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RESEARCH NOTE

Optimizing Agroforestry Plantation in Los Baños, Laguna

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Agroforestry has been a necessary practice as a land management system to aid the growing pressure on the forestry land. To support the local farmers in the Learning Laboratory for Agroforestry in Los Baños, Laguna who practice this system, a linear programming model was constructed to maximize the profit while considering the land, labor hours, rotation age constraints, and the combination of crops. The crops used in this study were grouped into nitrogen and non-nitrogen fixers, and combinations of alternation of these crops were formulated while taking rotation ages into account. The maximum profit was calculated using the Linear Programming Solver or LiPS. The model allocated the total land area to the combination of cucumber, string beans, and tomato, as it was the most profitable. Results indicate that the second-best option was the combination of bitter gourd and string beans, as it had the second-smallest reduced cost. Also, the maximum profit increased by PHP 264.43 per square meter increase in the land area available. Hence, it is suggested that the local farmers must expand their land areas or increase the selling prices to obtain higher profits.

Keywords: agroforestry, crops, linear programming, optimization

Forests are one of the most important natural resources in the Philippines. They provide a wide range of services – supplication of food such as crops, livestock, and fish, as well as provision of recreational activities (Senate of the Philippines 2015). In 1934, it comprised 57% of the total land area (Senate of the Philippines 2015). Currently, it only covers 24.11% (Trading Economics 2020).

The decline in the forest area puts food security at risk. Due to soil erosion, nutrients are depleting resulting in a low crop yield. Additionally, the country's climatic conditions such as typhoons contribute to this alongside mass wasting and landslides (ESSC 2017) due to the absence of forest cover, leaving the farmers with little to no crops.

Water security is also at risk due to the decline in the forest area. Due to poorly managed watersheds, more than 57% of these are severely depleted, which results in loss in water infiltration. Water quality has gotten worse and cities such as Manila, Cebu, Davao, and Baguio experience water shortage consistently (ESSC 2017).

With this, it is important to have a land management system that is agroforestry. Agroforestry is the simultaneous or sequential integration of crops or animals with woody vegetation such as trees and shrubs in a land management unit. This integration is intended to broaden production systems to provide environmental, economic, and social benefits through complementary interactions between the system components (Brown *et al.* 2018).

Agroforestry also provides protection to soil, animals, crops, and homes from extreme weather. It can make the water quality better as well. Aside from these, this practice can help the local farmers by providing them opportunities to gain more profit and produce jobs while being

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sustainable and considering risks associated with price spikes or drops (USDA n/d) using linear programming.

Linear programming is a powerful tool for solving optimization problems, wherein both constraints and objective function must be linear and the variables are continuous. This has been proven in several studies. One of these is a study conducted by Mohammadi *et al.* (2016) in Iran, which used linear programming to maximize the net present value of different tree species subject to the available number of workers, land area, and cost constraints. Five tree species were used – namely, oak, elm, ash, maple, and bald cypress. These were grouped into two based on the soil type. Oak, elm, and bald cypress were in the first group, whereas ash and maple were in the second group. The model allocated the total land area to a single tree species in each group with the highest net present value, which were bald cypress and maple; hence, it is suggested to prioritize these trees when planting.

This study focuses on the agroforestry practices of the Learning Laboratory for Agroforestry (LLA), which is located within the Makiling Forest Reserve. It is handled by the Institute of Agroforestry (IAF) under the College of Forestry and Natural Resources of the University of the Philippines Los Baños (UPLB). After gathering data from the learning laboratory through interviews and file sharing, a data analysis was performed. The crops used were categorized into nitrogen fixers and non-nitrogen fixers to generate the possible combination of alternation of these. The prices and costs were also considered for the formulation of the model. Once the model is formulated, it is run in the Linear Programming Solver (LiPS) software. After getting the results, an interpretation was discussed to come up with recommendation.

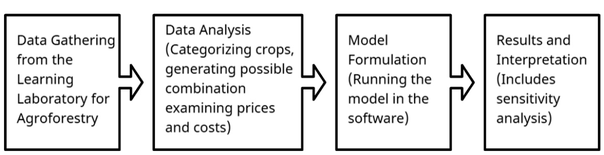

Figure 1. The general framework of the study.

The planted crops in the learning laboratory that were used in this study were classified into two groups – nitrogen-fixing and non-nitrogen-fixing crops. The planted nitrogen fixers were as follows: Baguio beans (*Phaseolus vulgaris*), string beans, and bush and pole *sitao* (*Vigna sesquipedalis* x *Vigna unguiculata*). The following are the non-nitrogen-fixers: bitter gourd (*Momordica charantia* L.), cucumber (*Cucumis sativus*), mung bean (*Vigna radiata*), squash (*Cucurbita maxima* L.), tomato (*Solanum lycopersicum*), and eggplant (*Solanum melongena* L.).

To formulate the model, linear programming was used. Linear programming is a tool for solving optimization problems, in which all relations among the variables are linear both in the constraints and the function to be optimized.

From the data collected in LLA, we had the following assumptions:

- The land area for sloping agricultural land technology or SALT 1 had five alleys. Computing the area of each alley, we had a total of 377.5 sq. m.
- In the model, all non-nitrogen-fixing crops will be planted first at the beginning of each cycle, which is every January. After the rotation age of each crop, nitrogen-fixing crops will be planted after land preparation. This pattern will be continued until the cycle, which is exactly 12 mo, is complete.
- The rotation age will be considered in the combinations of crops to be planted, as they have to be exactly 12 mo with the possible combinations of rotation age being 2-3-4-3, 3-3-3-3, 4-3-2-3, and 6-2-2-2. These combinations considered the alternation of nitrogen and non-nitrogen fixing crops.

The formulation of the linear programming model is given as follows.

Decision variables. Let x_{ijkl} be the area of land allocated for crops i, j, k, and l, where i and k are the indices for non-nitrogen-fixing crops, and j and l are the indices for nitrogen-fixing crops.

Objective function:

$$\text{Maximize } z = \sum_{i=1}^{6}\sum_{j=1}^{4}\sum_{k=1}^{6}\sum_{l=1}^{4} v_{ijkl}x_{ijkl} \quad (1)$$

where v_{ijkl} is the profit per square meter (sqm.) when crops i, j, k, and l are planted.

Land constraint:

$$\sum_{i=1}^{6}\sum_{j=1}^{4}\sum_{k=1}^{6}\sum_{l=1}^{4} x_{ijkl} \leq A \quad (2)$$

where A is the total land area available.

Labor hours constraint:

$$\sum_{i=1}^{6}\sum_{j=1}^{4}\sum_{k=1}^{6}\sum_{l=1}^{4} l_{ijkl}x_{ijkl} \leq L \quad (3)$$

where L is the total labor hours available in a year, and l_{ijkl} is the labor hours rendered per sqm. when crops i, j, k, and l are planted.

Rotation age constraint:

$$x_{ijkl} = 0 \tag{4}$$

if the sum of the rotation ages of i, j, k, and l do not complete a 12-mo cycle.

To solve this model, LiPS was used. It is a free software published by Components & Libraries list of programs – part of Development that can solve linear, mixed-integer, pure-integer, and goal programming. This software can run smoothly in a computer with a processor of Intel(R) Pentium(R) CPU N4200 @ 1.10GHz 1.10 GHz and can provide a solution in a few seconds.

This study considered the data provided by the LLA of the IAF at the UPLB. Other data used in this study are available on the official website of the Department of Agriculture. The crops, including the data needed based on the model, are given in Table 1.

Using LiPS as software to solve for the model, the optimal solution is to allocate the total land area with the highest net profit, which was x_{2252}.

By conducting the sensitivity analysis, we have the list of the reduced cost for each variable in Table 2.

The dual (or shadow) prices of labor time and land constraints are shown in Table 3. The dual price is the rate of change when the right-hand side of the constraint is either increased or decreased. This means that the maximum profit is affected by changes in the respective dual prices for each unit change on the right-hand side of each constraint. This may be used in planning if the local farmers want to produce more profit.

The total land area was allocated in x_{2252}. This means that following the rotation age, the total land area available must be planted – cucumber in January, string beans in March, tomato in June, and string beans in October – to produce a maximum profit. The model allocated the entire land area available to the most profitable combination of crops. Some combinations of crops were less profitable than the optimal solution, and some were not profitable, as they yielded negative net profit; hence, they were not allocated a single sqm.

This result was logical, as a study conducted by Mohammadi et al. (2016) used linear programming to maximize the net present value of different tree species subject to the available number of workers, land area, and cost constraints. The model allocated the total land area to a single tree species in each group with the highest net profit; hence, it is suggested to prioritize these trees when planting.

If constraints are added, the reduced cost is utilized to solve for the objective function value. For instance, there is a market demand that must be met. To satisfy this, each combination that completes a 12-mo cycle must include at least 1 sqm. of land. As a result, the model will satisfy its constraints first before allocating the remaining land area to the most profitable crop combination. To find the objective function value or the maximum profit, one must multiply the reduced cost by the number of sqm. assigned to that variable, then subtract it from the original objective function value.

The reduced cost can also be used to determine the model's second-best solution. Crop seeds are not always available on the market. The smallest reduced cost is considered to be the best choice for yielding the most profit based on the available seeds. In this case, the second-best solution is allocating the land area to x_{1212}, which means planting bitter gourd in January and July and Baguio beans in April

Table 1. The crops and the data used for the model.

	Crops	Gross price (PHP/sqm.)	Cost (PHP/sqm.)	Labor hours (h/sqm.)	Rotation age (mo)
	Nitrogen fixers				
1	Baguio beans	26.40	23.18	0.085	3
2	String beans	95.00	23.18	0.085	3
3	Bush *sitao*	10.20	18.87	0.057	2
4	Pole *sitao*	10.20	17.28	0.068	2
	Non-nitrogen fixers				
1	Bitter gourd	64.00	24.57	0.102	3
2	Cucumber	77.00	17.28	0.068	2
3	Mung bean	2.56	25.90	0.085	3
4	Squash	30.00	32.48	0.200	4
5	Tomato	94.00	31.85	0.136	4
6	Eggplant	79.00	60.65	0.429	6

Table 2. Reduced cost of each variable that completes a 12-mo cycle.

	Sequence	Net prices	Reduced cost
1	1 1 1 1	85.31	179.12
2	1 1 1 2	153.91	110.52
3	1 1 3 1	22.53	241.9
4	1 1 3 2	91.13	173.3
5	1 1 4 3	31.51	232.92
6	1 1 4 4	33.09	231.34
7	1 1 5 3	95.05	169.38
8	1 1 5 4	96.64	167.79
9	1 2 1 1	153.91	110.52
10	1 2 1 2	222.51	41.92
11	1 2 3 1	91.13	173.3
12	1 2 3 2	159.73	104.7
13	1 2 4 3	100.11	164.32
14	1 2 4 4	101.69	162.74
15	1 2 5 3	163.65	100.78
16	1 2 5 4	165.24	99.19
17	1 3 4 1	31.51	232.92
18	1 3 4 2	100.11	164.32
19	1 3 5 1	95.05	169.38
20	1 3 5 2	163.65	100.78
21	1 4 4 1	33.09	231.34
22	1 4 4 2	101.69	162.74
23	1 4 5 1	96.64	167.79
24	1 4 5 2	165.24	99.19
25	2 1 4 1	63.68	200.75
26	2 1 4 2	132.28	132.15
27	2 1 5 1	127.23	137.2
28	2 1 5 2	195.83	68.6
29	2 2 4 1	132.28	132.15
30	2 2 4 2	200.88	63.55
31	2 2 5 1	195.83	68.6
32	2 2 5 2	264.43	0
33	2 3 6 3	60.72	203.71
34	2 3 6 4	62.31	202.12
35	2 4 6 3	62.31	202.12
36	2 4 6 4	63.89	200.54
37	3 1 1 1	22.53	241.9
38	3 1 1 2	91.13	173.3
39	3 1 3 1	-40.25	304.68
40	3 1 3 2	28.35	236.08
41	3 1 4 3	-31.27	295.7
42	3 1 4 4	-29.69	294.12
43	3 1 5 3	32.27	232.16
44	3 1 5 4	33.86	230.57
45	3 2 1 1	91.13	173.3
46	3 2 1 2	159.73	104.7
47	3 2 3 1	28.35	236.08
48	3 2 3 2	96.95	167.48
49	3 2 4 3	37.33	227.1
50	3 2 4 4	38.91	225.52
51	3 2 5 3	100.87	163.56
52	3 2 5 4	102.46	161.97
53	3 3 4 1	-31.27	295.7
54	3 3 4 2	37.33	227.1
55	3 3 5 1	32.27	232.16
56	3 3 5 2	100.87	163.56
57	3 4 4 1	-29.69	294.12
58	3 4 4 2	38.91	225.52
59	3 4 5 1	33.86	230.57
60	3 4 5 2	102.46	161.97
61	4 1 1 3	31.51	232.92
62	4 1 1 4	33.09	231.34
63	4 1 2 1	63.68	200.75
64	4 1 2 2	132.28	132.15
65	4 1 3 3	-31.27	295.7
66	4 1 3 4	-29.69	294.12
67	4 2 1 3	100.11	164.32
68	4 2 1 4	101.69	162.74
69	4 2 2 1	132.28	132.15
70	4 2 2 2	200.88	63.55
71	4 2 3 3	37.33	227.1
72	4 2 3 4	38.91	225.52
73	4 3 1 1	31.51	232.92
74	4 3 1 2	100.11	164.32
75	4 3 3 1	-31.27	295.7
76	4 3 3 2	37.33	227.1
77	4 3 4 3	-22.30	286.73
78	4 3 4 4	-20.71	285.14
79	4 3 5 3	41.25	223.18
80	4 3 5 4	42.83	221.6
81	4 4 1 1	33.09	231.34
82	4 4 1 2	101.69	162.74
83	4 4 3 1	-29.69	294.12
84	4 4 3 2	38.91	225.52
85	4 4 4 3	-20.71	285.14
86	4 4 4 4	-19.13	283.56

Table 2. Cont.

87	4 4 5 3	42.83	221.6
88	4 4 5 4	44.42	220.01
89	5 1 1 3	95.05	169.38
90	5 1 1 4	96.64	167.79
91	5 1 2 1	127.23	137.2
92	5 1 2 2	195.83	68.6
93	5 1 3 3	32.27	232.16
94	5 1 3 4	33.86	230.57
95	5 2 1 3	163.65	100.78
96	5 2 1 4	165.24	99.19
97	5 2 2 1	195.83	68.6
98	5 2 2 2	264.43	0
99	5 2 3 3	100.87	163.56
100	5 2 3 4	102.46	161.97
101	5 3 1 1	95.05	169.38
102	5 3 1 2	163.65	100.78
103	5 3 3 1	32.27	232.16
104	5 3 3 2	100.87	163.56
105	5 3 4 3	41.25	223.18
106	5 3 4 4	42.83	221.6
107	5 3 5 3	104.79	159.64
108	5 3 5 4	106.38	158.05
109	5 4 1 1	96.64	167.79
110	5 4 1 2	165.24	99.19
111	5 4 3 1	33.86	230.57
112	5 4 3 2	102.46	161.87
113	5 4 4 3	42.83	221.6
114	5 4 4 4	44.42	220.01
115	5 4 5 3	106.38	158.05
116	5 4 5 4	107.96	156.47
117	6 3 2 3	60.72	203.71
118	6 3 2 4	62.31	202.12
119	6 4 2 3	62.31	202.12
120	6 4 2 4	63.89	200.54

Table 3. The dual prices of each constraint.

Constraint	Dual price
Labor time	0
Land	264.43

and October. Notice that x_{5222} had a zero reduced cost, but this cannot be considered as the second-best solution if the problem is the availability of the seeds, as it is just the same as the optimal solution; the schedule for planting cucumber and tomato were just swapped.

For the dual prices, the objective function value will not change regardless of whether the labor hours available are increased or decreased. The objective function value, on the other hand, increased by PHP 264.43 for every sqm. increase in total land area available. This means that the model predicts that the higher the available land area for allocation, the greater the maximum profit.

Among the crops utilized in this study, the combination of cucumber, string beans, and tomato proved to be the plantation's priority, mostly because it was the most profitable. It had the highest expected profit because of its high gross prices. This solution, however, may change due to market price variations driven by product exportation and importation, as well as politics. In the long run, labor hours and crop maintenance expenses may also vary as technology and processes improve, making it easier for local farmers to execute their jobs.

Market demands must be met, and to meet these expectations, constraints are added to which the model results in a smaller optimal solution. Results revealed that it is recommended for the less profitable crops' gross prices to be raised. Since certain crops yielded negative net pricing, the cost must be considered in this suggestion.

To further benefit the local farmers in this study, it is recommended to consider seasonal crops, as well as long-term crops, which are not included in this paper. Given the geological setting, these crops may require additional constraints to be considered and may aid the profit increase by the farmers. Also, timber products may be included to help in reviving the wood industry.

The findings from this study will aid IAF's LLA and other agroforestry farmers in determining which crops to plant and when to plant them. The available land area, labor hours, and cost were all analyzed. This study also encourages agroforestry, which benefits both the residents and the environment.

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