and farming system patterns

We interviewed 40 farmers of which 16 were cereal and livestock based farmers, 7 horticultural based farmers and 17 off farm income dependent farmers. The interview results revealed an estimated average farm size of more than 2 ha for Type 1 and less than 2 ha but more 1.5 ha for Types 3, with Type 1 farms exhibiting the largest average cropped area of 1.5 ha. Type 2 had the smallest average farm size of less than 1.5 ha which corresponded to the smallest average cropped area of less than 1 ha. Maize being the major crop grown by Type 1 and 3 farmers, although no crop yields records were available in almost all the households interviewed. The farmers estimated that the yields obtained were very poor averaging 1 t/ha and just above 0.5 t/ha for Type 1 and 3 respectively. All farm types were involved in vegetable production with only type 2 farms growing vegetables as their major crops and primarily as a cash crop and a major source of income. The results indicated that Type 2 farmers preferred to grow high value horticultural crops grown on a small area throughout the year. Type 1 and 3 farmers are involved in the production of legumes (mainly cowpea and groundnuts) and vegetables on a small scale mainly for household consumption and rarely as cash crops. Furthermore, results from the interviews further affirmed that Type 1 and 3 farms are involved in livestock production with Type1 farms possessing the most animals and the largest cattle herds. Type 2 farmers did not possess any cattle or small ruminants citing lack of capital to purchase as well as lack of resources and labour to rear the animals. Type 2 farmers generally lack access to animal traction, resulting in reduced crop area.

Chemical input use in all farm types was generally low with Type I and 3 farmers applying between 1-3 50kg bags of inorganic fertiliser per hectare. Type 2 (horticulture based) farms where chemical input use was moderate applied between 4 to 8 bags per hactare. This was because horticultural crops are input demanding and their lack of livestock meant lack of organic fertilisers such as manure as soil fertility amendments. Type 2 farmers highlighted that they relied more on suboptimal application of inorganic fertilisers for soil fertility improvement and sub optimal application agrochemicals for crop protection against pest and diseases. Although income from social grants helped Type 1 (cereal and livestock based) farmers to acquire some farming inputs, Type 1 and 3 low use is mostly due to fertilizer and herbicides cost and access. Hence Type 1 and 3 farms relied on traditionally low resource input methods of agriculture.

Type 1 farmers rely mostly on farming (sale of agricultural produce and livestock) for income although they are recipients of government social grants of the elderly and remittances from their children located in urban areas. Type 2 farmers rely on producing and selling high value horticultural products although most are also recipients of child support grants. Type 2 farmers also highlighted that financial returns from crops like maize, cowpea and groundnuts were often not worth the effort when set against the risks of producing those crops under rain fed conditions. Type 3 farms often engage in non-farm based strategies such as craft making, bead work, carpentry, brick moulding, traditional beer selling and seasonal work as hired labour for household income. They engage in agricultural activities to supplement household income.

3.3 Farmers perceptions to their current challenges and constraints

The interview results revealed that all farm types faced varying challenges and constraints in their agricultural activities, although poor seasonal rainfall distribution, low precipitation amounts and lack of and or poor irrigation infrastructure which was dilapidated were common constraints among all the farm types. A significant proportion of Type 1 farmers also cited poor access to inputs as well as high costs of input especially fertilizer as a major constraint. Furthermore, they pointed out shortage of livestock feed, especially during the dry season and drought years, leading to loss of livestock or crop damage by livestock during the dry season. Type 2 farmers cited high incidences of pest and diseases in their fields as a dominant constraint in their cropping fields. In addition, Type 2 farmers pointed out post-harvest losses and poor access to markets as major constraints. Furthermore, they highlighted poor access to pesticides despite having limited financial resources. Mechanization and draught power were their major challenges to increase area under crops. Type 3 farmers considered lack of access to inputs, lack of livestock feed during the dry season and drought years as well as damage of crops by livestock during the dry season as significant constraints

3.4 Perceived solutions to their farming constraints and challenges

All farmers in all the farm types proposed government subsidies on agricultural inputs as well as improved irrigation infrastructure as potential sustainable solution to their challenges and constraints. Type 1 farmers proposed access to drought tolerant varieties of their cereal crops to help achieve higher yields. Establishment of paddocks was cited to allow their livestock for their livestock to graze. Lastly, they highlighted the need to access to financial institutions for loans or grant as it would facilitate the acquisition of much needed irrigation systems machinery and or inputs for improved crop production. Type 2 farmers see quick access to markets and proper post-harvest handling facilities as direct improvements to cater for their perishable horticultural products. Furthermore, they pointed out the need for training in local horticultural crop production skills. Type 3 farmers, for whom farming is supplementary to off farm income, consider fencing of fields and establishment of paddocks for their livestock to graze as would greatly improve their agricultural activities.

3.5 Identification of ecosystem services as a framework for ecological intensification targeting

Using the interview results, three key ecosystem services needed for each farm type to improve agricultural productivity were identified (Table 2). All farm types, identified soil and water conservation as a key ecosystem service they would benefit from to increase agricultural production. Type 2 farmers (horticultural based) further emphasised the need for improved water quality for improved horticultural production. A significant proportion of Type 1 (cereal and livestock based) and Type 3 (off farm income dependent) farmers identified, nutrient recycling as a key ecosystem service for improving agricultural production in their farming landscapes. Type 1 farmers further emphasised the need for ecosystem services that improve availability of forage and fodder for improved livestock production. Type 2 and Type 3 identified pest and disease suppression as key ecosystem service needed for improved agricultural productivity.

Table 2: Showing the challenges and constraints, solutions and the key ecosystem services needed to implement ecological intensification in the three farmer types in Ha Lambani, Vhembe District South Africa

Farm Type	Cereal and livestock based	Horticultural based	Off farm income based
Initial problems	Poor rainfall	Poor rainfall	Poor rainfall
	Access to inputs	High incidences of diseases	Poor irrigation infrastructure
	Shortage of livestock feed	Poor mechanization	Shortage of livestock feed
	High input costs	Inputs not easily accessible	Damage of crops by livestock
	Poor irrigation infrastructure	Limited irrigation infrastructure	Access to inputs
	Damage of crops by livestock	Poor access to markets	
Proposed solutions	Government subsidies	Government subsidies	Government subsidies
	Irrigation infrastructure	Irrigation infrastructure	Irrigation infrastructure
	Tolerant varieties	Access to markets	Fencing of fields
	Access to finance	Knowledge and skills	Paddocking of livestock
	Paddocking of livestock	Proper post-harvest handling	
Ecosystems services related issues	Soil and water conservation	Soil and water conservation	Soil water conservation
	Nutrient recycling	Pest and disease suppression	Nutrient recycling
	Forage and fodder	water quality	Pest and disease suppression

4.0 Discussion

4.1 The diversity of the farm types and farming system patterns

The typology developed in this study combined both expert knowledge and participatory approaches to unravel the complexity and diversity in heterogeneous smallholder farming systems. The clear differentiating factors identified among farm types were farm size, the farm objective and the major contributor to household income, which resulted in three farm types (Table 1). Results have shown that farming systems are driven by different farming objective that in turn are shaped by various factors. These different objectives influence the different farming system patterns exhibited in different smallholder farm types. Of these farm types, we found that Type 2 (horticultural based) farms was well distinguished from Type 1 (Cereal and livestock based) and Type 3 (averaged sized farms with off farm income dependent farms). These two types showed intermediate properties, hence less distinctiveness.

Cereal and livestock based farm types have capacity to grow cereal and leguminous crops, use best agronomic practices, including early planting, weeding and application of organic manures fertilizers, and this enhances the yield difference when compared with off farm income and horticultural based farm types who have limited land and labour. Furthermore, the rearing of livestock is very important for satisfying food security in South Africa. Livestock represent the most important store of value for farmers and the wealth of a household can be measured by the number and type of animals owned (Chaminuka, Udo, Eilers, & Zijpp, 2014). Livestock herds owned by Type 1 (cereal and livestock based) farmers and Type 3 (off farm income dependent) farmers provide animal traction and manure, thus putting these farmers at an advantage in terms of agronomic performance, improved soil fertility and planting large area when compared to Type 2 (horticultural based) farmers.

Farmer income affects most decisions, including those regarding adoption of farming practices which can require financial investment and can reduce short term profitability. The extension workers we consulted in Ha Lambani segregated on farm and off-farm income because the source of income influences its connection to farm business investment decisions. Type 1 farms rely mostly on farming (sale of produce and livestock) for income although they are recipients of government social grants of the elderly and remittances from their children located in urban areas. Financial and resource limitation in Type 3 farms may often induce a shift in livelihood strategies towards a higher dependence on off-farm income. This influences decision-making, cropping patterns and farming practices. Engagement in non-farm activities limits the amount of time Type 3 farmers engage in cropping activities. Delays in farming operations are common in Type 3 farms resulting in poor yields. In semi-arid environments, where there is only a narrow window for getting the right balance of agronomic practices that facilitate high yields. To improve livelihoods and household income Type 3 farms often engage in non-farm based strategies such as craft making, bead work, carpentry, brick moulding, traditional beer selling and seasonal work as hired labour to supplement household income. These findings suggest income from farming, off farm income generating activities and social grants play an important role in the livelihoods of people in the study area. This is because the income from these activities determine the livelihood strategies to be adopted by the households.

A very small proportion of the rural population in Ha Lambani make a significant income from growing crops like maize, cowpea and groundnuts. This has led the few young people involved in farming to specialise in horticultural crops which are of high value with high returns for income in addition to the child support grants they receive. Hence type 2 farms are horticulturally based and derive most of their income from sale of horticultural produce. An important finding of this study that agrees with other studies is that very few young people want to engage in cereal and legume crop production in rural areas. This is because agriculture is often perceived as an occupation of the poor, hence young people have little desire to be involved in it (Leavy & Hossain, 2014). Furthermore, these findings highlight the importance of taking a comprehensive survey of the production envelope, rather than focusing only on blanket recommendations when targeting and tailoring agricultural interventions to local contexts. Technological interventions, development strategies and policies to address the problem of poor productivity and reduce poverty in smallholder agricultural systems must be designed to target socially diverse and spatially heterogeneous farms and farming systems in rural South Africa.

4.2 Perspectives on underperformance of farming systems

As shown by the results, the different farm types tend to experience the same major constraints in general. Poor seasonal rainfall distribution and amount, and poor or lack of irrigation infrastructure were common constraints among all farm types. This is because most smallholders, if not all farmers in Ha Lambani depend on rainfall for their agricultural activities. The unreliable and limited availability of water and infrastructure for irrigation, increases unpredictability thus affecting farmers' ability to plan what, when and where to plant their crops and other farm related decisions. The low mean annual rainfall of 500-800 mm, high annual evaporation of 2000-2500 mm in Ha Lambani (Botha et al., 2014) and recurring droughts indicate severe crop water stress during most seasons. Limited irrigation infrastructure that is dilapidated and malfunctional further exacerbates the problem.

Furthermore, the limited access to seed, farming equipment, fertilizers and agrochemicals by poorer households translate into a limited capacity to diversify their livelihood strategies by growing more demanding crops. In many aspects of smallholder production in Ha Lambani, declining soil fertility is a major constraint. Although Type 1 and Type 3 farms relied on animal manure for soil fertility improvement, the low nutrient content of manure tend to mean that very large quantities of manure are needed. The average quantity of manure applied to crops was insufficient to achieve good yields. Furthermore, manure alone may be an unsatisfactory source of nutrients, especially for nitrogen and phosphorus which are required by plants in large quantities, and therefore rarely provide the productivity needed for high yielding cereal crops. It has therefore been suggested that to sustain high crop yields, manure may need to be combined with nitrogen fixing legumes in resource constrained low input farming systems.

The fact that weed, insect pest and disease problems are amongst the major constraints being experienced by Type 2 farmers, lead us to suspect that they have an impact on their livelihoods due to the susceptibility of horticultural crops to these biotic stressors. Smallholder farmers in Ha Lambani operate in a resource constrained environment in terms of access to inputs such as pesticides and fertilisers. Furthermore, the demand for constant labour, herbicides, pesticides and the lack of a strong technical resource base for crop protection available further exacerbates the problem. Technical agronomic and horticultural information relating to cultivar and seed choice, soil fertility, water management and pest management using cultural, biological and chemical methods is also still lacking. The smallholder horticultural sector therefore requires support in the form of improved access to technical pest management information (in an appropriate form). Furthermore, research targeting knowledge gaps through in which ecological intensification can help manage pest and diseases via biological control methods such as, use of natural enemies, plant extracts and other sustainable integrated pest management (IPM) methods is needed.

Despite numerous efforts to promote production of high value cash crops in smallholder agriculture as a crucial step in solving food security problems in Africa, most famers including Type 2 farmers cannot easily access profitable cash crop markets for their high value horticultural produce. Their burden is further made worse due to lack of proper or poor storage facilities resulting in severe post-harvest losses. This indicates that most smallholder farmers are still excluded and marginalized with regards to markets access and market information. Moreover, farmers who can produce surpluses remain trapped in the poverty cycle and more often these farmers are forced to sell their produce at low prices to unscrupulous buyers who dictate market prices.

However, the low quality and quantity of available forages during the dry season is a major constraint for improved livestock production in Ha Lambani. Like in many rural areas of South Africa, the available grazing is not generally sufficient to meet the maintenance requirements of grazing animals (Matlebyane et al 2010) during dry periods. Although Type 1 (cereal and livestock based) and Type 3 (off farm income dependent) farmers use different types of feed to supplement for their livestock during the dry season and drought years, issues of availability, quantity and quality of feed resources tends of affect them. Feed problems are mainly attributed to land shortage, lack of improved forage technologies and awareness problem. Introduction of improved forage technologies that can fit into the existing land use system coupled with improved feeding systems would be necessary to resolve the feed related problems. At the same time, other problems affecting livestock production in the area should be addressed simultaneously to realize the potential benefits to be accrued from livestock.

Among the solutions mentioned by all the farm types, to the above-mentioned constraints and challenges were increased government subsidies for agricultural inputs and rehabilitation or improvement of existing irrigation infrastructure. This indicates that most of the agricultural activities are currently low input systems relying on supporting and regulating ecological process. Therefore, improving these farming systems in smallholder agriculture through improved ecologically based management strategies might represent a viable and sustainable pathway to increase productivity and resilience of smallholder agricultural systems given the limited financial support of smallholder farmers from government.

4.3 Opportunities for improved production through ecological intensification

Enhanced ecosystem service provision is therefore critical for building resilience and improving food and nutrition security for smallholder farmers in SSA. The farmer interviews identified four key ecosystem services needed to improve agricultural productivity in Ha Lambani. All farm types, identified soil and water conservation as a key ecosystem service they would benefit from to increase agricultural production. Insufficient rainfall over the years has resulted in severe water shortages for both domestic and agricultural purposes. Thus, managing and harnessing ecosystem services linked to soil and water conservation offer potential to increase agricultural production. This presents tremendous opportunities for ecological intensification practices and interventions like minimum tillage, mulching, water harvesting among others (Kassam et al., 2014) which make use of natural capital within the soil to promote soil and water conservation in agricultural landscapes. For instance, (Thierfelder et al., 2015) collated and summarised evidence on effects of minimum tillage, and various soil amendments on soil water storage in smallholder agriculture in southern Africa. Type 2 farmers mostly grow their horticultural crops under some form of irrigation. Horticultural crops are highly dependent on water quality therefore a clean and constant water supply is very important and would highly benefit Type 2 farmers.

A significant proportion of the Type 1 (cereal and livestock based) and Type 3 (off farm income improved agricultural production. This emerges from high nutrient demanding main cereal crops and would benefit from nutrient recycling ecosystem services to improve soil fertility. Furthermore, depletion of soil fertility because of low fertilizer use and high rates of nutrient mining are common challenges among smallholder farmers in South Africa and the region beyond. (Shamie Zingore, 2016). Ecosystem services and processes that increase soil fertility in their fields are therefore critical. This presents an opportunity for ecological intensification through practices and interventions that promote ecological processes and biological diversity in farming systems. The supporting and regulating ecosystem services and processes can be incorporated into cropping systems, such that production is improved, nutrient flow and soil fertility is enhanced and at the same time reducing the need for external inputs such as fertiliser. This further presents an opportunity for ecological intensification practices and interventions like intercropping, crop rotations to maximize production, nutrient flow and improve soil fertility in resource constrained farms in Ha Lambani.

Furthermore, provision of forage and fodder was identified as key ecosystem services they would benefit from to improve livestock productivity. Low quality and quantity of feeds are a major constraint limiting livestock productivity among smallholder farmers. Ecosystem services and processes that provide forage and fodder are important and could benefit Type 1 (cereal and livestock based) and Type 3 (off farm income dependent) farms. Although ecological intensification is widely documented in field crops (Gomes, et al., 2014), it is less well documented in animal production. However, it presents an opportunity for the development and operationalisation of ecological processes and services in resource constrained smallholder livestock systems. To foster such a development and operationalisation, we propose the introduction of improved forage technologies such as forage legumes and crop residues that can fit into the existing land use system coupled with improved feeding systems would be necessary to resolve the feed related problems.

Lastly Type 2 (horticultural based) farmers identified proposed pest and disease suppression as key ecosystem services needed for them to improve productivity. Weeds, insects and pathogens infestation a major challenge to their horticultural farming activities, demand constant labour and pesticides to treat them. In Ha Lambani where farmers access and ability to purchase chemical pesticides is limited, ecosystem services that enhance natural pest control are very critical. This presents an opportunity for ecological intensification to enhance crop protection in resource constrained farmers. Dicks et al., (2016) summarised evidence that identified practices that enhanced natural pest control in agriculture. In this regard, ecological intensification approaches that make use of biological processes (such as use of natural enemies, push-pull systems, crop rotations among others) to regulate pest population may enhance pest suppression and regulating ecosystem services thus contributing to crop protection. There is quite clear evidence that some of these interventions work, especially the push-pull systems (Khan et al., 2008; Midega et al., 2014). This could be a beneficial low costs and environmentally friendly crop protection strategy in resource constrained farms.

5.0 Conclusion

This study was in response to the need to identify the heterogenous farming system patterns and diversity in smallholder farmers in South Africa to target ecological intensification in the design and implementation of agricultural development interventions and technologies. The farmer classification is the first step to identify diversity of the 3 farm types in Ha Lambani, a village in Vhembe district, Limpopo, South Africa. Farmers can be distinguished based on their sources of income, household involvement in both on and off farm activities and the diversity of the farmers' agricultural land use. The farmer classification offered a more contextualized representation of farming system heterogeneity in terms of challenges, constraints and opportunities faced by farmers of the 3 identified farm types. Different types of farmers are expected to pursue different trajectories in farm system design for targeting ecological intensification to harness ecosystem services that flow from the agroecosystems under study.

List of Abbreviations

ACCESS: Alliance for Collaboration for Climate and Earth System Sciences

ADCI: African Climate Development Initiative

NRF: National Research Foundation

SSA: Sub Saharan Africa

WRC: Water Research Commission

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of Data and materials

Not applicable

Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

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Authors contributions

Farirai Rusere and Siyabusa Mkuhlani was responsible for developing the initial content of the manuscript, including literature search, data collection and analysis. Olivier Crespo and Lynn Dicks were the supervisors for the research and provided guidance in terms of the article structure and directed the retrieval of relevant literature and finalization of the manuscript

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