Resource Use Efficiency in Soybean Production in Rwanda

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Abstract
Even though soybean (Glycine Max) is currently a minor crop in Rwanda, it is one of the crops that the government of Rwanda is promoting because of its high nutritional value, adaptability to the climate of the country, and its good response to organic and mineral fertilizer inputs. Since farm resources are limited in Rwanda, it is critical to devise ways of improving their productivity and use efficiency even in soybean production. This study used on-farm data from Kamonyi district collected during two agricultural seasons from September 2007 to July 2008 and identified key factors determining soybean production and resource use efficiency in soybean production. Cobb-Douglas production function was fitted. Results indicate that, with an elasticity of 0.46, plot size was the most important factor of soybean production. It was closely followed by intermediate inputs (fertilizers, pesticides and seeds), with a coefficient of 0.44. When intermediate inputs were decomposed, fertilizers with an elasticity of 0.062 appears to contribute more to soybean production than pesticides (0.057) and seeds (0.034). Technical inefficiency was responsible for at least 93% of total variation in soybean output among the survey farmers. The relative efficiency (allocative efficiency) of resource use, expressed as the ratio of marginal value product (MVP) to marginal factor cost (MFC), were 1.73 for soybean plot size, 1.36 for fertilizers, and 1.92 for pesticides. These indicate that too little of these inputs are being used in relation to the prevailing market conditions.
Keywords: Soybean, Resource use, Efficiency, Cobb-Douglass production models, Rwanda

1. Introduction

In the manufacturing sector today, human capital is still essential for most factories to carry out a variety of Compared to common bean (Phaseolus vulgaris), soybean (Glycine max) is a minor crop in the farming systems of Rwanda in terms of acreage and consumption. It, however ,constitutes one of the crops that the government of Rwanda is currently relying on to achieve economic growth because of its high nutritional value, adaptability to the country's agro-climatic conditions, and potential to respond to organic and mineral fertilizer applications (Republic of Rwanda, 2004). In fact, in the framework of promoting oil crops in Rwanda, the Strategic Plan for Agricultural Transformation (SPAT) states that interventions will be concentrated on soybean with the following specific actions: "(i) increase the production capacity of good quality seeds and of inoculation for soybean (Rhizobium); (ii) develop research programs on mineral fertilization in order to increase the production potential even in regions having acidic soils; (iii) support the development of transformation units of soybean into flour and other derived products(milk and tofu) and, (iv) make the consumption of products based on soybean popular"(Republic of Rwanda, 2004). One can see that the government's soybean program is extremely important, but its implementation would face, at least in the short run, various constraints. First, household landholdings are small. Second, availability of recommended varieties and quality seed is limited. Third, regional specific technologies are not yet available. Fourth, capacity constraints of the extension system and high illiteracy of small scale farmers. Since available resources are limited, it is important to identify key determinants of soybean production and know how resources are being utilized in this farm enterprise.

We consider then examining the determinants of soybean production in this study for two major reasons. First, given that soybean is not a traditional crop in Rwanda, that is, not common in major farming systems and in the normal diet of majority of Rwandans, it is important to identify key factors on which farmers should place the greatest emphasis for successful soybean production. Second, soybean incorporation either in rotation or intercrop with a cereal constitutes one of the low-cost soil fertility management options.

This study is guided by the following hypotheses: (i) Factors of production (land, labor and intermediate inputs) have positive and significant influence on soybean output; and (ii) soybean growers are efficient given that resources under their management are efficiently used.

2. Methodology

2.1 Study area and data collection

The data used in this study were collected from Kamonyi district of the Southern Province. This district was purposively chosen because it has more soybean growers than other districts in the country. The process of selecting participating farmers started with a meeting with local agricultural extension agents in which objectives of the study were explained and lists of farmers that are likely to grow soybean twice a year were requested. In the second meeting that took place one week later, 80 households were randomly selected from a list of 150 farmers from 7 villages in two administrative sectors. Each selected household had to fill a farm data recordkeeping form intwo consecutive agricultural seasons. The data recorded on that form include the soybean plot area, quantity of family and hired labor (clearing, plowing, fertilizer application, planting, weeding, pest control, harvesting), quantity and price of inputs(seeds, organic fertilizers, mineral fertilizers, pesticides) used, farm implement costs associated with soybean production, household income from livestock, quantity produced and price of output. According to Ellis (1993), in order to investigate the efficiency attributes of peasant farmers, two main kinds of information are required: (i) the observation of different yields or productivities between farms; (ii) farmers' judgment with respect to the relative prices of inputs and outputs. The latter requires that the marginal physical product (MPPs) of the main productive resources are known. During the first season, from September 2007 to January 2008, nine households were dropped for not being able to follow instructions. For this reason, there were only 71 households who completed the farm data form in the second season (i.e. March to July 2008).

2.2 Analytical framework

Ali and Chaudhary (l990) affirm that "in developing economies, resources are meager and opportunities for developing and adapting better technology are dwindling". Shapiro (1983) had earlier said that "if farmers are not making efficient use of existing technologies, then efforts designed to improve efficiency would be more cost effective than introducing a new technology as a means of increasing output". It is then clear that to achieve optimum production level, scarce resources must be used efficiently. Fortunately, production theory provides a basis for analyzing the factors that explain changes in output level and measuring resource use efficiency, which have important implications for both policy formulation and farm management.

The production function specifies the technical relationships between inputs and output in any production scheme or process (Olayide and Heady, 1982; Beattie and Taylor, 1985; Chambers, 1988; Debertin, 1992). In its implicit form it can be expressed as follows:

$$Y = f(x_i) \quad (1)$$

whereY denotes output and x_i denotes vector of inputs (labour, land,seed, fertilizer, chemicals, etc.), "i"stands for the ithinput.

In general a production function shows the maximum level of output that can be obtained from given inputs and prevailing technology. Maximum output does vary however either as a result of stochastic effects (luck, bad weather, damaged output, environmental conditions "topography and soil type", etc.),measurement error on the dependent variable or of various levels of inefficiency at which firms in the industry may be operating. Aigner, Lovel and Schmidt (1977) and Meeusen and Van den Broeck (1977) developed independently stochastic production frontier models that assume that firms may deviate from the frontier not only because of non-systematic influence but also because of technical inefficiency. These authors specified and estimated a stochastic production function that can be written as

$$Y_i = F(X_j, B)e^{\varepsilon_i} \quad i = 1, 2,.....,n \quad (2)$$

Where Y_i is the output of i-th farm, X_j is a vector of inputs, B is a vector of coefficients, n is the number of observations and ε_i is a random disturbance composed of two independent error components, viz:

$$\varepsilon_i = v_i - u_i \quad (3)$$

The error term v_i captures random variation in output due to factors outside the farmer's control and is assumed to be independently and identically distributed as N(0, σ_v^2). The disturbance component u_i represents non-negative random variables which are independently and identically distributed as N(0, σ_u^2), or a half normal distribution and captures the factors that are under the farmer's control. The condition $u_i \geq 0$ ensures that all observations lie on or below the frontier.

In line with the original models of Aigner, Lovel and Schmidt (1977) and Meeusen and Van den Broeck (1977), Battese and Coelli (1995) proposed a stochastic frontier production model in which the variance of error terms, σ_u^2 and σ_v^2, are parameterized by replacing them with $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\lambda = \sigma_u / \sigma_v$ and $\gamma = \sigma_u^2 / \sigma^2$, where the coefficients λ and γ indicate the relative variation in the two sources of random errors, γ lying between 0 and 1. A γ equal to zero or λ approaching zero means that the discrepancy between the observed output Y_i and the frontier for a given set of input values is primarily due to factors beyond the control of the farmer. On the other hand, when γ equal to one or λ becomes large, they indicate that the discrepancy between the observed output and the frontier output is entirely or mainly due to technical inefficiency. Technical efficiency constitutes the first dimension of efficiency attributes of peasant farmers that corresponds to their varying degrees of success at maximizing output from given levels of inputs. The second dimension is known as allocative efficiency and refers to how resources are being used under the existing price condition, that is, the adjustment of inputs and outputs to reflect relative prices, the technology of production having been chosen. The later requires that the marginal physical product (MPPs) of major productive resources are known.

Technical, allocative and economic efficiency can be explained by Figure 1 that shows the efficient unit isoquant for a group of farms using inputs x_1 and x_2. Points A, B, C located on this isoquant represent farms that are technically efficient while farm D would be judged technically inefficient. The isocost line PP' indicates the minimum cost of producing one unit of output, the overall economic efficiency is greatest at point A. According to Farrell cited in Colman and Young (1989), the measure OR/OC represents the allocative efficiency, that is, the divergence between the minimum cost point and the cost incurred at point C, given that a farm represented by point "R" has the same level of cost as farm A.

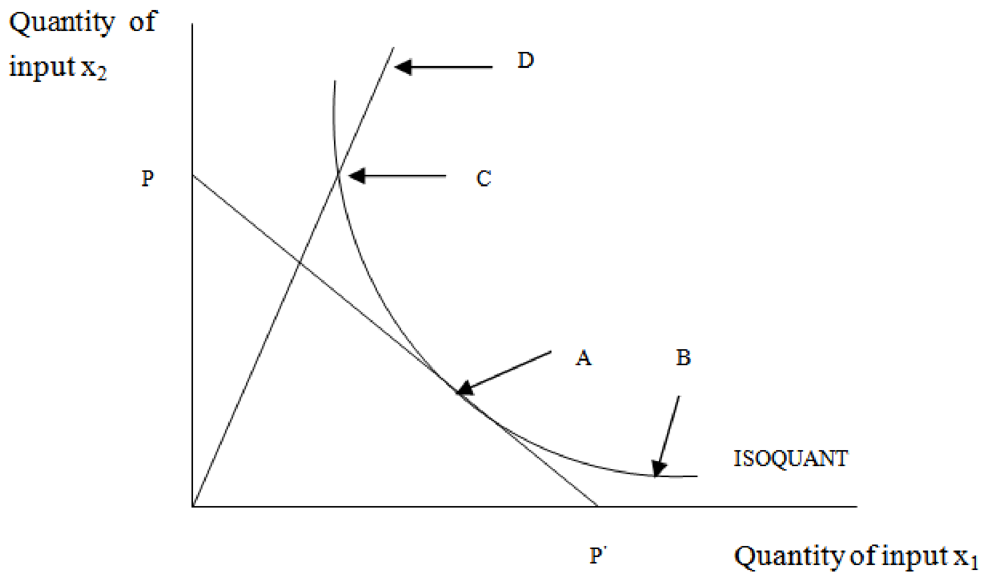

Figure 1:Farrel's efficiency indices

Source: Colman and Young 1989

Following Ellis (1993), marginal physical products (MPPs) of productive resources are computed from the production function coefficient X_j's and are required to examine whether the conditions of allocative efficiency are met. The marginal physical product is computed by the equation below.

$$MPP_i = \beta_i * \frac{Y_m}{X_{mi}} \quad (4)$$

where:

MPP_i	=	Marginal Physical Product of input i (i =1, 2, 3, 4, 5);
β_i	=	The coefficient associated with the input i;
Y_m	=	Geometric mean of soybean output;
X_{mi}	=	Geometric mean of the input i used in soybean production.

The marginal value of product is then calculated using the following equation:

$$MVP_i = MPP_i . P_y \quad (5)$$

where P_y corresponds to the unit price of output and MPP_i is as defined in equation (4).

The marginal value product (MVP) is divided by the cost of one unit of the factor of production or the marginal factor cost(MFC) to get the relative efficiency of resource use.

$$r_i = \frac{MVP_i}{MFC_i} \quad (6)$$

wherer_i = the relative efficiency of resource i (also known as the allocative efficiency)

2.3 Model specification

Olayide & Heady (1982) observed that the most extensively used production function to model agricultural production were linear, Cobb-Douglas, semi log and exponential. Econometric forms of these production functions are given as follows:

Linear: $Y_i=\alpha + \beta_1 X_1 + ... + \beta_n X_n + \varepsilon_i$ (7)

Cobb-Douglas: $Y_i=\alpha\, x_1^{\beta_1}\, x_2^{\beta_2} \ldots x_n^{\beta_n}\, e^{\varepsilon_i}$ (8)

$\Leftrightarrow$Normal (OLS): $\ln Y_i=\delta + \beta_1 \ln X_1 + ... + \beta_n \ln X_n + \varepsilon_i$ (9)

$\Leftrightarrow$ Frontier (MLE): $\ln Y_i = \delta + \beta_1 \ln X_1 + ... + \beta_n \ln X_n + v_i - u_i$ (10)

Semi-Log: $Y_i= \alpha + \beta_1 \ln X_1 + ... + \beta_n \ln X_n + \varepsilon_i$ (11)

Exponential: $Y_i = \alpha e^{\beta_1 x_1 + ... + \beta_n x_n + u_i}$ $\Leftrightarrow \ln Y_i = \delta + \beta_1 X_1 + ... + \beta_n X_n + \varepsilon_I$ (12)

The variables used in the soybean production function models are the following:
Y = Total amount of soybean harvested during the seasons A and B 2008 expressed in kilograms;
X_1 = Land area under soybean during the seasons A and B 2008 expressed in ares[2];
X_2 = Amount of labour (family "X_{21}" and hired "X_{22}") utilized in soybean activities during the seasons A and B 2008 expressed in hours; and
X_3= Expenditures on intermediate inputs (fertilizers "X_{31}", pesticides "X_{32}" and seeds "X_{33}") during the seasons A and B 2008 expressed in Rwanda francs.

All the above functional forms were fitted and compared. The test of specification error by Ramsey RESET test produced a significant F test for specification error for semi-log and exponential production functions but not for the other two models implying that the linear and Cobb-Douglas production functions fitted our data. The Cobb-Douglas production function was however preferred to the linear for two major reasons: first, it has been used in many empirical studies, in particular with data from developing country agriculture (Ajibefun et al. 2002; Bravo-Ureta and Pinheiro 1997; Obi and Chisango, 2011); second, it has the property of generating partial elasticities that allow for the analysis of allocative efficiency.

From the Cobb-Douglas production function results, the following parameters were computed for each input used in soybean production: marginal physical product (MPP), marginal value product (MVP) and returns to scale (RS). It is common knowledge that the economic optimum level of input occurs when the marginal value product of the input is equal to the price of the input. In other words, profit is maximized when the ratio of the marginal value product to the marginal factor cost equals one. Following Ellis (1993), when the ratio is less than one the farmer is using too much of the variable input under the existing price conditions, implying inefficient resource use while a ratio greater than one indicates that too little of the resource is being used, and increased use of the resource would result in increased profits.

In this study the prevailing wage for hired labor in the study area was used for both family and hired labor while for land its rental value is used as the market price. Since intermediate inputs (fertilizer, pesticides and seeds)were measured in monetary terms using market price, the marginal value product of these resources corresponds to their efficiency ratios (r_i).

Elasticity of production (ELP) and return to scale (RS) are derived directly from β_{is}, following the properties of the Cobb-Douglas production which are as follows:

- β_i is the partial elasticity of output with respect to the ith input. It measures the percentage change in the ith input, holding other input levels constant;
- The sum of $\beta_i$gives information on the returns to scale, that is, the response of output to a proportionate change in input.

3. Results and discussions

Before fitting the model, a preliminary analysis was done to check for some inconsistencies that would impact the results. Six outliers were detected in two variables, namely the quantity of soybean produced and the area cultivated to soybean. The affected observations were eliminated from the dataset for the descriptive and the regression analyses, with final sample size falling to65 from the 71 responses obtained.

Table 1 presents the descriptive statistics of variables included in the Cobb-Douglas production functions. Results indicate an average annual soybean output of about 43.8 kg for an average soybean plot size of 0.06 hectare, which corresponds to an average yield of about 730 kg per hectare.

From the estimates of the translog production function not presented in this paper, none of the variables showed significant effects on output, suggesting that there are no interactions amongst the variables.

The test for the worthiness of decomposing the error term to account for technical inefficiency effects consists in testing the null hypothesis,H_0: $\sigma_u^2 = 0$ (no technical inefficiency) against the alternative hypotheses, H_1: $\sigma_u^2 > 0$. Results in Table 3 show likelihood-ratio (LR) estimates significant at 5% probability level for "frontier 1" (3.25) and "frontier 2"(3.40) while for "frontier 3" the likelihood-ratio of 0.17 is not significant. These results allow us to reject the null hypothesis for the two first frontier models, indicating then that technical inefficiency does exist in soybean production. Furthermore, results of parameters λ (3.79) and γ (0.94 and 0.93) with frontier 1 and 2

[2] 1 are = 0.01 hectare

respectively suggest that variation in soybean output among farmers is mainly due to technical inefficiency and that inefficiency is responsible for at least 93% of total variation.

Table 1. Summary statistics for variable in the Cobb-Douglas production functions

Variable	n	Mean	Std. Dev.	Min	Max
Soybean output season A and B 2008 (kg)	65	43.80	21.81	12.50	119.50
Total labor (hours)	65	179.82	67.73	76.00	366.00
Area under soybean season A and B 2008 (are)	65	6.02	2.89	2.38	14.73
Intermediate inputs (Frw[3])	65	1236.41	780.37	250	3425
Family labor (hours)	65	146.47	58.28	75	350.00
Hired labor (hours)	65	33.35	35.89	0	128.00
Fertilizers (Frw)	65	494.87	406.52	0	1540
Pesticides (Frw)	65	138.42	238.77	0	950
Seeds (Frw)	65	603.12	313.94	250	1800

Source: Farm household recorded data, season A and B 2008

Results of F tests for the three ordinary least square estimations and Wald tests for the three maximum log likelihood estimations are significant at the 1% probability level, implying the overall significance of the models reported in Table 2. R-squared results reveal that splitting total labor in family and hired labor does not improve the regression outcomes while splitting intermediate inputs in fertilizers, pesticides and seeds yields better results. The results discussed in this section are those of production functions in models "frontier 1" and "normal 3" given that they appear to fit the data better.

The coefficients estimated in the models were in accordance with the a priori expected signs except for total labor in model "frontier 1" and hired labor in model "normal 3". Land, fertilizers and pesticides had positive and significant effect on soybean output while family labor and seeds had positive but not significant effect. On the other hand total labor and hired labor had negative but with no significant effect on soybean production. Thus, land and intermediate inputs are the main constraints in soybean production. Labor does not appear to be constraining. Although the negative effect of labor in the estimations appears to be counterintuitive, it has been found to be the case in some other empirical studies. In fact, negative and significant effect of labor on agricultural production were found by Msuya et al. (2008) using small-scale farmers' maize data from Tanzania and Mousavi-Haghighiet al. (2008) with Iranian agricultural sector data. The former authors explain that situation as a consequence of too much time being spent in the maize production process probably due to limited opportunities for income generating activities outside agriculture especially in rural areas. In line with this explanation, the latter authors, observing the negative marginal product of labor recommend that policy makers should reduce the labor force in the agricultural sector and improve capital-intensive methods.

Table 2: Parameter estimates of the Cobb-Douglas production functions

	Normal 1[a]	Frontier 1	Normal 2[a]	Frontier 2	Normal 3[a]	Frontier 3
Constant	-0.03769 (0.51583)	0.29364 (0.49967)	-0.0753611 (0.48622)	0.34756 (0.46799)	1.58372*** (0.47112)	1.74864*** (0.48749)
Soybean plot size	0.56240*** (0.09228)	0.45922*** (0.08110)	0.55692*** (0.09052)	0.46476*** (0.07858)	0.8220*** (0.09001)	0.8326*** (0.08833)
Total labor	0.00097 (0.11213)	-0.0392945 (0.10189)				
Intermediate inputs	0.39703*** (0.04670)	0.44471*** (0.04793)	0.39616*** (0.04723)	0.44499*** (0.04914)		
Family labor			0.01122 (0.0186)	-0.0527218 (0.09444)	0.02020 (0.08258)	0.01230 (0.07975)
Hired labor			0.00108 (0.0186)	-0.0032612 (0.0164)	-0.01166 (0.01500)	-0.01307 (0.0145)
Fertilizers					0.06223*** (0.01141)	0.06227*** (0.01067)
Pesticides					0.05686*** (0.00986)	0.05311*** (0.00939)
Seeds					0.03373 (0.07408)	0.02919 (0.07114)
R-squared	0.7850		0.7850		0.8666	
F statistics (Wald test)	74.24***	245.24***	54.78***	248.02***	62.77***	410.33***
Lambda (λ)		3.79503 (0.07869)		3.79232 (0.08008)		0.92497 (0.14929)
Gamma (γ)		0.94		0.93		0.46
Likelihood-ratio test		3.25**		3.40**		0.17
Nbr of observations	65	65	65	65	65	65

Notes: - Single, double and triple asterisks (*) denote significance at the 10%, 5% and 1% levels, respectively.
- Figure in parenthesis "( )" are standard errors.

[3]Frw = Rwandan Francs

a: Cobb-Douglas production function with undecomposed error term
Source: Farm household recorded data, season A and B 2008

Soybean plot size constitutes the most important factor of production with an elasticity of 0.4592. This implies that a 1% increase (decrease) in the size of land under soybean production, ceteris paribus, will result in a 0.46% increase (decrease) soybean output. Tadesse and Krishnamoorthy (1997), Basnayake and Gunaratne (2002), Amaza and Ogundari (2008), Msuya et al. (2008) and Barnes (2008) obtained similar results among paddy farms of Tamil Nadu in India, Sri Lanka smallholder tea producers, soybean growers in the Guinea Savanna of Nigeria, Tanzania small-scale maize farmers and Scottish cereal producers, respectively. However, compared to our results, the coefficients in paddy farms of Tamil Nadu (0.8872), Tanzanian maize farmers (0.6988) and Sri Lanka smallholder tea producers (1.11) are high while those of soybean growers in Nigeria (0.40) and Scottish cereal producers (0.289) are relatively low. Intermediate inputs (fertilizers, pesticides and seeds) with a coefficient of 0.4447 constitute the second most important factor of production meaning that the increase in their use would significantly and positively increase smallholders soybean output. When intermediate inputs are decomposed, fertilizers (0.062) seems to contribute more to soybean production than pesticides (0.057) and seeds (0.034). Similar results were found by Tadesse and Krishnamoorthy (1997) with data from paddy farms in India (fertilizer "0.05169", seeds "0.0239") while Amaza and Ogundari (2008) found that planting materials (0.12) had larger effect than fertilizers on soybean production in Nigeria. Amos (2007) using smallholder cocoa farmers' data in Nigeria found a positive relationship between the level of output and the intensity of fertilizer and pesticide use.

The soybean production efficiency parameters are presented in Table 3. These parameters were computed for only resources whose regression estimates were statistically significant. Results showed that the elasticities of production with respect to soybean plot size, fertilizers and pesticides were positive and less than one, indicating decreasing returns to each of these factors. The sum of input elasticities (0.98)is however closer to unity, indicating overall constant returns to scale. Results showed also that the marginal productivity of land was higher than that of the other factors used in the production of soybean in the study area. This led to higher marginal value product for land. This would not however imply that farmers are more technically efficient in land use than in other factors, since units of factors of production are different.

The ratios of MVP to MFC for soybean plot size (1.73), fertilizers (1.36) and pesticides (1.92) were greater than one. These ratios indicate that too little of these inputs are being used in relation to the prevailing market conditions. Hence the farmers are allocatively inefficient in the use of the available land and capital inputs. This implies that there were ample opportunities for the farmers to increase production by using more of these inputs.

Table 3. Productivity and resources use efficiency in soybean production

	Land	Family labor	Hired labor	Fertilizers	Pesticides	Seeds	Return to scale
Elasticity of production	0.8220	0.0202	-0.0116	0.06223	0.05686	0.03373	0.9834
Marginal physical product	5.3375			0.00419	0.00592		
Marginal value product	1734.7			1.36270	1.92551		
Ratio of MVP to MFC	1.7347			1.3627	1.9255		

Source: Farm household recorded data, season A and B 2008

4. Conclusion

The findings of this study indicate that if soybean growers need to increase their soybean productivity, they should allocate more land to the crop and make sure that they use capital intensive inputs such as fertilizers and pesticides. Since land is a very limited resource in Rwanda, the only alternative for increasing soybean cultivated area is to replace some crops that are grown on household farm by soybean. The success of this operation is possible if farmers are convinced of its benefits by a well designed and implemented soybean resource-to-consumption chain development program. Participatory approaches including farmers and other stakeholders in the subsector are to be preferred to imposing the rotation soybean-maize rotation to farmers when inputs and output markets issues are still pending.

Better utilization of resources should be emphasized through increased use of capital intensive inputs such as fertilizers, pesticides and improved seeds. However, given the prevailing situation with farmers to access and buy these inputs because of high prices, use of improved inputs can be achieved through promoting and encouraging farmers to form associations /cooperatives or enabling farmers to enter into contract farming with traders and/or input suppliers.

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