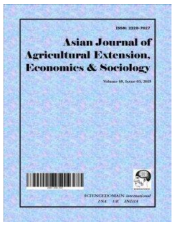

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Determination of Optimum Crop Mix Using Linear (LP) Programming among Small Holder Farmers in Agricultural Zone Four of Adamawa State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Linear programming was applied to farm data collected from 120 smallholder farmers in 2017/18 cropping season in agricultural zone four (4) of Adamawa state, Nigeria for the purpose of identifying optimal crop mix to maximize revenue. A total of twenty (20) cropping enterprises were identified in the existing cropping pattern, fifteen (15) mixed and five (5) sole cropping enterprises. Popular enterprises identified included four mixed and two sole cropping enterprises and all the six enterprises showed positive net return. The result of the linear programming analysis however, showed that the optimal farm plan at observed maximum resource levels admitted only groundnut and sorghum in the final plan to be produced at 2 hectares with an associated total gross margin of ₦478, 380.00. In the sensitivity analysis identified with the observed maximum resource level, land was the only binding resource in the final plan. The optimal farm plan at observed average resource levels showed that three enterprises; groundnut/sorghum, maize/sorghum and sole maize were admitted in the final plan under 0.45ha, 0.21ha and 0.17ha, respectively. The associated total gross margin was ₦153, 003.99. In the sensitivity analysis associated with the observed average resources, only NPK, SSP, Laraforce were binding resources. The study recommended that the optimum enterprises and resources combination obtained in the Linear Programming output should

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be extended to the farmers to enhance their profit level, beside; farmers should be encouraged through adequate support and promotions to improve the production techniques of these recommended enterprises.

Keywords: Linear programming; mix cropping; existing plan; optimum plan; enterprise; small holder farmers.

1. INTRODUCTION

The current global population of 7.6 billion people is expected to reach 9.8 billion by 2050. Presently around 11% of world population suffers from hunger and in fact those facing chronic food deprivations, has reached to nearly 821 million people in 2017 [1]. This means world food production will need to rise by 70% in sub-Saharan Africa and other developing world to cope with food demand [2]. However, Smallholder farmers are central to this renewed emphasis on world food demand. Smallholder farmers are the main producers of the global food demand and they account for between 60 to 80 percent of the food produced in the developing nations [3]. There are more than 570 million smallholder farmers globally cultivating about 75% of the world agricultural land [4]. Of the two-thirds of sub-Saharan Africa's population that resides in the rural areas, majority can be regarded as smallholder farmers [5]. Nigeria is predominantly an agrarian economy, engaging about two-thirds of the country's workforce [6]. In 2018, agricultural sector contributed 25.13% to real GDP [7]. Nonetheless, the Nigerian agriculture is still at subsistence level, with low productivity and poor return on investment as farm activities is majorly in the hand of small holder farmers [8]. In smallholder agriculture, farmers are presumed to be concerned with maximization of some measure of achievement such as sustainable food for the family throughout the year, increase in income and ensuring minimum resource usage [1].

In general life, we all have finite resources and time but we always want to make the most of them optimally. In this manner, Smallholder farmers are usually confronted with these challenges of how to allocate scarce production resources for optimal cropping activities that maximize their objectives such as food security for the family, steady flow of income and efficient resource usage among others [9]. Smallholder farmers also do not only produce different crops but also have to choose among the varieties of ways of producing them as resources are finite. Traditionally, such decisions are usually influenced by farmers' experiences, instincts and neighborhood comparison [10]. However, instincts and experience do not always guarantee optimal results [11].

In developing countries like Nigeria the situation is even more where basic farm resource like land is being lost to modern developmental projects, exploration excesses and lately security challenges in Northern and other parts of Nigeria, hence, the need to increase production of crops per unit area through proper resource utilization [12]. The aforementioned challenge is one of the emphasis as to why the application of crop modeling enterprise is becoming significant in smallholder farming systems [13]. Actualizing self-sufficiency in food crops among other things requires that, for the local food crop in which Nigeria has a comparative advantage over some nations of the world, significant increases are experienced given the prevailing socio-economic and cultural circumstances of Nigeria [14].

Of particular interest is the Northern States of Nigeria, where an inheritance land tenured system is intensely practiced and farmland as the major agric resource is seriously fragmented into smaller individual farm sizes resulting in persistent food crises from declining crop productivity. Hence, farmland optimization is therefore one way forward.

Cropping plan decisions are the basic land-use decisions in farming systems and consist of at least, the choice of crops to be grown, their acreage and their resource allocation within a particular farmland [15]. These decisions mostly take place at the farm level and are usually part of the global technical management of farm production [16]. Linear programming (LP) is one of the most important tools that can be used for farm planning and decision making particularly in farming practice of raising more than one crop on the same land at the same time known as mixed [17]. Optimized agricultural planning is an essential activity in business profitability because it can increase the income from an operation with low additional costs [18].

Various approaches have been scientifically used in diverse studies that involved analysis of cropping decision patterns in many countries over a period of time. Nevertheless, of all optimization techniques available (e.g. Linear Programming (LP), Dynamic Programming (DP) and Genetic Algorithm etc), it is LP that is more popular because of the proportionate characteristics of the allocation problems which helps in defining the technical relationship between inputs and outputs [12]. Bowman and Zilberman [19] stated that in agriculture, where different crops are competing for a limited quantity of land and other resources, Linear programming models can handle such limitations and constraints and thus, an effective tool to aid optimization. Linear programming technique is a scientific and mathematical tool considered as suitable for farm planning due to its simplicity and practical applicability to resource allocation planning for the purpose of optimal solutions [20]. Linear programming is therefore a technique where we depict complex relationships through linear functions and then find the optimum points [21].

Linear programming (LP) is considered as important tool that can be used for optimal farm planning. Nevertheless, there is no known study on the application of LP to cropping decisions by smallholder farmers in the study area. These smallholder farmers who operate with crude implements, cultivate small pieces of land and have a poor resource base are mostly faced with the challenge of optimal utilization of their small resources to improve their incomes and consequently their living standards.

This study applied linear programming which was not common among smallholder farmers and specifically in the study area to be able to know the best crop enterprise combination that will be promoted and equally help the farmers diversify their production, assist in efficient resource use, ensure consistency in revenue generation and also take care of the vagaries of weather. Linear programming (LP), when applied to farm planning represents a systematic approach of determining mathematically the optimum plan for the selection and combination of farm enterprises, in order to maximize income and/or minimize costs within the limits of available farm resources [22]. Although most farming activities in the study area are done on small scale, farmers generally, rarely specialize along individual crop without a relative combination of more than one enterprise. Hence, the use of linear programming (LP) as a scientific tool for farm planning and resource allocation in determining optimal crop mix decision among smallholder farmers was the objective of this study.

Although there are many ways to define smallholder farmers, the FAO's criterion of plot size is widely accepted, with 'smallholder farmers' are being farmers who own or farm plots of 2 hectares or less [23]. While for the purposes of this report this definition covers mainly crop growers producing both cereal and horticultural crops, generally it will also mean to include small-scale, family-run livestock farms as well as pastoralists, fishermen and forest dwellers.

2. MATERIALS AND METHODS

2.1 The Study Area

The research was carried out in Michika and Mubi South Local Government Areas (LGAs) in Zone four (Mubi zone) of the Agricultural Development Programme of Adamawa State, Nigeria. The State has twenty one (21) LGAs that have been divided into four agricultural zones. Zone four comprises of Michika, Madagali, Mubi North, Mubi South and Maiha LGAs (5 of the 21 LGAs in the state). This zone has a land area of 4,728.77 km^2 [24]. Mubi zone lies between latitude 9°30^{1}N-11°N and longitude 13°E – 13°45^{1}E (Google Map data, 2017). The zone has a population of 681,353 people based on [25]. However, the estimated population for 2018 is 1,221,287 people obtained by applying an annual growth rate of 3% as provided by the NPC using 2006 population as the base Figure. The Zone falls within the tropical climate with distinct wet and dry seasons and the mean annual rainfall is about 1100 mm. Agriculture is the major occupation of about 80% of the inhabitants of the zone and the major crops grown in the area includes; sorghum, maize, millet, rice, groundnut, beans, bambara nuts, pepper, sugar cane [26].

Multistage sampling approach was used to sample 120 small holder farmers in the study area. This involved the purposive selection of two (2) out of the five local government areas in the zone, followed with a purposive selection of five (5) farming communities from each LGA and lastly, a total of 120 smallholder famers as sample size was proportionately taken through simple random selection of the respondents for this study. Primary data were used for the

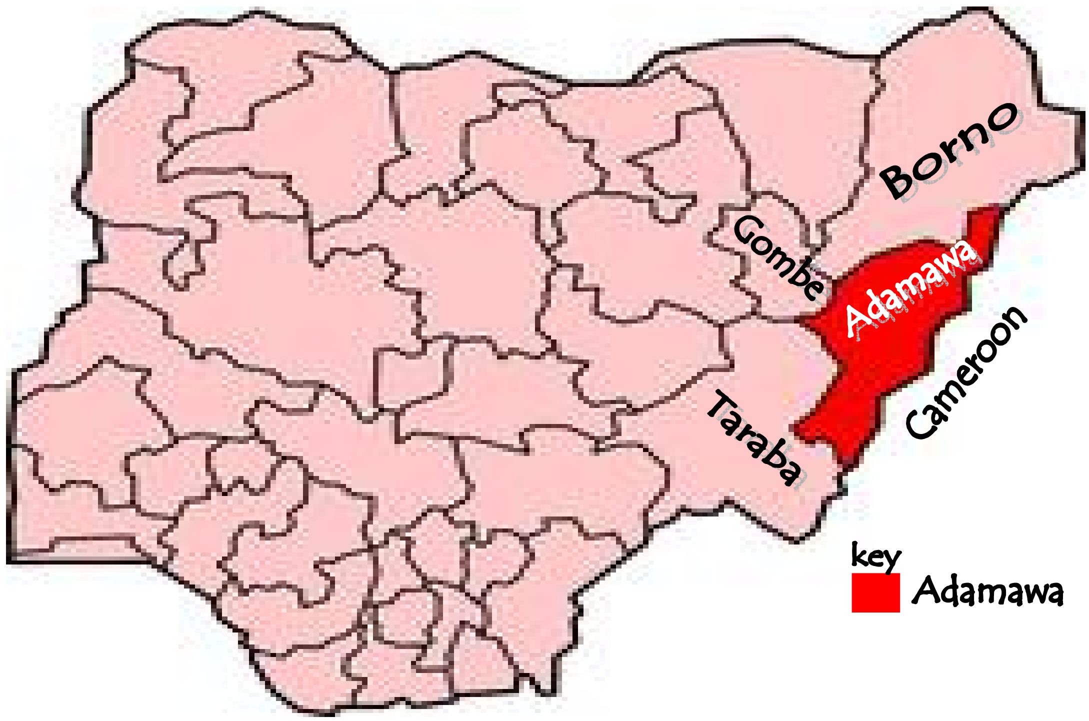

Fig. 1. Map of Nigeria showing Adamawa State
Source: Google map 2018

purpose of this study generated through the use of structured questionnaire that were administered to small holder farmers for 2017/18 cropping season. Twenty cropping enterprises were identified in the existing plan from which six were observed to be popular based on relative frequencies. The popular enterprises were made up of two major sole cropping and four mix cropping activities. The six most popular enterprises from the sample were Maize and Beans, Maize and Groundnut, Groundnut and Sorghum, Maize and Sorghum, Sole Maize and Sole groundnut.

All inputs were converted into their standard units of measurement per hectare and all crops into kg per hectare and prices used were in naira per kg of each crop.

2.2 Data Analysis and Tools

The study examined different crop enterprises among smallholder farmers in agricultural zone four (4) of Adamawa state and Linear programming model was used to achieve the objective by the analysis of the farmers resource level and other constraints in crop production so as to develop optimum enterprise combination that maximize revenue in the study area while determining slack and limiting resources comparing optimum and existing farm plan in terms of activities, output and resource usage.

2.3 Specification of Linear Programming Model

The activities in the models were grouped into sole cropping or mix-cropping activities (crop production), cost of inputs activities and output sales activities. For each of the crop production activities, the unit of activity is one hectare. The price coefficient ‘’Cj’’ of a production activity in the model is the gross margin per hectare.

The LP maximization problem may be illustrated as:

Maximize: Z = $\sum_{j=1}^{n} C_j X_j$

Subject to: $\sum_{j=1}^{n} a_{ij} X_{j \le B_i}$, i=1,2,…….k resources.

$X_i \geq 0$, j=1,2,………….. ,n

where:

Z= Total gross margin from all crops
n= the number of crops
C_i = gross margin from jth enterprise
X_j = the area under jth enterprise

B_i = maximum level of resource i available
a_{ij} = requirement for resource i by enterprise j

Therefore, the algebraic expression of the linear programming model with "n" decision variables and "m" constraints can be mathematically modeled as:

Max TGM = C_1X_1+ C_2X_2+ C_3X_3+ C_4X_4------------- C_nX_n

Subject to:

$a_{i1}x_1+a_i2x_2+a_{i3}x_3+a_{i4}x_4+a_{i5}x_5$ +------------+$a_{in}X_n$ ≤ B_i, i=1,2…K

Where all variables are as previously defined

$X_1 \geq 0$, $X_2 \geq 0$, $X_3 \geq 0$, $X_4 \geq 0$, $X_5 \geq 0$,---------Xn= non negativity constraints.

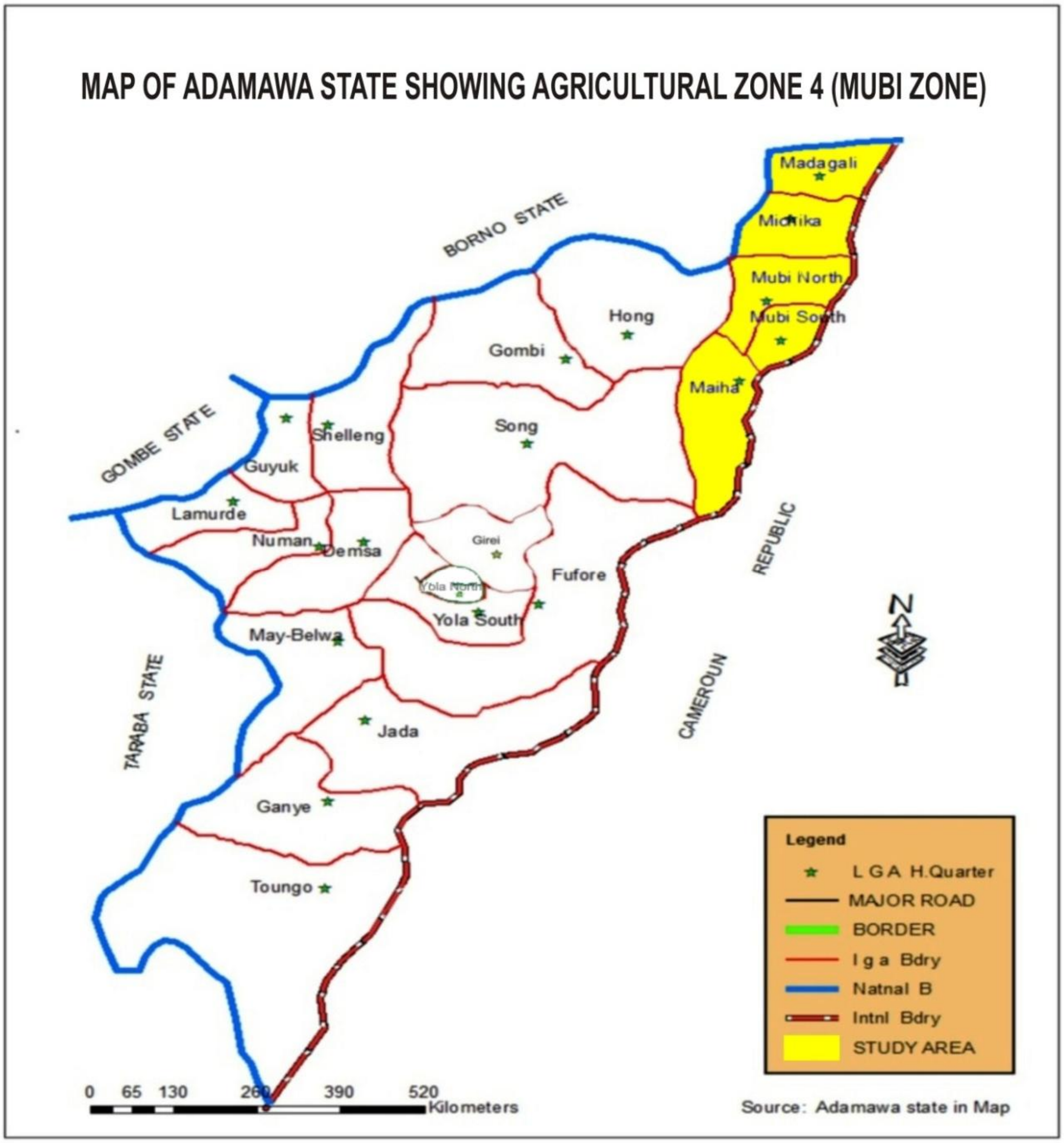

Fig. 2. Map of Adamawa State showing agricultural zone 4
Source: Google map 2018

3. RESULTS AND DISCUSSION

3.1 Frequencies of Farmers Based on Cropping Enterprise (Enterprise Decisions)

The summary of the cropping decision and combination practiced by the smallholder farmers in the study area is presented in Table 1. A total of twenty (20) cropping pattern were identified, in which fifteen (15) were mixed cropping system and five (5) were sole cropping activities.

3.2 Optimal Activity Levels in the Final Plan Using Observed Maximum Resource Levels

The result in Table 3 showed the optimal farm plan at observed maximum resource levels. As shown, only groundnut/sorghum enterprise was admitted in the final plan, and to be produced at 2 hectares. The associated total gross margin, which was the measure of profitability in this study, was ₦478, 380. The result suggested that the recommended enterprise or best crop combination that entered the model was groundnut/sorghum when cultivated at the maximum resource of 2ha of land and would generate ₦478, 380 as profit to the smallholder farmer in the area.

The result in Table 4 showed the sensitivity analysis associated with the observed maximum resource levels in the survey. Only land was fully used in the final plan, suggesting that an extra one hectare would add ₦239, 190 to the total gross margin. The LP therefore revealed that land was a binding constraint with slack value of zero. A resource with a shadow price greater than zero and slack value of zero, means that additional unit of that resource will change the ultimate plan by adding the coefficient of the shadow price to gross margin.

The result in Table 5 showed the optimal farm plan at observed average resource levels. As shown, three enterprises, groundnut/sorghum, maize/sorghum and sole maize were admitted in the final plan, 0.45ha, 0,21ha and 0.17 ha, respectively. The associated total gross margin was ₦153,003.99. This was lower than obtained at maximum resource levels, suggesting that resource restrictions will always lower the final profit. From this optimal farm plan at observed average resource levels, the average farmer or farmer with an average land size of 0.8ha should allocate his resources in a manner that 3 crop enterprises shown in Table 5 should be cultivated according to specification. The recommended enterprises accepted in the model were Groundnut/Sorghum at 0.45ha, Maize/ Sorghum at 0.21ha and sole Maize at 0.17ha with a gross margin of ₦153, 003.99.

Table 1. Frequencies of farmers based on cropping decisions

Crops grown	Frequency	Percentage
Maize	8	6.7
Groundnut	7	5.8
Beans	3	2.5
Sorghum	2	1.7
Rice	2	1.7
Maize & Groundnut	19	15.8
Maize & Beans	23	19.2
Maize & Sorghum	15	12.5
Maize & Banbara Nut	2	1.7
Sorghum & Banbara Nut	2	1.7
Groundnut & Beans	3	2.5
Groundnut & Sorghum	17	14.2
Groundnut & Banbara Nut	6	5.0
Beans & Sorghum	2	1.7
Beans & Banbara Nut	1	0.8
Maize, Groundnut & Beans	3	2.5
Maize, Groundnut & Sorghum	1	0.8
Maize, Groundnut & Banbara Nut	1	0.8
Maize, Groundnut, Beans & Banbara Nut	2	1.7
Maize, Groundnut, Sorghum & Banbara Nut	1	0.8
Total	120	100

Source: Field survey (2018)

Table 2. Implemented basic LP data that shows resource utilization and the gross margin of selected enterprise

Resource	Maize & Beans (X_1)	Maize & G/Nut (X_2)	G/Nut & Sorhum (X_3)	Maize & Sorghum (X_4)	Sole Maize (X_5)	Sole G/Nut (X_6)	Restr Type.	Resource level	
Net Price (Gm)	122,988.00	158,801.00	239,190.00	153,442.00	74,130.00	151,737.00		**Obs. max**	**Obs. Ave**
Land (Ha)	1	1	1	1	1	1	Max	2	2
Npk (Kg)	146.7	102.3	140.5	112.2	118.6	7.1	Max	350	120
Ssp (Kg)	2.2	5.3	10.1	2.2	2.2	10.1	Max	167	5.4
Urea (Kg)	6.5	18.4	16.2	21.7	6.5	6.5	Max	200	13
Chemsate	3	1.8	1.2	2.3	0.9	2	Max	10	2
Altrazine	2	1	0.8	0.8	0.8	4.2	Max	10	1.6
Laraforce	1.5	2.4	1.9	1.8	4.5	1.3	Max	10	2
Lab Land Prep	5.7	10.7	4.1	5.3	10.6	8.4	Max	40	7
Lab Planting	8.3	13.2	9.4	8.5	13.1	15.3	Max	40	11
Lab Weed	4	9.3	8.3	6.1	13	6.4	Max	40	8
Lab Chem Appl	2.8	3.4	3.4	2.8	8.1	4.7	Max	20	4
Lab Harvest	15.1	17.6	20	18.1	17	16.8	Max	50	17
Lab Processing	14.3	20	18.2	14.8	24.3	19	Max	70	18

Source: Field survey (2018)

Table 3. Optimal activity levels in the final plan using observed maximum resource levels

Enterprise		Optimum. level (ha)	Total Gross Margin (₦)
Maize & Beans	(X_1)	0	
Maize & G/Nut	(X_2)	0	
G/Nut & Sorghum	(X_3)	2	478,380
Maize & Sorghum	(X_4)	0	
Sole Maize	(X_5)	0	
Sole G/Nut	(X_6)	0	

Source: LP result of field survey (2018)

Table 4. Optimal resource levels in the final plan using observed maximum resource levels

Name	Used	Slack (unused)	Status	Shadow price (Naira)
Land (Ha)	2	0	Binding	239,190
Npk (Kg)	281	69	Not Binding	0
Ssp (Kg)	20.2	146.8	Not Binding	0
Urea (Kg)	32.4	167.6	Not Binding	0
Chemsate	2.4	7.6	Not Binding	0
Altrazine	1.6	8.4	Not Binding	0
Laraforce	3.8	6.2	Not Binding	0
Lab Land Prep	8.2	31.8	Not Binding	0
Lab Planting	18.8	21.2	Not Binding	0
Lab Weed	16.6	23.4	Not Binding	0
Lab Chem Appl	6.8	13.2	Not Binding	0
Lab Harvest	40	10	Not Binding	0
Lab Processing	36.4	33.6	Not Binding	0

Source: LP result of field survey (2018)

Table 5. Optimal activity levels in the final plan using observed average or near-average resource levels

Enterprise		Optimum level (ha)	Total Gross Margin (₦)
Maize & Beans	(X_1)	0	
Maize & G/Nut	(X_2)	0	153,003.99
G/Nut & Sorhum	(X_3)	0.45	
Maize & Sorghum	(X_4)	0.21	
Sole Maize	(X_5)	0.17	
Sole G/Nut	(X_6)	0	

Source: LP result of field survey (2018)

Table 6. Optimal resource levels in the final plan using observed average or near-average resource levels

Variable	Used	Slack(unused)	Status	Shadow price (₦)
Land (Ha)	0.83	1.17	Not Binding	0
Npk (Kg)	107.24	12.76	Not Binding	0
Ssp (Kg)	5.40	0.00	Binding	14,643.88
Urea (Kg)	13.00	0.00	Binding	5,469.11
Chemsate	1.18	0.82	Not Binding	0
Altrazine	0.67	0.93	Not Binding	0
Laraforce	2.00	0.00	Binding	1,414.27
Lab Land Prep	4.77	2.23	Not Binding	0
Lab Planting	8.26	2.74	Not Binding	0
Lab Weed	7.24	0.76	Not Binding	0
Lab Chem Appl	3.50	0.50	Not Binding	0
Lab Harvest	15.73	1.27	Not Binding	0
Lab Processing	15.46	2.54	Not Binding	0

Source: LP result of field survey (2018)

The result in Table 6 showed the sensitivity analysis associated with the observed average resource levels in the survey. Unlike the results obtained at maximum resource levels, land was no longer binding or restraining in the present plan. However, SSP, Urea and Laraforce were now binding because they were fully used in the final plan. Specifically, extra units of SSP, Urea and Laraforce as farm inputs would add ₦14,643.88 kobo, ₦5,469.11 kobo and ₦1,414.27 kobo to the total gross margin, respectively. This would imply that using an additional unit of SSP, Urea or Laraforce as farm inputs by an average smallholder farmer in the study area would add ₦14, 643.88k, ₦5, 469.11k and ₦1, 414.27k respectively to the total gross margin, again only at the observed average or near average resource level.

4. CONCLUSION

The result of the study revealed that mixed cropping decisions yields higher revenue and provide for efficient use of farm resources per ha compared to sole cropping activities. A total of twenty (20) enterprises were identified, out of which fifteen (15) were mix cropping and five (5) were sole cropping activities. Six popular enterprises were identified to be common among the smallholder farmers in the area. However, in the observed maximum resource only groundnut/sorghum enterprise was admitted in the final plan, and to be produced at 2 hectares. The associated total gross margin, which was the measure of profitability in this study, was ₦478, 380. Resource allocations in the final plan were also different from that of the existing plan. In the final plan on the observed maximum resources, only land was fully used hence a limiting factor, suggesting that an extra one hectare will add ₦239, 190 to the total gross margin. In the optimal farm plan at observed average resource level, three enterprises; groundnut/sorghum, maize/sorghum and sole maize were admitted in the final plan, 0.45 ha, 0.21 ha and 0.17 ha, respectively. The associated total gross margin was estimated at ₦153, 004. This was lower than obtained at maximum resource levels, suggesting that resource restrictions will always lower the final profit. Conclusively the research indicated that the resource allocation pattern in the optimum plan were significantly different from that in the existing plan. The optimum gross margin showed sensitivity to increase in land. The study recommended that the optimum enterprises and resources combination obtained in the Linear Programming output should be extended to the farmers through the use effective extension programme via trained extension workers such that these smallholder farmers will be educated on how to efficiently allocate their resources to enhance their profit level. Furthermore more government policies should be geared towards addressing the provision of accessible credit facilities and subsidizing farm inputs. Also, the LP optimal farm plan at observed average resource should be embraced by average land holding farmers and specifically deploying resources in this regard. Finally the LP sensitivity analysis associated with the observed; maximum and average resource levels which revealed binding slack resources of zero value and non binding constraint with shadow price of zero be adhered to by the farmers so as minimize wastages.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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