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Understanding the factors that influence cereal-legume adoption amongst smallholder farmers in Malawi.

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Abstract

Although sustainable intensification (SI) practices such as intercropping of cereals with legumes are believed to offer productivity benefits to farmers, the adoption of cereal-legume intercropping remains low in Malawi. We use dynamic programing to assess the impact of four key constraints that smallholder farmers face. These constraints are i) land, ii) labor, ii) input market access and iv) output market access. We use the model to evaluate farmers' optimal production plans across six scenarios in which these constraints are relaxed and compare their production plans across these scenarios. The farmer's decision process given these alternative scenarios is modeled to assess the impact of these constraints on SI adoption decisions. Our model preliminary results suggest that both resource (land and labor) and institutional constraints (access to input and output market) play a key role in influencing smallholder farmers' SI adoption decisions. The model results help to illustrate how labor constraints, land constraints and limited access to input and output market affect smallholders' adoption of cereal-legume intercropping in Malawi.

Keywords: Sustainable intensification, dynamic programming, production risk

Introduction

Over the years, population growth in sub-Saharan Africa (SSA) has excarbated land contraints amongst smallholder farmers limiting their ability to fallow or expand their cropping land. This has resulted into repeated cultivation and degradation of soil fertility reducing farmers' productivity (Headey, 2014; Jayne, Chamberlin, and Headey 2014). Sustainable agricultural intensification (SI) is one of the widely promoted intervention strategies to help curb land degradation, conserve soils while also enhancing land productivity (Pretty, Toulmin, and Williams 2011). SI includes agricultural practices and cropping systems that conserve the chemical, physical and biological qualities of the soil to maintain and improve soil health and fertility, the environment and natural resources. Some of the widely promoted SI practices are agroforestry, crop rotation, soil conservation, zero tillage and cereal-legume intercropping (Silberg et al. 2017). Previous literature suggests that SI practices have the potential to increase crop yields by offering a low-cost improvement of: (i) soil health and fertility (Holden et al. 2018; T. R. Silberg et al. 2017); (ii) pest and disease management (Seran H., and Karunarathna 2010; Carson, 1989; Carsky et al., 1994); (iii) weed control (Mhango, Snapp, and Phiri 2013; Fernandez-Aparicio, Silberg, and Rubiales 2007); and, (iv) increased resilience and adaptation to production risk due to the adverse effect of climate change like drought and floods (Holden et al. 2018; Kassie, Teklewold, Marenya, et al. 2015).

Despite these reported benefits of sustainable intensification, the adoption of the SI practices amongst smallholder farmers in most of the region remains limited. In fact, there is a wide gap between awareness and adoption of sustainable intensification practices in most of the region (Ragasa, 2019; Jambo et al. 2019; Kassie, Teklewold, Jaleta, et al. 2015). Why are smallholder farmers not widely adopting these SI practices in SSA? Are the researchers overestimating the benefits of SI? Is there some heterogeneity in the gains of SI adoption? The literature shows that there are many factors that influence smallholder farmers' adoption of SI. According to Silberg et al. (2017), commercial production of legumes and use of other SI practices like composting are associated with intercropping cereals and legumes in Malawi. In another study, Silberg, Richardson, and Lopez (2020) found that farmers preferred using intercropping as a weed control measure. Mhango, Snapp, and Phiri (2013), also found that constraints including limited access to improved seed and low yields were also key factors limiting farmers from producing legumes.

Limited access to output markets and susceptibility to pest and diseases were also considered key constraints limiting farmers' incorporation of legume crops like pigeon peas and common beans in their cropping systems. In addition, policy incentives, climatic conditions and preferences are also considered key factors in farmers' SI adoption decisions (Jambo et al. 2019). Previous studies have also shown that wealth and education levels also influence the yield gains that farmers get from use of SI practices such as crop rotation or intercropping. This is due to heterogeneity in use of complementary input as well as variations in crop management skills (Vugt, Franke, and Giller 2018; 2017). In this paper, we advance this literature on SI adoption by modeling farmers' choice of production technologies or cropping system (i.e., cereal-legume intercropping systems) and evaluating the role of land, labor and market constraints on these production choices in Malawi.

For farmers with limited landholding, intercropping is a more practical form of crop diversification. Silberg et al. (2017) found that about 60 percent of the plots in their study in Malawi were intercropped. However, only about 28 percent involved maize-legume intercropping. Although intercropping is considered a common agricultural practice in the country, the adoption of the maize-legume intercropping, which is the most benefitial form of intercopping in terms of increasing crop yields, is relatively low (Kassie, Teklewold, Marenya, et al. 2015; T. R. Silberg et al. 2017). Another study by Kenamu et al. (2020), found that maize-legume intercropping alone acounted for about nine percent of total crop area in the 2017/2018 cropping year in Malawi. In this paper, our overall objective is to explore the factors that influence smallholder farmers' adoption of the maize-legume intercropping systems in Malawi. We consider pure stand maize and four maize-legume intercropping systems or technologies namely: Pure stand (T1); maize-bean intercropping (T2); maize-pigeon pea intercropping (T3); Bean-pigeon pea intercropping (T4) ; and maize-beans-pigeon pea intercropping (T5). We use dynamic programming to evaluate the role of land, and labor constraints as well as limited access to input and output markets on farmers' adoption of these cereal-legume intercropping systems in Malawi.

To better understand the role of resource and market constraints on farmers' production under risk, we simulate a typical Malawian farmer's production decision for six scenarios or states of the world and compare their optimal production plans across these scenarios. Our preliminary model results show that in the status quo, (Scenario 1): a state of the world where households face both resource (land and labor) and market (input and output) constraints, the farmer takes a subsistence approach where the optimal production plan has the pure stand maize (T1) dominating the share of land throughout the 3-year planning horizon. That is, about 80 percent of the farmland is allocated to pure stand maize (T1) with the rest allocated to intercropped maize with either beans or pigeon peas (T2 or T3); intercropped legumes (T4) and intercropping of maize, beans and pigeon peas (T5) are not in the optimal solution plan. However, when we simulate a scenario that represents the state of the world in which households do not face any resource or market constraints, the farmer's optimal production plan is to allocate all the land to triple intercropping of maize, beans and pigeon peas (T5) in year 1 and then downscale to double intercropping of maize with beans(T2), or pigeon peas (T3) or beans and pigeon peas (T4) in years 2 and 3. The model results help to evaluate the impact of policy alternatives that address the resource (land and labor) and market (input or output markets) constraints that farmers face in Malawi.

Methodology

In this section, we present the details of the dynamic model setup. We start by presenting the specific parts of the dynamic model and how it is set up and then, present the model scenarios and data.

Model Set-up and stochastic processes

We develop a dynamic programing model of household technology adoption using Discrete Stochastic Programming (Rae 1971). For modeling purposes, we consider some representative cereal-legume cropping systems in Malawi, where the farm household produces three crops: maize, a staple food crop, and two legumes which are mostly produced for sale, common beans and pigeon peas. The farmers' cropping year is divided into two periods: Lean or Planting season (October –March) and Harvest season (April to August).[1] The decision stages or points for these planting and harvest season are assumed to be in December and May respectively and these are modeled as our decision stages for the DSP model (see Figure 1 below). The farm household is considered to make sequential conditional decisions with the objective of maximizing ending wealth or profit (i.e., wealth at end of time horizon) under risk.[2]

In order to capture the medium to long-term effects of sustainable intensification system like intercropping, we consider a finite-horizon model spanning three cropping years with a total of six

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[1] For simplification of the model, we do not consider winter or "*dimba*" cropping in the model because, on average, the percentage of farmers that engage in production during this season is relatively low and less representative of the average farmer. That is, only about 8.8 percent farm households cultivated crops during the 2016 *dimba*" season based on the IHS4 survey data and this rose to 18.8% in 2019 based on IHS5.

[2] The current model assumes that farm households are risk neutral. However, it provides the option to include risk aversion and there are trivial variations in the results when we compare the results for risk aversion and the results for risk-neutral case. For simplification of the model, we consider the risk neutral case in this paper.

decision stages. The household, then, makes decisions sequentially from planting year 1 to harvest year 3 with the goal of maximizing end of period expected wealth.

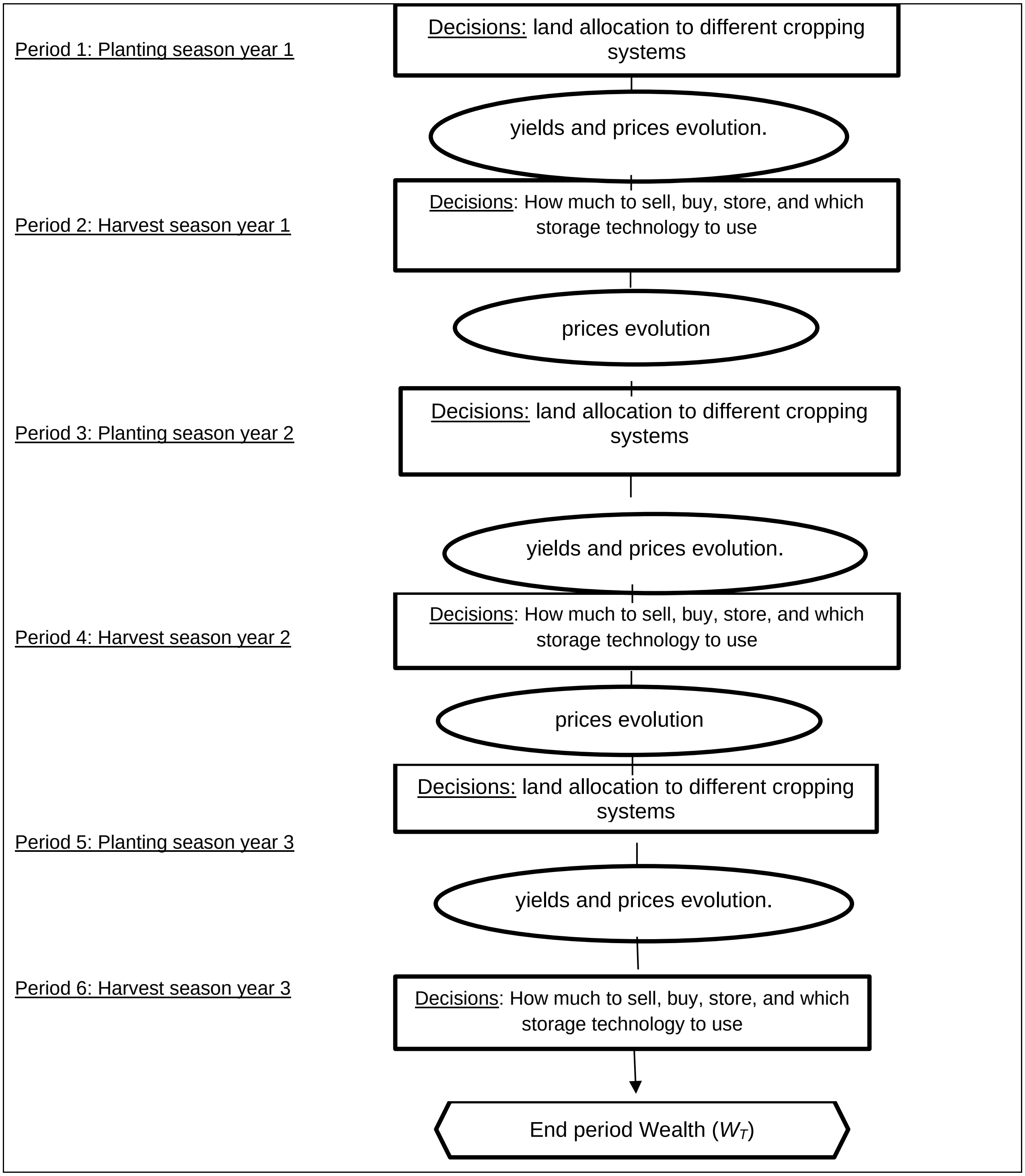
The key random variables, we consider in the model include yields and prices and these evolve between the decision stages. When moving from planting to harvest both prices and yields are considered to evolve. However only prices evolve from the harvest to planting periods. Prices are jointly distributed with yields and they follow some autoregressive process, and these are empirical approximated using Gaussian Quadrature. Yields are assumed to be influenced by random weather and these are also empirically approximate using Gaussian quadrature.

Five pre-planting technologies or cropping systems that involve maize and two legumes (soybean and pigeon peas) are considered in the model: production technology 1: pure stand (T1); production technology 2: maize-bean intercropping (T2); production technology 3: maize-pigeon peas intercropping (T3); production technology 4: beans-pigeon peas intercropping (T4); and production technology 5: maize-beans-pigeon peas intercropping (T5). At the planning stage, the farmer chooses which cropping system or production technologies to use out of the 5 systems. That is, how much land to allocate to each of the different cropping systems and we assume that for T2 to T5, the ratio or share of land allocation to each crop within each system follow a one-to-one ratio.

We also consider two post-harvest technologies: the traditional woven bag and the PICS bags such that, at harvest, the farmer chooses how much to store, sell, or purchase and also which of the two storage technologies to use for storage at harvest.

In *Figure 1* below, the rectangles show the decision stages and corresponding decisions that the farmer makes in the given decision stages. The circles in *Figure 1* show the random variables and their evolution across stages. The polygon at the end shows the ending period wealth, such that the farmers make sequential decisions with the goal to maximize the expected end of period wealth. Some key non-random parameters include initial endowment of resources including cash, maize and groundnuts stocks in planting period 1, as well as some cash remittances or income in each given period for typical expenses including school fees, groceries and utilities.

Figure 1: Discrete Stochastic Programming Model Timeline



Model Variables and Constraints

In this section, we present the model variables and the relationships between these variables and the parameters that define the constraints.[3] We assume the farmer has three key production resources: land, labor and cash and we have accounting constraints at each stage and realized state of nature to track the farmer's use of each of the three resources to make sure the uses of these resources are equal or less than the sources or endowments of these resources. The farm household's expected ending wealth or profit maximization objective is then optimized subject to these resource accounting constraints.

In the planting period of each year, there is a limit on the allocation of land to the three crops to be no more than the endowment of the household's farmland. This is a single constraint for year one. For year two and three, there is a set of land constraints – one for each realization of the sequence of random variables that occurs in a given period. As such, beyond the year one planting period, the number of constraints is conditional on the sequence of random variables that have been realized up to that point in time. We also have constraints that limit the use of labor to be no greater than the endowment of family labor plus hired labor for each planting and harvest period.

In each decision stage, we track the quantities of the inventory that the farmer has, namely: maize, beans, pigeon peas and cash, using some accounting constraints to make sure that the "uses" of the resources do not exceed the "sources" in each by decision period that are conditional on the random variables that have been realized up to that decision period. For the crops, these constraints are measured in kilograms while cash is in the local currency (Malawi Kwacha where US$1=MK750). The other constraint relates to grain storage in each period and serves to limit the smallholder farmer's storage capacity to the total quantity of crop inventory that the farmer can hold to reflect the smallholder farmer's secure storage space.

Model Scenarios

In order to understand how the resource and market constraints that farmers face influence their cropping system choices under risk, we simulate the farmer's production decisions for six scenarios or states of the world and compare their optimal production plans across these scenarios.

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[3] The full model is displayed in Appendix in GAMS notation (Brooke et al. 1997).

Scenario 1: The status quo – represents a state of the world where households face both resource (land and labor) and market (input and output) constraints. For this scenario we use the survey data described in Section 2.4 to inform the level of land holding and labor availability for the average representative farm household. Similarly, for expected and realized prices and yields in this scenario, we use actual historical data to approximate the empirical distributions of price and yields used in the model.

Scenario 2: the state of the world where households face the status quo but with relaxed labor constraints. However, the market and land constraints remain existent for households except they have more labor available than in the status quo. That is, the total labor hours available for the farm household in a given period are doubled in this scenario. The idea of modeling this state of the world is to show the impact of labor constraint on households' choice of cropping systems.

Scenario 3: the state of the world where households face constraints similar to the status quo but with a relaxation of the land constraints. In order to simulate a more practical structural change in landholding, unlike scenario 2 where we implement a 100 percent change, in this scenario we consider a 20 percent increase in the household's landholding to evaluate the impact of land constraints on the farmers' choice of cropping systems.

Scenario 4: is the state of the world similar to the status quo except that households are considered to have access to high yielding legume varieties. In this scenario, we consider a doubling of the realized yields of legumes in the baseline scenario 1, or the status quo, and evaluate the impact of high yields, which are assumed to resulting from growing improved legume varieties on the farmers' choice of cropping systems.

Scenario 5: is the state of the world similar to the status quo except that households are considered to have access to high-value output markets which offer them higher prices. In this scenario, farmers are considered to face higher legume output prices which are captured by doubling the realized prices in the status quo or the base scenario (i.e., can also simulate either 15%, 25% and 50% price increase).

In Scenario 6: The unconstrained scenario, we consider a state of the world where households do not face any resource or market (input and output) constraints. As such, in this scenario we run the model given a state of the world where the farm household has more (i.e., double) land and labor resources and access to high yielding varieties and high-value legume markets. This scenario helps to illustrate the impact of alternative policies that address these constraints on farmers' production decisions. We, then, compare the farm household's optimal decisions across scenarios to illustrate the impacts of these constraints on farmers' choices of cropping systems.

Table 1: A summary of model scenarios

Scenario	Details	Parameter or model changes
Scenario 1: Status quo	The baseline scenario	None
Scenario 2	Relaxed labor constraints	Labor endowments are doubled to simulate the impact of relaxing labor constraints on smallholder farmers.
Scenario 3	Relaxed land constraints	Landholding is increased by 20% to simulate the impact of relaxing land constraints on smallholder farmers.
Scenario 4	Increased legume input market access (improved seed).	Doubling legume yields due to increased access or use of high yielding legume varieties.
Scenario 5	Increased legume output market access (higher prices).	Doubling legume prices due to increased access to high value legume markets.
Scenario 6	Relaxed labor, land and market constraints	Labor endowments are doubled, land endowments are increased by 20% and legume yields, and prices are doubled.
Scenario 7[4]	Relaxed post-harvest storage constraints	Reduced post-harvest losses due to use of PICS technology

Data

In order to model the smallholder farmer's adoption decisions, we use data from several sources including: i) the pluralistic agricultural extension survey collected by IFPRI in 2018; ii) the fourth Integrated Household Surveys of 2016-17 conducted by the National Statistics Office with technical support from the World Bank[5]; and iii) the Ministry of Agriculture's Agricultural Markets Information Systems (AMIS) to generate key parameters for the model. We use annual yield data for Malawi as reported by Food and Agricultural Organization (FAO) statistics (FAOSTAT) from 1989

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[4] Given that the focus of the paper is on the adoption of cereal-legume intercropping, we present the details of the Scenario 7 which focuses on post-harvest storage technology adoption in the appendix.

[5] The IHS are part of the World Bank Living Standard Measurement Surveys, and since 2009-2010 have also been part of their expanded Integrated Surveys on Agriculture. See https://www.worldbank.org/en/programs/lsms/initiatives/lsms-ISA.

to 2018. Supplementary yield data for different production technologies are based on yield estimates from previous literature (or estimates from field trials- pending LUANAR data). Similarly, the specific input and labor requirements per unit of land by cropping system or technology is also based on estimates from previous literature (Holden n.d). For price data, we use historical data collected through the Ministry of Agriculture's Agricultural Markets Information Systems (AMIS), a data collection system that is built to inform the Ministry's food security policies in collaboration with FAO's Global Information and Early Warning System (GIEWS). These price data are collected daily for key food crops in major commodity markets, and these are used to derive weekly and monthly average prices reported by the Ministry. We use the reported (national average) monthly price data from 1989 to 2018, these are adjusted to account for inflation using CPI index from World Bank with January 2018 as the base year.

Other key parameters for the model including, *inter alia*, household demographics such as average household size, and endowments of labor and land, production inputs and costs, minimum grain consumption requirements, average monthly household expenditure, average planting and harvest labor use per acre, average monthly income and average grain inventory capacity are based on estimates from the Integrated Household Survey 4 (i.e., IFPRI Key Facts Sheets for Malawi and /or own calculations). Other supplementary parameter information is also based on estimates from the literature or calculations from the 2016-17 Integrated Household Survey and the PICS pilot project baseline survey data from Malawi (see Tables 2 and 3 below for details of parameters used in the model).

Table 2: Summary of data and sources

Parameters for Baseline Scenario	Details	Units	Sources
Prices	1989 to 2018 (Monthly)	(MK/kg)	FAO /AMIS data
Yields	1989 to 2018 (Annual)	(kg/ac)	FAO /AMIS data
Yields variations by cropping system	Literature	(kg/ac)	Holden n.d.; Mutenge et al. 2019; Nyagumbo et al. 2020.
Grain Consumption	2016/17 surveys	kgs	IHS4 Household module G1to G3
Fertilizer use	2016/17 surveys	MK	IHS4 Household module G1 to G3
Fertilizer use by cropping system	Literature	(kg/ac)	Holden n.d.; Mutenge et al. 2019; Nyagumbo et al. 2020.
Labor	2016/17 surveys	Hours	IHS4 Agricultural Module D
Labor use by cropping system	Literature	(kg/ac)	Holden n.d.; Mutenge et al. 2019; Nyagumbo et al. 2020.
Land	2016/17 surveys	acres	LSMS data
PHL	Recent estimate	Loss rate	APHLIS website
Transaction Costs	IFPRI Key Fact Sheets	MK	IHS data
Initial endowments	IFPRI Key Fact Sheets	Kgs, MK	IHSS data
Variable costs	IFPRI Key Fact Sheets	MK	IHSS data
Inventory Capacity	IFPRI Key Fact Sheets	kgs	IHSS data
Minimum wage	2018 MoL	MK/hour	Ministry Labor

Table 3: Model Parameters for Baseline Scenario

Parameter	Value	Units	Source
Landholding	1.5	Acres	IHS4 Data: Agriculture Module B1
Household expenditure	18,386	MK per month	IHS4 WB Household Module G1 to G3
Maize consumption	109	Kgs per month	IHS4 Data: Household Module G1 to G3
Pigeon peas consumption	10.5	Kgs per month	IHS4 Data: Household Module G1 to G3
Beans consumption	14	Kgs per month	IHS4 Data: Household Module G1 to G3
Household size	4	Persons	IHS4 WB aggregate consumption per capita
PHL maize	4.1	percent	APHLIS website
PHL Pigeon peas	12	percent per month (Estimate/proxy)	Affognon et al. 2015; Ambler et al. 2018
PHL Beans	12	percent per month (Estimate/proxy)	Ambler et al. 2018
Inventory capacity	1,500	Kg	PICS Baseline Survey for RCT 1 Module F1
Trade capacity	250	kgs per month	PICS Baseline Survey for RCT 1 Module F1
Wage per hour	175	Mk per hour	IHS4 Data: Household Module E waged jobs
Hired labor hours	14	hours per week per person	IHS4 HH Module E Casual labor hours
Available hired labor harvest period	1,975	Hours available harvest season	Imputed IHS4 Data: Agriculture Module D & E
Family agricultural labor	12.5	hours per week per person	Malawi IHS4 Report (Page 112)
Available family labor	860	Hours available per season	Imputed IHS4 report (page 112) & Household size
Enterprise revenue	20,821.4	MK per month	IHS4 Data: Household Module E enterprises

Other cash sources	3275	MK per month	IHS4 Data: Household Module E other sources
Cash remittances (Wages + other transfers)	44,296.4	MK per Month	PICS Baseline Survey for RCT 1 Module D1
Cash savings (Initial cash endowments)	85,500	Malawi Kwacha (2016)	IHS4 Data: Household Module P Incomes
Maize stocks (Initial endowments)	295	Kgs	IHS4 Data: Agricultural Module I Sales and Storage
Pigeon peas stocks (Initial endowments)	42	Kgs	IHS4 Data: Agricultural Module I Sales and Storage
Beans stocks (Initial endowments)	35	Kgs	IHS4 Data: Agricultural Module I Sales and Storage

Model Results

In order to understand the role of resource and market constraints on farmers' production choices under risk, we simulate the farmer's production decision for six scenarios or states of the world and compare the optimal production plans across these scenarios. The model results in Figure 2 below, show that in Scenario 1: The status quo-a state of the world where households face both resource (land and labor) and market (input and output) constraints, the farmer takes a subsistence approach where the optimal production plan has the T1 (Pure stand-maize) dominating the share of land throughout the 3-year planning horizon. That is, about 80 percent of the farmland is allocated to T1 with the rest allocated to either T2 or T3 while T4 and T5 are not in the optimal solution plan.

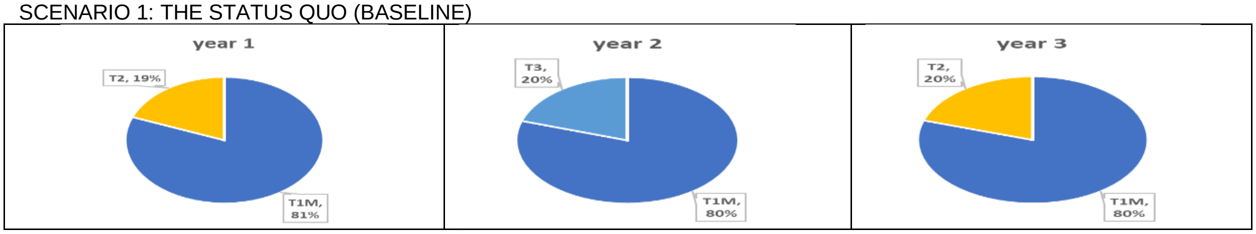
However, in Scenario 2 where the labor constraints are relaxed (Scenario 2: doubling the farmer's labor availability), our model shows that on average the farmer's optimal plan is to consistently allocate land to intercropping maize with beans and/or pigeon peas (technologies: T2, T3 or T5). This is likely influenced by the household's need to increase returns from their scarce land resource by ensuring output from more than a single crop while at the same time minimizing the risk of loss to production shocks that may affect the crops. Relaxing the labor constraints may push the farm household optimal plan towards a labor intensification strategy. In Scenario 3, where the land constraints are relaxed (i.e., 20 percent increase in the household's land holding), we observe that, on average, the optimal production plans for the household have over 50 percent of the land allocated to triple cropping of maize and legumes (T5) for all the cropping cycles in our planning horizon (i.e., more crop diversification). However, pure stand maize (T1) and double cropping of legumes (T4) are not part of the optimal production plan.

In Scenario 4, we consider a state of the world where households face some improvement in legume yields (doubling yields) due to introduction or access to improved legume seeds. In this scenario, we observe a production plan that only has double cropping of legumes (T4) and triple cropping of maize and legumes (T5) with T4 taking up to about 30 percent of the total farmland (i.e., legume-orientated cropping systems). Scenario 5 represents a state of the world where the households have access to high-value legume markets such that the farmer faces high legume prices (i.e., doubling the realized prices from status quo or base model to represent export markets). In this scenario, we observe similar solution patterns as in scenario 4 where only double intercropping of legume (T4) and triple intercropping of maize, beans and pigeon peas (T5) are part of the optimal production plan. However, in this scenario, close to 60 percent of the total farmland is allocated to intercropping of beans and pigeon peas.

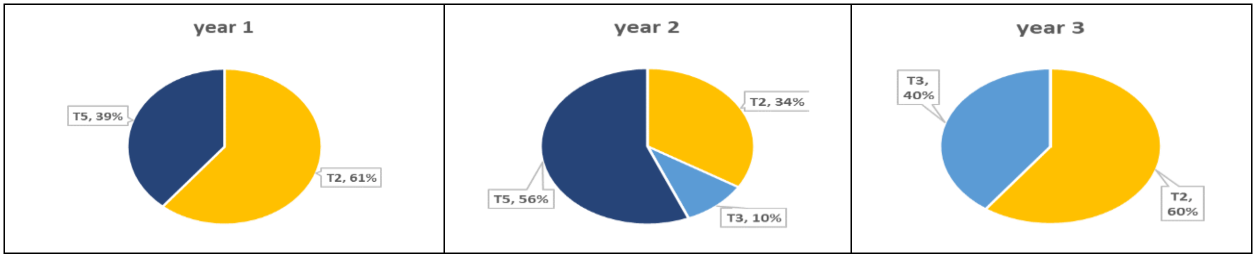
Finally, in order to model the impact of policy alternatives that address the resource (land and labor) and market (input or output markets) constraints that farmers face, we simulate a scenario to represent the state of the world where households do not face any resource or market constraints (Scenario 6: the unconstrained scenario). The farmer’s optimal production plan in this scenario is to allocate all the land to triple intercropping of maize, beans and pigeon peas (T5) in year 1 and then downscale to double intercropping of maize with beans (T2), or pigeon peas (T3) or beans and pigeon peas (T4) in years 2 and 3.

Figure 2: Percent land allocation to the alternative cropping system

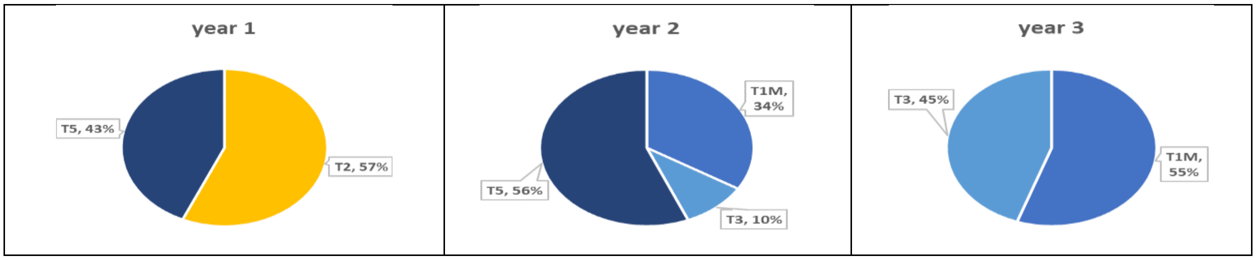
SCENARIO 1: THE STATUS QUO (BASELINE)



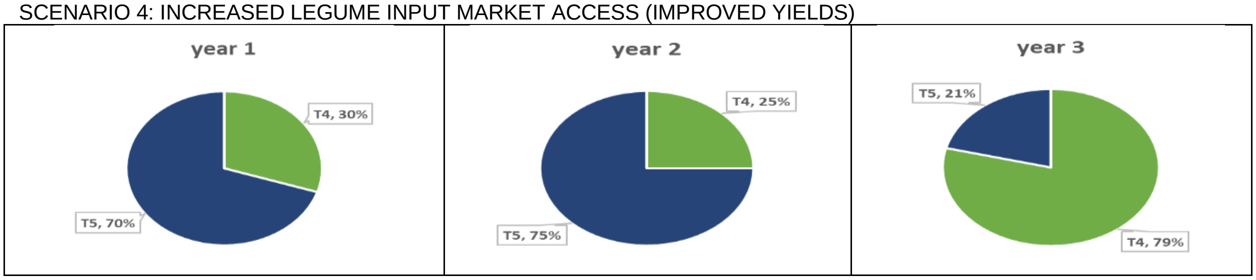
SCENARIO 2: RELAXED LABOR CONSTRAINTS



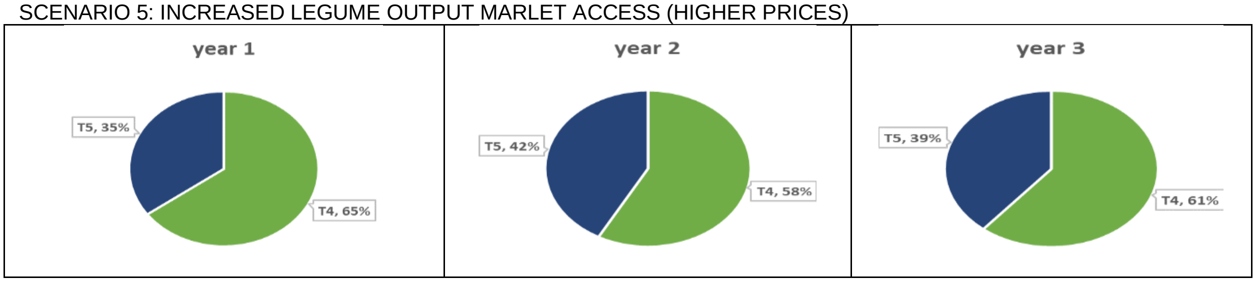
SCENARIO 3: RELAXED LAND CONSTRAINTS



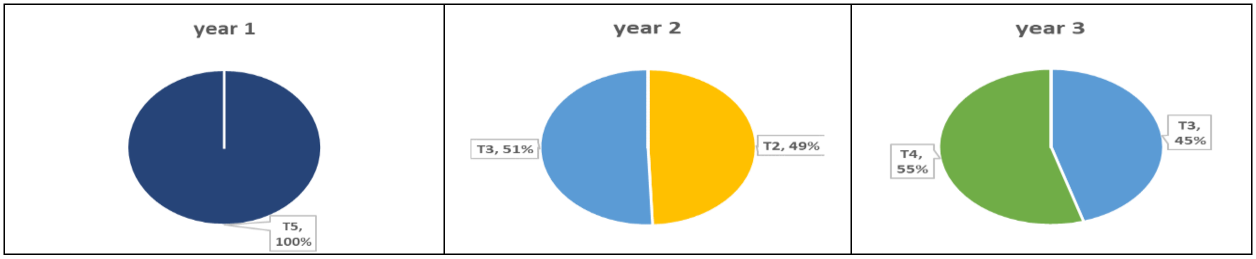
SCENARIO 4: INCREASED LEGUME INPUT MARKET ACCESS (IMPROVED YIELDS)



SCENARIO 5: INCREASED LEGUME OUTPUT MARLET ACCESS (HIGHER PRICES)



SCENARIO 6: UNCONSTRAINED SCENARIO



Notes: T1M is pure stand maize; T1P is pure stand pigeon peas; T1B is pure stand common beans; T2 is double intercropping of maize with beans; T3 is double intercropping of maize with pigeon peas; T4 is legume double intercropping; and T5 is triple cropping of maize, beans and pigeon peas. Total landholding is 1.5 acres Total landholding is 1.5 acre

Conclusions

The model results suggest that constraints including land, labor and legume market access influence their farmers' choice of cropping system. The results from scenario 2 show that relaxing labor constraints by doubling the farm household's labor endowments pushes the farmer towards more labor-intensive production systems involving intercropping of maize with beans and/or pigeon peas. Relaxation of the land constraints results in an optimal production plan involving triple intercropping of maize with legumes (T5), which is again relatively labor intensive. Results for the scenarios that simulate increased access to high yielding varieties and high-value markets also show that the farm household will move towards a relatively more legume-based cropping pattern. When the input and output market access constraints are relaxed, cropping systems involving the double cropping of legumes and triple cropping of maize and legumes become key components of the farmer's optimal production plans. These results help to illustrate how labor constraints, land constraints, and limited access to input and output markets affect smallholder farmers' adoption of maize-legume intercropping in Malawi.

Appendix A: Post-Harvest Storage Technology Adoption

In this appendix, we consider Scenario 7, the introduction of an improved post-harvest storage technology. In this scenario, we consider a state of the world where farm households have access to an improved hermetic storage technology, popularly known as PICS bags. The farmers' post-harvest losses are assumed to be reduced from 4 percent to 1 percent for maize and from 12 percent to 2 percent for legumes after the introduction of PICS bags.[6] This scenario demonstrates how adoption of an improved post-harvest storage technology influences smallholder farmers' production and storage decisions.

Figure 3: Percent of crop storage at harvest

SCENARIO 7: PERCENT CROP STORAGE AT HARVEST FOR BASELINE WOVEN BAG VS. RELAXED STORAGE CONSTRAINTS

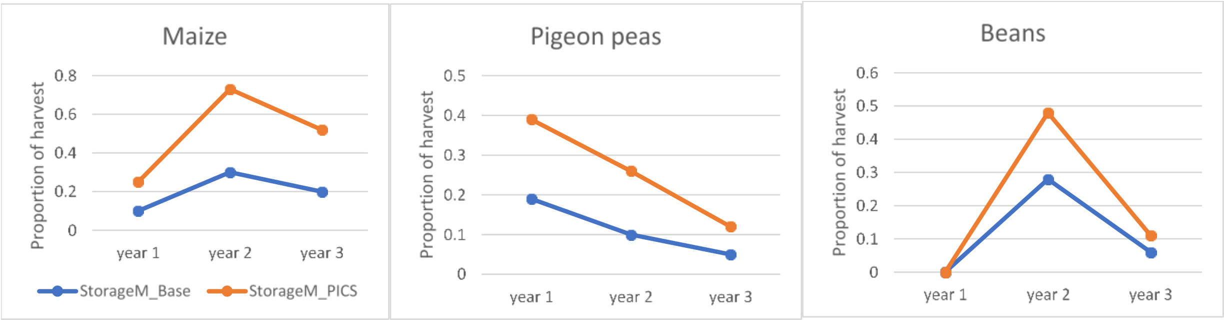


Figure 3 shows results for the representative farmer's crop storage decisions. We compare the farmer's grain storage decision in the baseline scenario, where the farmer uses the ordinary woven bags for grain storage, to scenario 7, a state of the world where the farmer has access to PICS bags. Our results show that the optimal storage plan for the farmer in Scenario 7 has the farmer storing a much higher proportions of his harvest compared to the baseline scenario. For example, the proportion of maize stored at harvest is between 10 to 30 percent of maize harvested with ordinary woven bags but this increases to 22 to 73 percent of the harvest with PICS bags. A similar pattern is observed for pigeon peas and beans (see Figure 2 above). This is likely due to the improvement in the storage technology, as the farmer experiences a substantial reduction in storage losses when PICS bags are used, which incentivizes the farmer to store relatively more in this scenario.

Our results show that the farmer will store relatively more of the three crops when s/he has access to PICS bags due to reduction in storage losses associated with the PICS technology. This suggests that when farmers face substantial post-harvest loses, the lack of effective storage technologies may prevent them from participating in grain storage in the post-harvest period. This helps show the impact that improved storage technology can have on farmers' grain storage decisions.

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[6] Approximated loss when using improved bags is not due to pests and molds but contingency weight loss because of moisture if farmer does not dry the grain properly. This can be reduced to zero for maize given guaranteed moisture regulation by farmers.

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REFERENCES

Carsky, R.J., Singh, L., Ndikawa, R., 1994. Suppression ofStrigahermonthicaon sorghum using a cowpea intercrop. Exp. Agric. 30,349–358.

Carson, A.G., 1989. Effect of intercropping sorghum and groundnuts ondensity ofStriga hermonthicain The Gambia. Trop. Pest Manage. 35,130–132

Fernandez-Aparicio, Mónica, Josefina C. Sillero, and Diego Rubiales. “Intercropping with Cereals Reduces Infection by Orobanche Crenata in Legumes.” *Crop Protection* 26 (8): (2007): 1166–72. doi: 10.1016/j.cropro.2006.10.012.

Headey, Derek D. “Adaptation to Land Constraints: Is Africa Different?” *Food Policy*, 16. (2014.)

Holden, Stein T. “Agricultural Household Models for Malawi: Household Heterogeneity, Market Characteristics, Agricultural Productivity, Input Subsidies, and Price Shocks. A Baseline Report.” 2014. Accessed September 24.https://www.academia.edu/21775459/

Holden, Stein T., Monica Fisher, Samson P. Katengeza, and Christian Thierfelder. “Can Lead Farmers Reveal the Adoption Potential of Conservation Agriculture? The Case of Malawi.*” Land Use Policy* 76 (July 2018): 113–23. doi:10.1016/j.landusepol.2018.04.048.

IFPRI (2018) "Key Facts Sheet on Agriculture and Food Security." Lilongwe: International Food Policy Research Institute.

Jambo, Isaac Jonathan, Jeroen C.J. Groot, Katrien Descheemaeker, Mateete Bekunda, and Pablo Tittonell. “Motivations for the Use of Sustainable Intensification Practices among Smallholder Farmers in Tanzania and Malawi.*” NJAS - Wageningen Journal of Life Sciences* 89 (November 2019): 100306. doi:10.1016/j.njas.2019.100306.

Jayne, Thomas., Jordan Chamberlin, and Derek D. Headey. “Land Pressures, the Evolution of Farming Systems, and Development Strategies in Africa: A Synthesis.” *Food Policy* 48 (October 2014): 1–17. doi:10.1016/j.foodpol.2014.05.014.

Kassie, Menale, Hailemariam Teklewold, Moti Jaleta, Paswel Marenya, and Olaf Erenstein. “Understanding the Adoption of a Portfolio of Sustainable Intensification Practices in Eastern and Southern Africa.” *Land Use Policy* 42 (January, 2015): 400–411. doi:10.1016/j.landusepol.2014.08.016.

Kassie, Menale, Hailemariam Teklewold, Paswel Marenya, Moti Jaleta, and Olaf Erenstein. “Production Risks and Food Security under Alternative Technology Choices in Malawi: Application of a Multinomial Endogenous Switching Regression.” *Journal of Agricultural Economics* 66 (3): 640–59. (2015) doi:10.1111/1477-9552.12099.

Mhango, Wezi G., Sieglinde S. Snapp, and George Y.K. Phiri. 2013. “Opportunities and Constraints to Legume Diversification for Sustainable Maize Production on Smallholder Farms in Malawi.” *Renewable Agriculture and Food Systems* 28 (3), (2013): 234–44. doi:10.1017/S1742170512000178.

Pretty, Jules, Camilla Toulmin, and Stella Williams. 2011. “Sustainable Intensification in African Agriculture.” *International Journal of Agricultural Sustainability* 9 (1): 5–24. doi:10.3763/ijas.2010.0583.

Seran Thayamini, and Brintha Karunarathna. “Review on Maize Based Intercropping.” *Journal of Agronomy 9* (March 2010). doi:10.3923/ja.2010.135.145.

Silberg, Timothy R., Robert B. Richardson, Michele Hockett, and Sieglinde S. Snapp. “Maize-Legume Intercropping in Central Malawi: Determinants of Practice.*” International Journal of Agricultural Sustainability* 15 (6): 662–80. (2017) doi:10.1080/14735903.2017.1375070.

Silberg, Timothy, Robert Richardson, and Maria Claudia Lopez. 2020. “Maize Farmer Preferences for Intercropping Systems to Reduce Striga in Malawi.” *Food Security* 12 (January 2020). doi:10.1007/s12571-020-01013-2.

Vugt, Daniel, Linus Franke, and Ken Giller. “Participatory Research to Close the Soybean Yield Gap on Smallholder Farms in Malawi.” *Experimental Agriculture 53* (3). (2017). doi:10.1017/S0014479716000430.

Vugt, Daniel, Linus Franke, and Ken Giller. 2018. “Understanding Variability in the Benefits of N2-Fixation in Soybean-Maize Rotations on Smallholder Farmers’ Fields in Malawi.” *Agriculture, Ecosystems & Environment* 261 (July 2018): 241–50. https://doi.org/10.1016/j.agee.2017.05.008.

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