

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

3 **Abstract**

4 Linear programming was applied to farm data collected from 120 smallholder farmers in
5 2017/18 cropping season in agricultural zone four (4) of Adamawa state, Nigeria for the purpose
6 of identifying optimal crop mix to maximize revenue. A total of twenty (20) cropping enterprises
7 were identified in the existing cropping pattern, fifteen (15) mixed and five (5) sole cropping
8 enterprises. Popular enterprises identified included four mixed and two sole cropping enterprises
9 and all the six enterprises showed positive net return. The result of the linear programming
10 analysis however, showed that the optimal farm plan at observed maximum resource levels
11 admitted only groundnut and sorghum in the final plan to be produced at 2 hectares with an
12 associated total gross margin of ₦478, 380.00. In the sensitivity analysis identified with the
13 observed maximum resource level, land was the only binding resource in the final plan. The
14 optimal farm plan at observed average resource levels showed that three enterprises;
15 groundnut/sorghum, maize/sorghum and sole maize were admitted in the final plan under 0.45ha,
16 0.21ha and 0.17ha, respectively. The associated total gross margin was ₦153, 003.99. In the
17 sensitivity analysis associated with the observed average resources, only NPK, SSP, Laraforce
18 were binding resources. The study recommended that the optimum enterprises and resources
19 combination obtained in the Linear Programming output should be extended to the farmers to
20 enhance their profit level, beside; farmers should be encouraged through adequate support and
21 promotions to improve the production techniques of these recommended enterprises.

22 Keywords: Linear programming, mix cropping, existing plan, optimum plan, enterprise, small
23 holder farmers

24 **Introduction:**

25 The current global population of 7.6 billion people is expected to reach 9.8 billion by 2050.
26 Presently around 11% of world population suffers from hunger and in fact those facing chronic
27 food deprivations, has reached to nearly 821 million people in 2017 (FAO, 2018). This means
28 world food production will need to rise by 70% in sub-Saharan Africa and other developing
29 world to cope with food demand (IFPRI, 2017). However, Smallholder farmers are central to this
30 renewed emphasis on world food demand. Smallholder farmers are the main producers of the
31 global food demand and they account for between 60 to 80 percent of the food produced in the

32 developing nations (IFAD, 2018). There are more than 570 million smallholder farmers globally
33 cultivating about 75% of the world agricultural land (FAO, 2016). Of the two-thirds of sub-
34 Saharan Africa's population that resides in the rural areas, majority can be regarded as
35 smallholder farmers (Dixon *et al.*, 2004). Nigeria is predominantly an agrarian economy,
36 engaging about two-thirds of the country's workforce (Phillip *et al.*, 2009). In 2018, agricultural
37 sector contributed 25.13% to real GDP (NBS, 2019). Nonetheless, the Nigerian agriculture is
38 still at subsistence level, with low productivity and poor return on investment as farm activities is
39 majorly in the hand of small holder farmers (FGN, 2008). In smallholder agriculture, farmers are
40 presumed to be concerned with maximization of some measure of achievement such as
41 sustainable food for the family throughout the year, increase in income and ensuring minimum
42 resource usage (FAO, 2018).

43 In general life, we all have finite resources and time but we always want to make the most of
44 them optimally. In this manner, Smallholder farmers are usually confronted with these
45 challenges of how to allocate scarce production resources for optimal cropping activities that
46 maximize their objectives such as food security for the family, steady flow of income and
47 efficient resource usage among others (Majeke *et al.*, 2013). Smallholder farmers also do not
48 only produce different crops but also have to choose among the varieties of ways of producing
49 them as resources are finite. Traditionally, such decisions are usually influenced by farmers'
50 experiences, instincts and neighborhood comparison (Hazell and Norton, 1986). However
51 instincts and experience do not always guarantee optimal results (Mohamad and Said, 2011).

52 In developing countries like Nigeria the situation is even more where basic farm resource like
53 land is being lost to modern developmental projects, exploration excesses and lately security
54 challenges in Northern and other parts of Nigeria, hence, the need to increase production of crops

55 per unit area through proper resource utilization (Sofi *et al.*, 2015). The aforementioned
56 challenge is one of the emphasis as to why the application of crop modeling enterprise is
57 becoming significant in smallholder farming systems (Bharwani *et al.*, 2015). Of particular
58 interest is the Northern States of Nigeria, where an inheritance land tenured system is intensely
59 practiced and farmland as the major agric resource is seriously fragmented into smaller
60 individual farm sizes resulting in persistent food crises from declining crop productivity. Hence,
61 farmland optimization is therefore one way forward.

62 Cropping plan decisions are the basic land-use decisions in farming systems and consist of at
63 least, the choice of crops to be grown, their acreage and their resource allocation within a
64 particular farmland (Nevo *et al.*, 1994). These decisions mostly take place at the farm level and
65 are usually part of the global technical management of farm production (Aubry *et al.*, 1998).
66 Linear programming (LP) is one of the most important tools that can be used for farm planning
67 and decision making particularly in farming practice of raising more than one crop on the same
68 land at the same time known as mixed cropping (Igwe *et al.*, 2013). Optimized agricultural
69 planning is an essential activity in business profitability because it can increase the income from
70 an operation with low additional costs (Scarpari and Beauclair, 2010).

71 Various approaches have been scientifically used in diverse studies that involved analysis of
72 cropping decision patterns in many countries over a period of time. Nevertheless, of all
73 optimization techniques available (e.g. Linear Programming (LP), Dynamic Programming (DP)
74 and Genetic Algorithm etc), it is LP that is more popular because of the proportionate
75 characteristics of the allocation problems (Sofi *et al.*, 2015). Linear programming technique is a
76 scientific and mathematical tool considered as suitable for farm planning due to its simplicity and

77 practical applicability to resource allocation planning for the purpose of optimal solutions (Lawal
78 *et al.*, 2015)

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

85 This study applied linear programming which was not common among smallholder farmers and
86 specifically in the study area to be able to know the best crop enterprise combination that will be
87 promoted and equally help the farmers diversify their production, assist in efficient resource use,
88 ensure consistency in revenue generation and also take care of the vagaries of weather. Linear
89 programming (LP), when applied to farm planning represents a systematic approach of
90 determining mathematically the optimum plan for the selection and combination of farm
91 enterprises, in order to maximize income and/or minimize costs within the limits of available
92 farm resources (Yang, 1995). Although most farming activities in the study area are done on
93 small scale, farmers generally, rarely specialize along individual crop without a relative
94 combination of more than one enterprise. Hence, the use of linear programming (LP) as a
95 scientific tool for farm planning and resource allocation in determining optimal crop mix
96 decision among smallholder farmers was the objective of this study.

97 Although there are many ways to define smallholder farmers, the FAO's criterion of plot size is
98 widely accepted, with 'smallholder farmers' are being farmers who own or farm plots of 2
99 hectares or less (IFPRI, 2007). While for the purposes of this report this definition covers mainly

100 crop growers producing both cereal and horticultural crops, generally it will also mean to include
101 small-scale, family-run livestock farms as well as pastoralists, fishermen and forest dwellers.

102 **Materials and Methods**

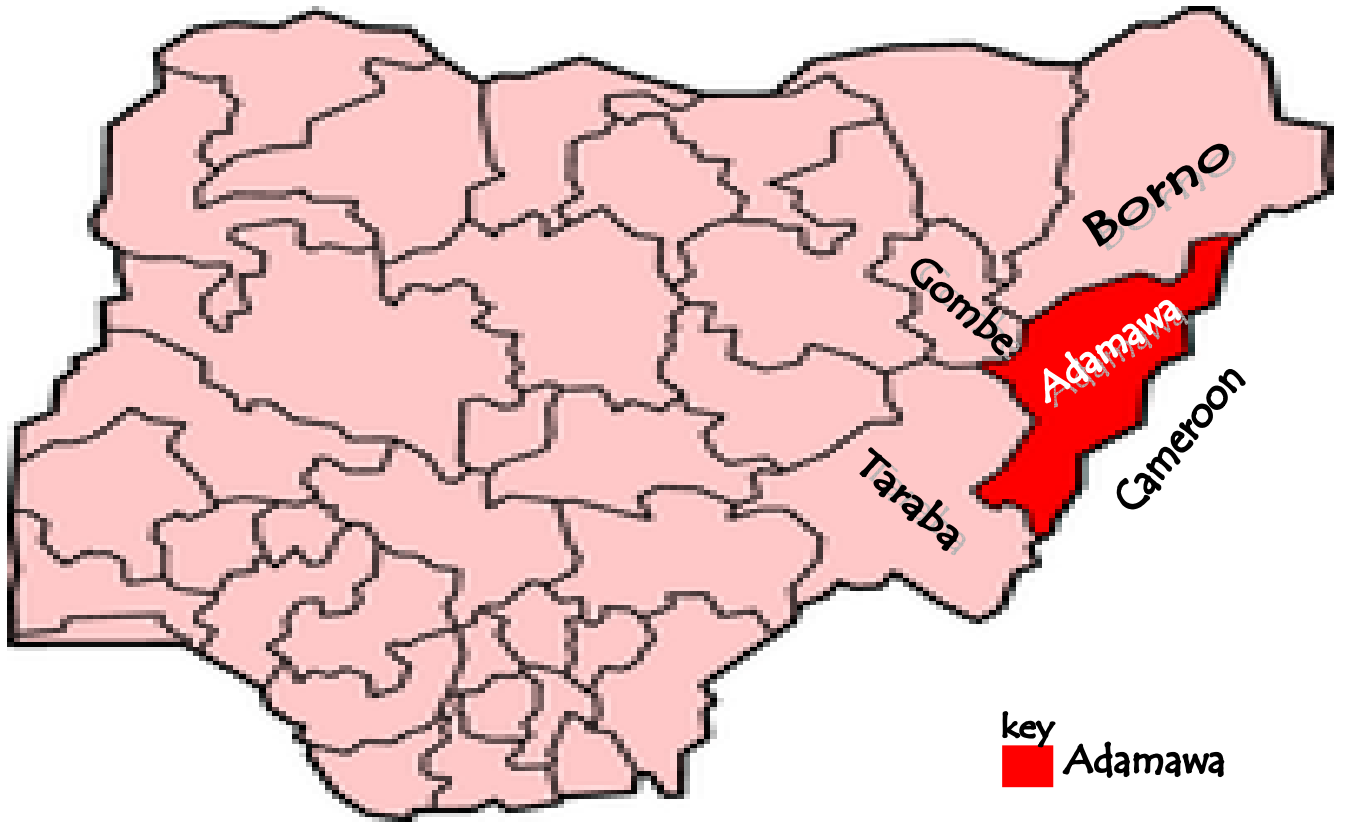
103 **The study area**

104 The research was carried out in Michika and Mubi South Local Government Areas (LGAs) in
105 Zone four (Mubi zone) of the Agricultural Development Programme of Adamawa State, Nigeria.
106 The State has twenty one (21) LGAs that have been divided into four agricultural zones. Zone
107 four comprises of Michika, Madagali, Mubi North, Mubi South and Maiha LGAs (5 of the 21
108 LGAs in the state). This zone has a land area of 4,728.77 km² (Adebayo, 2004). Mubi zone lies
109 between latitude 9°30¹N-11°N and longitude 13°E – 13°45¹E (Google Map data, 2017). The
110 zone has a population of 681,353 people based on (NPC, 2006). However, the estimated
111 population for 2018 is 1,221,287 people obtained by applying an annual growth rate of 3% as
112 provided by the NPC using 2006 population as the base figure. The Zone falls within the tropical
113 climate with distinct wet and dry seasons and the mean annual rainfall is about 1100mm.
114 Agriculture is the major occupation of about 80% of the inhabitants of the zone and the major
115 crops grown in the area includes; sorghum, maize, millet, rice, groundnut, beans, bambara nuts,
116 pepper, sugar cane (Jongur, 2005).

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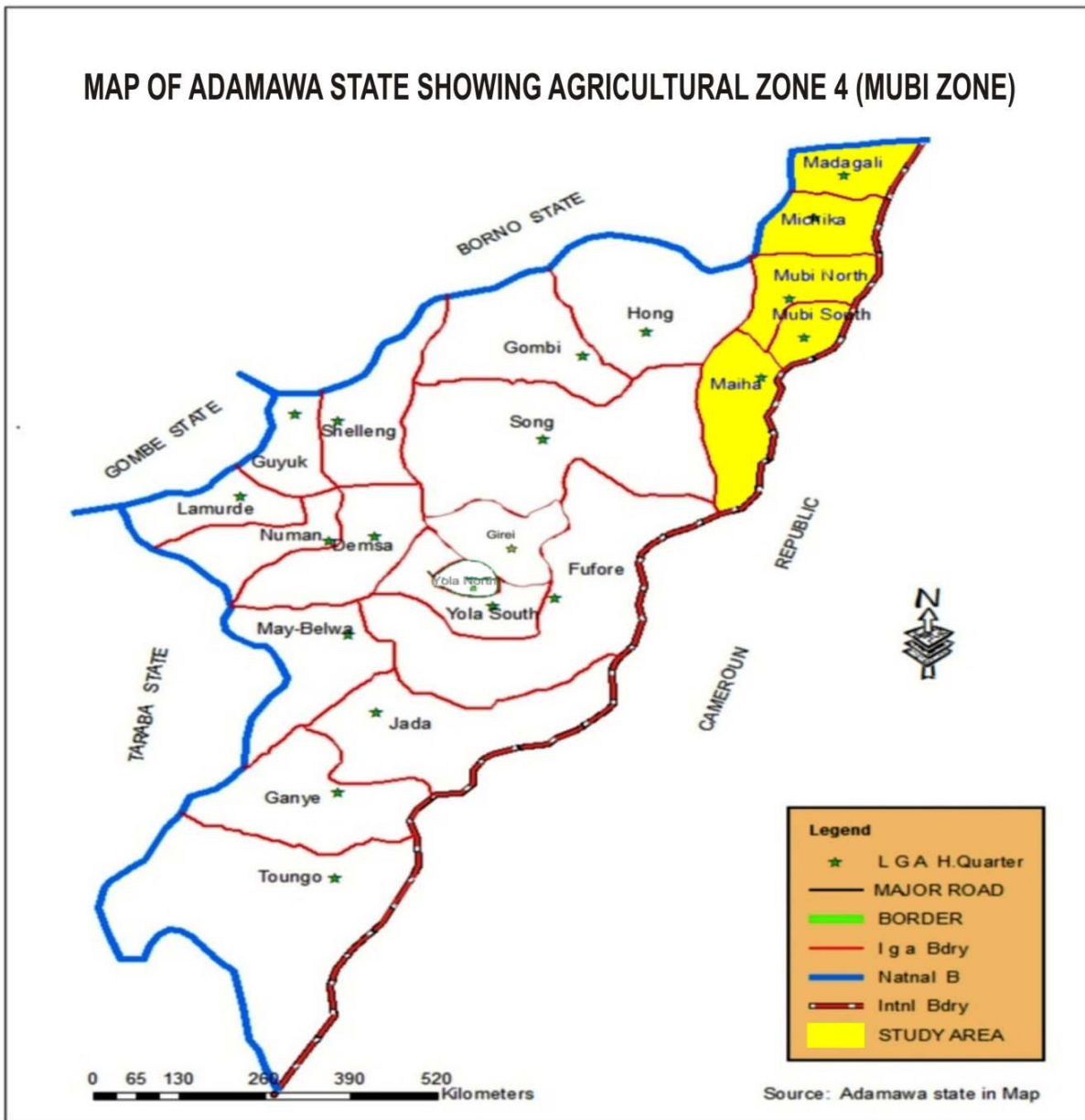


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121 **Fig 1.0: Map of Nigeria Showing Adamawa State**

122 **Source: Google map 2018**

UNDER



123 **Fig 2.0: Map of Adamawa State showing agricultural zone 4**

124 **Source: Google map 2018**

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129 Multistage sampling approach was used to sample 120 small holder farmers in the study area.
130 This involved the purposive selection of two (2) out of the five local government areas in the
131 zone, followed with a purposive selection of five (5) farming communities from each LGA and
132 lastly, a total of 120 smallholder famers as sample size was proportionately taken through simple
133 random selection of the respondents for this study. Primary data were used for the purpose of this
134 study generated through the use of structured questionnaire that were administered to small
135 holder farmers for 2017/18 cropping season. Twenty cropping enterprises were identified in the
136 existing plan from which six were observed to be popular based on relative frequencies. The
137 popular enterprises were made up of two major sole cropping and four mix cropping activities.
138 The six most popular enterprises from the sample were Maize and Beans, Maize and Groundnut,
139 Groundnut and Sorghum, Maize and Sorghum, Sole Maize and Sole groundnut.

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

142 **Data analysis and tools**

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

149 **Specification of Linear Programming model**

150 The activities in the models were grouped into sole cropping or mix-cropping activities (crop
151 production), cost of inputs activities and output sales activities. For each of the crop production

152 activities, the unit of activity is one hectare. The price coefficient ‘‘Cj’’ of a production activity
153 in the model is the gross margin per hectare.

154 The LP maximization problem may be illustrated as:

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

156 Subject to: $\sum_{j=1}^n a_{ij} X_j \leq B_i$, $i=1,2,\dots,k$ resources.

157 $X_j \geq 0$, $j=1,2,\dots,n$

158 Where:

159 Z = Total gross margin from all crops

160 n = the number of crops

161 C_j = gross margin from j th enterprise

162 X_j = the area under j th enterprise

163 B_i = maximum level of resource i available

164 a_{ij} = requirement for resource i by enterprise j

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

167 Max TGM = $C_1 X_1 + C_2 X_2 + C_3 X_3 + C_4 X_4 + \dots + C_n X_n$

168 Subject to:

169 $a_1x_1+a_2x_2+a_3x_3+a_4x_4+a_5x_5 +-----+a_nx_n \leq B_i , i=1,2...K$

170 Where all variables are as previously defined

171 $x_1 \geq 0, x_2 \geq 0, x_3 \geq 0, x_4 \geq 0, x_5 \geq 0,-----x_n =$ non negativity constraints.

172 **RESULTS AND DISCUSSION**

173 **Frequencies of farmers based on cropping enterprise (Enterprise decisions)**

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

177 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

178 Source: Field survey (2018)

180

181

182 **Optimal activity levels in the final plan using observed maximum resource levels**183 **Table 2: Implemented basic LP data that shows resource utilization and the gross margin**
184 **of selected enterprise**

185

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

186 Source: Field survey (2018)

187

188 Table 3 shows the optimal farm plan at observed maximum resource levels. As shown, only
189 groundnut/sorghum enterprise was admitted in the final plan, and to be produced at 2 hectares.190 The associated total gross margin, which is the measure of profitability in this study, is ₦478,
191 380. The result suggests that the recommended enterprise or best crop combination that entered
192 the model was groundnut/sorghum when cultivated at the maximum resource of 2ha of land and
193 will generate ₦478, 380 as profit to the smallholder farmer in the area.

194

195 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	478,380
Maize & G/Nut	(X ₂)	0	
G/Nut & Sorghum	(X ₃)	2	
Maize & Sorghum	(X ₄)	0	
Sole Maize	(X ₅)	0	
Sole G/Nut	(X ₆)	0	

196 Source: LP result of field survey (2018)

197

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

204 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

205 Source: LP result of field survey (2018)

206

207 Table 5 shows the optimal farm plan at observed average resource levels. As shown, three
 208 enterprises, groundnut/sorghum, maize/sorghum and sole maize were admitted in the final plan,
 209 0.45ha, 0,21ha and 0.17 ha, respectively. The associated total gross margin was ₦153,003.99.
 210 This is lower than obtained at maximum resource levels, suggesting that resource restrictions
 211 will always lower the final profit. From this optimal farm plan at observed average resource
 212 levels, the average farmer or farmer with an average land size of 0.8ha should allocate his
 213 resources in a manner that 3 crop enterprises shown in table 5 should be cultivated according to
 214 specification. The recommended enterprises accepted in the model were Groundnut/Sorghum at
 215 0.45ha, Maize/Sorghum at 0.21ha and sole Maize at 0.17ha with a gross margin of ₦153, 003.99

216 Table 5: Optimal activity levels in the final plan using observed average or near-average resource levels
 217

Enterprise		Optimum level (ha)	Total Gross Margin (₦)
Maize & Beans	(X ₁)	0	153,003.99
Maize & G/Nut	(X ₂)	0	
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	

218 Source: LP result of field survey (2018)
 219

220 **Table 6** shows the sensitivity analysis associated with the observed average resource levels in
 221 the survey. Unlike the results obtained at maximum resource levels, land is no longer binding or
 222 restraining in the present plan. However, SSP, Urea and Laraforce are now binding because they
 223 were fully used in the final plan. Specifically, extra units of SSP, Urea and Laraforce as farm
 224 inputs will add ₦14,643.88 kobo, ₦5,469.11 kobo and ₦1,414.27 kobo to the total gross margin,
 225 respectively. This implies that using an additional unit of SSP, Urea or Laraforce as farm inputs
 226 by an average smallholder farmer in the study area will add ₦14, 643.88k, ₦5, 469.11k and ₦1,

227 414.27k respectively to the total gross margin, again only at the observed average or near
 228 average resource level.

229 Table 6: Optimal resource levels in the final plan using observed average or near-average
 230 resource levels

Name	Used	Slack (unused)	Status	Shadow price (Naira)
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

231 Source: LP result of field survey (2018)

232 Conclusion

233 The result of the study revealed that mixed cropping decisions yields higher revenue and provide
 234 for efficient use of farm resources per ha compared to sole cropping activities. A total of twenty
 235 (20) enterprises were identified, out of which fifteen (15) were mix cropping and five (5) were
 236 sole cropping activities. Six popular enterprises were identified to be common among the
 237 smallholder farmers in the area. However, in the observed maximum resource only
 238 groundnut/sorghum enterprise was admitted in the final plan, and to be produced at 2 hectares.
 239 The associated total gross margin, which is the measure of profitability in this study, is ₦478,
 240 380. Resource allocations in the final plan were also different from that of the existing plan. In
 241 the final plan on the observed maximum resources, only land was fully used hence a limiting

242 factor, suggesting that an extra one hectare will add ₦239, 190 to the total gross margin. In the
243 optimal farm plan at observed average resource level, three enterprises; groundnut/sorghum,
244 maize/sorghum and sole maize were admitted in the final plan, 0.45 ha, 0.21 ha and 0.17 ha,
245 respectively. The associated total gross margin was estimated at ₦153, 004. This is lower than
246 obtained at maximum resource levels, suggesting that resource restrictions will always lower the
247 final profit. Conclusively the research indicated that the resource allocation pattern in the
248 optimum plan were significantly different from that in the existing plan. The optimum gross
249 margin shows sensitivity to increase in land. The study recommended that the optimum
250 enterprises and resources combination obtained in the Linear Programming output should be
251 extended to the farmers to enhance their profit level, and government policies be geared towards
252 addressing the provision of accessible credit facilities and subsidizing farm inputs. Also, the LP
253 optimal farm plan at observed average resource should be embraced by average land holding
254 farmers and specifically deploying resources in this regard. Finally the LP sensitivity analysis
255 associated with the observed; maximum and average resource levels which revealed binding
256 slack resources of zero value and non binding constraint with shadow price of zero be adhered to
257 by the farmers so as minimize wastages.

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