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Application of Mixed Integer Linear Programming Approach on Crop Rotation Practices in Organic Farms in Central Luzon and Calabarzon, Philippines

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Abstract. The primary objective and purpose of agriculture is to sustain society. With this is mind, two farming concepts have emerged with different methods and systems in complying with the industry's objective. Organic farming, the less practiced between the two, is more fitting to uphold the sustenance of society in a healthier and long term span. Crop rotation scheduling, the required method in organic farming has always been done manually with no established basis. The aim of this study is to maximize the efficiency of organic farming in the second and third highest agricultural land area in the Philippines. Thus, a decision making tool is utilized to be applied to simple crop rotation practices in the industry. This tool takes into consideration several variables in organic farming. Best-selling and top produce in the areas are used with the corresponding profit organic farms may obtain with planting them. Constraints are generally stated to fit a realistic situation in farms, neglecting too complex variables to maintain simplicity and uniformity. Generation of a crop rotation schedule has been successful, showing which crops to be planted, how many, and in what period to be planted in the span of twelve (12) months, including the fallow. However, we suggest that further study and tests must be conducted using more powerful and complex analytic tools with consideration of specific variables and constraints applicable to different settings to generate more accurate crop rotation schedules.

1. Introduction

Agriculture is a system that was established to provide sustenance in a society. It was derived from the ancient system of hunters and gatherers where the first humans. were known to get food as they needed it [1]. Now, the concept of hunting and gathering for food has evolved to raising farm animals and growing crops. Come Industrial Age, many aspects and industries turned to technology and mechanization. Agriculture, notwithstanding its traditional nature, also joined the transition to industrialization, paving way for what we call conventional or industrial farming [2].

As indicative of its nature, conventional farming is mostly used by large-scale farms that support corporations mostly ones that deal with food because of the general recognition that they can provide large amounts of crops intensively [3]. Most corporations also specialize in specific products that use a few or less ingredients making the farms that support them be more inclined to grow crops on their fields with not much variety.

Other farms opt out of the practices of conventional farming and instead try to get accredited for organic farming [4]. These farms are usually smaller than conventional ones and are supported by agricultural cooperatives and non-governmental organizations because unlike its counterpart, organic farms focus on sustainability and have been known to have lower yield [5].

Conventional farming is commonly known for its tendency to be largely scaled farms that use chemical inputs like pesticides, herbicides, and fertilizers, have high efficiency and high intensive productivity, have popularized the use of mono-cropping, and have been supported by the rapid innovation of technology [6]. In contrast, organic farming is characterized by smaller farms that locally produce its inputs, frowning at the use of chemically based ones, are extensive in nature, have lower yield, use crop rotation due to its diversity, and have been supported by integrated knowledge centered on avoiding harm towards the people and the environment [7].

Although many studies have indicated that organic farming has lower yield than conventional farming, there have been studies that come up with organic farming having higher yield than conventional because of the environment in which the farms are in. As an example, Te Pas and Rees [8] analyzed the difference in yield between organic and conventional farming in the tropics and sub-tropics, arriving with results of organic farming yield achieving a 26% higher difference on average on least developed and generally dry lands. In addition to this, studies are conducted to figuring out how to minimize the yield gap between conventional and organic farming in favor of the latter [9]. There are two main objectives of organic farming in general: to protect the environment and to protect the health of consumers [10].Indeed, these objectives have been the flair of organic farming and its niche in the market.

In the Philippines, with its generally tropical climate and lush forests, organic farming is not an entirely new concept. Organic farming in the country showed to have higher capital-output and land-output ratio compared to its conventional counterpart [11,12] . In a study by Sajadian et al. (2017), they quantified indicators of organic farming in terms of relative importance in its own development. Results show that of six concluded important indicators, yield is top two with a weight of 0.098, behind pest management of weight 0.16 [13].Therefore, improving the yield is important in the development of organic farming in the country. As one of the main differences of organic and conventional farming, crop rotation best defines the system in of itself. The study by Ponisio et al. [9] showed results that multi-cropping and crop rotation, when applied in organic farming, substantially decreased the yield gap between the organic and conventional farming data that they have and it was suggested integrating Operations Research into crop rotation practices as ideal bridge for Filipino organic farmers to consider innovation in their methods and give organic farming another niche in its race with conventional farming. Mixed integer linear programming was used by two studies: first in the selection of crops [14] and second for the rest of the production decisions to be made by the farmers [15]. The crop selection study by Filippi et al. [14] came up with two models: crop selection problem (CSP) as the first model, and the second being denoted by CSP(β). You and Hsieh's [15] two-phase approach is more relevant to what the proponents want to accomplish. In their study, they have come up with an approach that, aside from the main factors that previous models have used, considers the fact that reaped crops are harvested multiple times which can concur inventory holding costs.

Thus, the aim of this study is to maximize the efficiency of organic farming in the second and third highest agricultural land area in the Philippines. Thus, a decision making tool is utilized to be applied to simple crop rotation practices in the industry. This tool takes into consideration several variables in organic farming. Operation Research Tool Mixed Integer Linear Programming (MILP) was applied in this work for crop rotation practices on a theoretical case study.

2. Methodology

2.1. Research Design
In this case, a Case Study Research Design is used in order to narrow down a wide scope into components applicable only to the study. The MILP model will be formulated based on the common constraints from the organic farms visited by the researchers. The model will generate an appropriate and realistic crop rotation schedule to be applied on the farm, which will result to either a positive or negative impact on organic farm practices. Since there are no known studies similar to this applied in the Philippines, the researchers will rely mostly on existing models applied in similar settings with the study, which will add validity to the new model. It is the application of combined theories and new concepts to be proven useful in the practice and methods of organic farming in Luzon.

2.2. Subjects and Study site
The study considered the 2nd and 3rd regions with the largest agricultural land area in Luzon, Philippines which are Calabarzon (Region IV-A) and Central Luzon (Region III) respectively. The researchers reached out to nine organic farms in the areas and were able to visit and personally interview the management of three farms: one in Central Luzon, and two in Calabarzon. Specifically, these farms were Melendres Farm of Antipolo City in Rizal, Gourmet Farms of Silang in Cavite, and Prado Farms of Lubao in Pampanga.

The interviews consisted of a trip around the facilities of the farms while processes and practices were explained. The interview questions consisted of 22 items as the base questions and other inquiries from the researchers based on their personal observations were also made. The interviewees who participated from each farm were: Ms. Lisney Dela Cruz, Farm Administrator of Melendres Farm, Mr. Jayson Niño Cabagon, Operations Manager of Gourmet Farms, and Mr. --, Farm Supervisor of Prado Farms.

2.3. Data Measure
For the Mixed Integer Linear Programming Model, the researchers considered the following situation: A Filipino organic producer in Calabarzon, Philippines is planning to optimize one of his poly houses' yield by making a crop rotation schedule of time length L divided equally into T planning periods. He has a pool of B botanic families, where F(s) is the number of crops belonging in family S. Crops have their own price (P), production cost (C), and production time (R). The producer is also limited to the following constraints: 1. Rotation constraint – crops of the same botanical family should not be planted in sequence. 2. Fallow requirement – a moment of fallow must be established in each rotation. Thus, the notation in Table 1 was used in establishing the model. In translating the model and coding it into Excel, the following data measures shown in Table 2 were established.

Table 1. Notations and decision variable used in establishing the model

Notation	Descirption
□	Number of planning periods in each crop rotation (of predefined length L), e.g. □=12 months; □=1□□□□
□	Set of crops for planting, e.g. □ = {□□□□□□□,□□□□□□□□,□□□□□□□□}
h	Hypothetical crop for fallow K+1
□	Number of botanic families
□(□)	Set of crops that belong to botanic family s, s = 1…B
□□	Number of periods for production of crop □ _from soil preparation to harvesting
□□	Production cost of crop □ _per batch, i.e. in this case, seed costs
□□	Price of crop □ per batch

□□□	Set to 1 if crop □ is to be planted on period □, otherwise, 0

Table 2. Data Measure

Parameter	Unit of Measurement	Source
Crop price	Peso/kg	Interviews
Production length	Period	Interviews
Seed cost	Peso/10g	Interviews and research

2.4. Mode of Data Analysis

In this portion, the data gathered from related literature and organic farm interviews will be analyzed to help the researchers decide on the operations research tool to be used for the generation of a more efficient model for crop rotation scheduling in the Philippine setting. In this case, the operations research tool used is the Mixed Integer Linear Programming, commonly known as MILP. Using this tool will take into consideration the variables (controlled and uncontrolled), and constraints applicable in the Philippines that may have been overlooked from previous studies. Making use of this tool will help determine whether the solutions generated are feasible or optimal.

3. Result and Discussion

The first sub-objective of the group is to generate a realistic case related to the actual farms' current situation and with the information gathered from reviewed literatures. Hence, the group was able to generate the problem indicated in the data measure. In this problem, the proponents assumed the following, The crop rotation schedule is in an annual layout (one year long) and divided into twelve (12) equal periods, The fallow period was set to one (1) month, The listed crops are the crops that the farm aims to plant with respect to the profit that the farm may gain and not because of a specific client's demand, On the first year of crop rotation, the farm bought 10 grams worth of seeds in full price, Electric and water costs are negligible since it would be uniform regardless of what crop the schedule would indicate to plant.

The group's next sub-objectives was to see the applicability of the chosen tool to the crop rotation practices; in terms of mathematical formulation (using the OR tool MILP) and MS Excel translation (for the generation of the schedule). In terms of the OR formulation, as shown in the previous section of the study, the proponents were able to formulate the model using the chosen OR tool. However, with the group's first few attempts in translating it to excel and using the inclusive solver, it failed to read and solve the problem as it is too complex for its reach.

The group had several attempts in solving the model. The first one had seven hundred sixty-eight (768) variables which was too many for the excel solver to handle. The second attempt had two hundred and four (204) variables, however, the formula used for the constraints were faulty and had resulted to only ninety percent (90%) successful. On the third attempt, with the same number of variables with the second attempt and revised formulas, the group was able to generate a proper and feasible solution for the model thus, meeting the proponents' second and third sub-objective. Figure 1 shows the input used in the model. Figure 2 shows the optimal solution from the model and Figure 3 shows generated sequence for the first crop rotation. Based on Figure 2 and figure 3, The schedule generated above shows that the farm should plant lettuce romaine for six (6) times for that year, and five (5) periods should be allocated for the Taiwanese pechay, and to leave one (1) month of fallow for the period six (6). The generated solution reflected reality since these two are some of the top or best-selling produce in all the farms visited by the group, especially the romaine lettuce – a product of high demand in organic farms. See appendix for further details on the problem and solution. With this, the proponents were able to come up with a feasible solution and a step of innovation to the current heavily manual practices of crop rotation in the organic farms of the selected areas of the study.

Crop	Srp	Production time	F(s)	Cost
Carrots	260	3	1	18
Lettuce Romaine	520	1	2	154
Broccoli	490	2	3	680
Cabbage	220	2	3	210
Cauliflower	600	2	3	440
Pechay Native	300	1	3	7.2
Taiwan Pechay	340	1	3	7.5
Camote Tops	210	4	4	20
Ampalaya Special	326	2	5	49
Cucumber	265	1	5	36.5
Upo	175	3	5	7
French Beans	500	3	6	11.75
Green Bell Pepper	575	3	7	52
Tomato	380	3	8	66
Cherry Tomato	650	4	8	70
Fallow	0	1	x	

Figure 1. Inputs used on model

Crop/Period	1	2	3	4	5	6	7	8	9	10	11	12	13	
Carrots	0	0	0	0	0	0	0	0	0	0	0	0		0
Lettuce Romaine	1	0	1	0	1	0	1	0	1	0	1	0		6
Broccoli	0	0	0	0	0	0	0	0	0	0	0	0		0
Cabbage	0	0	0	0	0	0	0	0	0	0	0	0		0
Cauliflower	0	0	0	0	0	0	0	0	0	0	0	0		0
Pechay Native	0	0	0	0	0	0	0	0	0	0	0	0		0
Taiwan Pechay	0	1	0	1	0	0	0	1	0	1	0	1		5
Camote Tops	0	0	0	0	0	0	0	0	0	0	0	0		0
Ampalaya Special	0	0	0	0	0	0	0	0	0	0	0	0		0
Cucumber	0	0	0	0	0	0	0	0	0	0	0	0		0
Upo	0	0	0	0	0	0	0	0	0	0	0	0		0
French Beans	0	0	0	0	0	0	0	0	0	0	0	0		0
Green Bell Pepper	0	0	0	0	0	0	0	0	0	0	0	0		0
Tomato	0	0	0	0	0	0	0	0	0	0	0	0		0
Cherry Tomato	0	0	0	0	0	0	0	0	0	0	0	0		0
Fallow	0	0	0	0	0	1	0	0	0	0	0	0		1

Figure 2. Generated optimal solution from the model

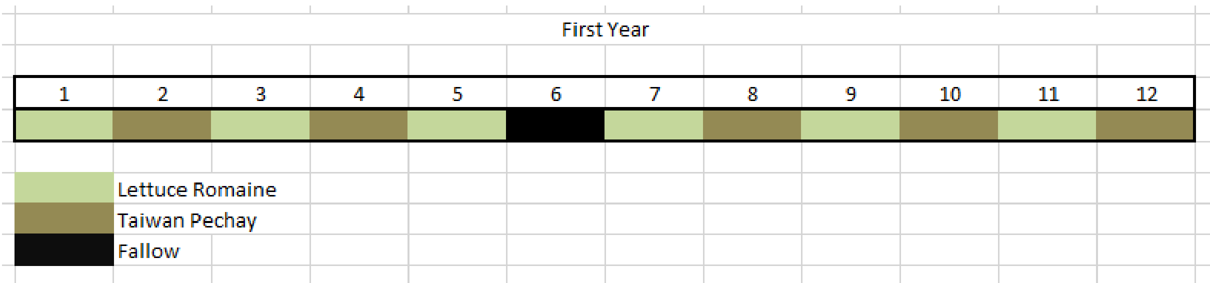

Figure 3. Generated sequence for the first crop rotation

Table 3 shows the cost benefits of using this proposed model. The expected benefits from the proposed model are the reduction of costs of the current situation; the cost is highly variable depending on the salary paid by the farm to their consultant and the number of hours they plan and generate their crop rotation schedule. The only cost to be incurred by the farm or organization that would choose to apply the template created by the group is the short training or orientation to be conducted by the group to the farm. In addition, The benefits of the current state of organic farms are no longer indicated as those are highly dependent on the individual practices, sales, and profit of each farm base on how they perform in terms of meeting their demand.

Table 3. Cost - Benefit Analysis

Without The Proposed Model (Current scenario in the three farms visited)	With The Proponents' Milp Crop Rotation Model	
Cost	Cost	Benefits
i)Salary for regular visit of agriculturalist; fee for consultation iii)Added labor for the planning of crop rotation schedule iv) Time spent to generate crop rotation schedule.	Training of operators in using the template	Time saved in planning or generating a crop rotation schedule Reduced visit of agriculturalist to adjust the crop rotation schedule Reduced effort to generate a crop rotation schedule

Assuming that the farms have a uniform monthly crop scheduling, a once a year visit from an agriculturalist consultant, and a weekly adjustment of the schedule by a resident employee to fix the actual planting. This shows that the possible costs for hiring farm managers and a consultant for crop scheduling will be equal to the expected benefits that farms may gain in the long run. Since the proponents' rates for training are still unknown and will depend on the negotiation with interested farms, the benefits computed were based solely on the costs of the current practice. Based on Table 4, Assuming that only one (1) farm supervisor does the forecasting and scheduling, and one (1) consultant is hired annually to check on the farm, it is estimated that a farm may save up to Php 317,304 per year by reducing the time spent on generating a crop rotation schedule. This however would still be subjected to the needs and complexity of the farm – its structure and number of commodities. Also, the indicated benefits shall be fully actualized and realized once a more stable and reliable crop rotation software would be innovated. Thus, shows the importance of the proponents' study in aiming to be one of the pioneers in the country to reach out to small-scale practices and process improvement regarding an industry lacking advanced systems and technology such as the Philippines' organic farming.

Table 4. Possible costs incurred annually of one organic farm in the Philippines

Assumptions	Time spent	Cost incurred annually
Monthly crop scheduling	Php 22,000, the average monthly salary of an agriculturist (Department of Labor and Employment)	Php 22,000 x 12 months = Php 264,000.
Visit of a consultant	Php 2,500, the average daily fee of a consultant including transportation costs (Payscale Philippines)	Php 2,500 x 1 day = Php 2,500
Weekly Crop Scheduling adjustment	Php 977, the average salary of a farm manager in an 8-hour shift (Payscale Philippines)	Php 977 x 52 weeks = Php 50,804
Total		Php 317,304

4. Conclusion
With the proponents' usage of the Operations Research tool – Mixed Integer Linear Programming the group was able to generate a crop rotation schedule with the data received from the farms of the study and from the reviewed literatures. With MILP, the proponents were able to come up with a model that quantified and simplified the situation given related to the farms of Central Luzon and Calabarzon. The proponents were able to formulate and translate the model to MS Excel, however, Excel solver can barely solve it as the aim itself is complex, requiring a more flexible and powerful solver. Thus, proving the point of the proponents that innovations regarding the study are needed and the basis or the generated template is a necessity produced to help future breakthroughs on the subject.

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