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Optimization of Farm Income of Communities Vulnerable to Climate Change Conditions

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Abstract

With the growing concern over climate change impacts locally and globally, the need to take action to adapt and mitigate its consequences are becoming essential. The Philippines with agriculture at its backbone is considered to be much vulnerable to these effects. Rice production, which needs much water, is in danger. Marginalized rain-fed farmers are especially highly susceptible to this. The use of linear programming is of practical importance specifically because resources are always scarce and constrained. With the primary objective of optimizing farm income of marginalized farmers in the context of linear programming, this study primarily designates what crop/s is most optimal instead of rice during drought conditions exacerbated by climate change. Crop alternatives to rice include cassava, corn, mungbean, peanut, sweet potato, and taro/gabi. These crops can thrive under drought conditions and were most commonly cultivated by farmers in Baybay and Albuera, Leyte. Most of the marginal rain-fed rice farmers resided in these areas. Samples were selected following the non-probability sampling technique employing snowball sampling. Results showed that cassava and sweet potato are optimal alternatives to plant given the constraints. Results also revealed that with pronounced drought brought about by climate change, prevalence of poverty among farmers served as limiting factor hindering high farm productivity and income. It is recommended to put emphasis on policies that increase access of farmers to financial assistance to fund their farm operation as well as the irrigation system since increase in budget and water availability, respectively, would consequently increase farmers' income.

Keywords: Linear programming, optimization, marginal farm production, climate change

Introduction

The relationship between climate change and agriculture has been one of the most significant topics in research agenda and intergovernmental panels (Buzarovska, 2012). Zhai and Zhuang (n.d.) saw that the uneven distribution of productivity losses across global regions brings significant structural adjustments in worldwide agricultural production and trade, ultimately leaving the developing world as net losers. Climate change is seen to worsen the effects of El Niño (Ranada, 2016). El Niño-related droughts affect not only the water sector but also other sectors such as agriculture, health, and environment (Jose & Cruz, 1999). Drought is a chronic problem that affects about 38% of the world's area (Mohanty *et al.*, 2012).

Agricultural crop production is most vulnerable to these adverse effects (Food and Agriculture Organization [FAO], 2009) since any slight variation in climate translates to change in weather, which is an important factor in agriculture (Lansingan & Salvacion, 2007; Lasco *et al.*, 2011). All over the world, farmers are struggling to keep up with the shifting weather and increasingly unpredictable water supply (Environment Defense Fund, n.d.). Results from global models indicate that farming populations that reside in tropical (low latitude) regions are expected to experience deterioration in their agricultural yields and incomes (Karfakis *et al.*, 2013). Many of these at-risk populations are located in South, Southeast Asia, and Africa (Aydinalp & Cresser, 2008). Particularly, depending on a country's economic structure, the adverse effects are expected to be higher for the Philippines,

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Indonesia, Thailand, and Vietnam and lesser for Singapore and Malaysia (Zhai and Zhuang, n.d.).

The Philippines is one of the most vulnerable countries to climate change (Ngilagil *et al.*, 2013) because of its geographical location, level of economic development (Defiesta & Rapera, 2014), and limited resources (Jose & Cruz, 1999). One of the sectors in the Philippines that has been severely affected by climate change is small-scale agriculture (Defiesta & Rapera, 2014). Between 1991 and 2010, the environmental group German Watch ranked the Philippines as number 10 in the Climate Risk Index of the most affected nations to climate change (Shah, 2015). In the 2016 Climate Change Vulnerability Index (CCVI) released by risk analysis company VeriskMaplecroft, the Philippines ranked 13th in the most climate-vulnerable countries, which was elevated from the 2015 Index at the 8th place.

The upland population in the Philippines today has been estimated to be more than 20 million, and upland settlers are accounted to be poorest among the rural population (Fortenbacher & Alave, 2014). Leyte is one of the poorest provinces in the country with a poverty index of 23.6 in 2015 ranking 5th in the list of high poverty incidence in the region (PSA, 2016). With wide mountainous areas in Leyte, a significant part of the population reside in these areas, and this marginal group relatively relies on upland farming as a source of income. Climate change, which improves drought conditions, is expected to worsen marginality of poor farmers in the province. Farmers would struggle in keeping up with weather shifts. With this vulnerability to climate change, adaptation and mitigation measures, techniques, and interventions have to be done, and the application of linear programming (LP) is one of them.

The use of linear programming in management and decision making originated in the 1940's during World War II (Taha as cited Igwe *et al.*, 2013). Linear programming can be used to select optimal crop combinations subject to fixed farm constraints (Majeke *et al.*, 2013). Igweet *et al.* (as cited by Majeke, 2013) believes that LP technique is relevant in the optimization of resource allocation and achieving efficiency in production planning, specifically to achieve increased agricultural productivity. LP model solves the problem by selecting a combination of farm activities that is feasible, upon given a set of fixed constraints that maximizes profit, while achieving other goals such as food security (Majeke, 2013). Comparison of results obtained by using the traditional method of planning and LP model initially reveals that results obtained from the LP model are more superior. Buzarovska (2012) used LP for optimization of agricultural production under climate change conditions. Because climate change affects the productivity of crops with different intensity depending on the crop variety, a diversified farming system could substantially reduce risk and variability of economic returns. This study is vital and all-important to farmers that are greatly affected by climate change, enabling them to optimize farm income given the current scenario encountered by the exacerbation of drought. This study provides the best crop selection or preference under the effects of climate change conditions.

Conceptual Framework

Climate change affects every country in different ways. Effects such as drought, slowing of economic growth, erosion of food security, and exacerbation of poverty. It also alters soil moisture, temperature, precipitation and cloud cover; increases CO_2 concentrations; and impairs crop growth that results in decreased crop yield and productivity. Because of the highly ascending effects of climate change to the world, especially to agriculture, rice production is of high risk. Its semi-aquatic phylogenetic origins and the diversity of rice ecosystems and growing conditions, current rice production

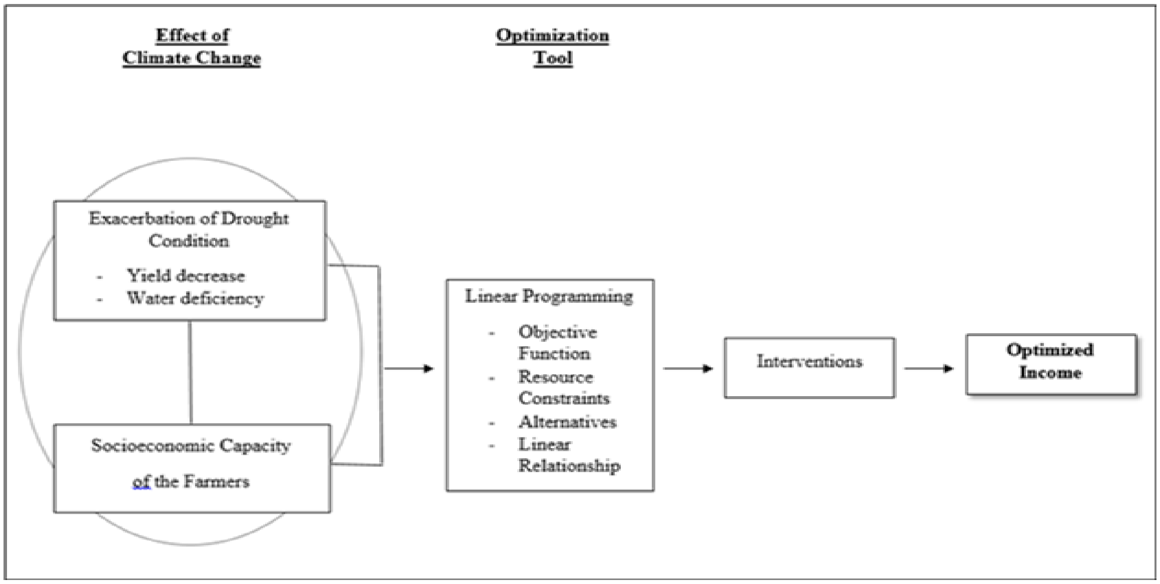

Figure 1: *Conceptual framework in determining the optimized farm income in the context of linear programming.*

systems that rely on ample water supply are more vulnerable to drought stress than other cropping systems (O'Toole as cited by Mohanty *et al.*, 2012). Yield and revenue decline as drought, heat, and water stress disturb the crop.

Due to high vulnerability of rice production to climate change, the idea to look for adaptation measures and strategies is becoming an opportunity. Diversification of farming activities such as crop diversification, change of crop or crop variety, and crop insurance (Perez, 2009; Lasco *et al.*, 2011) is now becoming imperative (Jose & Cruz, 1999). Farmers' socio-economic capacity with the current situation is included in conducting the study. The availability of monetary resources that finance their farming activities, the available land to be tilled, the target and actual revenues that are expected to cover costs among others are taken into account (Figure 1).

This is where the use of LP tool comes into the picture. This study considers corn/maize, mungbean, peanut, cassava, sweet potato, and taro/gabi as alternative crops to rice during severe drought elevated by climate change. To have a reference point for the 6 alternative crops, rice was also considered in the study. Each crop was assumed to be constrained by the following factors: land availability, fund availability, target harvest, amount of water, available time for planting, yield decrease due to water deficit, and farm costs. Similarly, each of these crop is compared to one another in terms of satisfying the objective function which is to optimize farm income.

To influence the unwanted turn of events or prevent undesirable consequences, interventions were made. Such interventions are essential to be able to adapt and mitigate the drastic effects of climate change. With the fulfillment of such action, optimal income in farming is substantially achieved.

Methodology

Data Collection and Gathering

This study relied on primary as well as secondary data. The former were sourced from the marginal farmers of Baybay and Albuera, Leyte and the latter were obtained from some of the recognized organizations nationally and internationally. Data gathered were used vitally as numerical coefficients of the variables in each of the constraints in the model formulated. This model was keyed into the LINDO software to be able to have the optimal result that this study generally wanted to realize.

Data that were primarily gathered included maximum budget cost per hectare per year (Php), target revenue per hectare per year (Php), and the total labor cost budget per hectare per year (Php).

As for secondary data, the cost and returns analysis for each of the 7 crops involved in the study was sourced from the CounrySTAT Philippines of the Philippine Statistics Authority (PSA) and the Visayas State University (VSU) Philrootcrops. Also, the water footprint of a crop I per hectare per year (m^3) and yield response factor of a crop I (k_y) were obtained from the publications of the Food and Agriculture Organization of the United Nations (FAO). Lastly, the mean annual rainfall (m^3) during drought was taken from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

For primary data, 50 marginalized rain-fed rice farmers of Baybay and Albuera, Leyte served as samples in this study. Samples were selected following the non-probability sampling technique employing snowball sampling. Snowball sampling was used because the target respondents were not particularly pre-identified. Also, there were very few of them and normally, the farmers were considered the most knowledgeable of who had the same social and farming status. Hence, the researcher asked the initial subject to identify another potential subject who also met the criteria (marginalized rain-fed farmers) of the research. All samples were surveyed through one-on-one interview using a structured guide questionnaire. The interview was communicated using the vernacular (Cebuano) so as to facilitate respondents' comprehension and ease of understanding of the survey.

Data were collected from at least a part of the population as basis for assessing the incidence, distribution, and interrelations of phenomena as they occur in the lives of the people. During the survey, it was ensured that the participation of every respondent was voluntary, and there was anonymity and confidentiality of results (Librero as cited by Espinazo *et al.*, 2014). For the secondary sources, data were gathered by reading literatures through Internet search using some of the common search engines.

Problem Formulation

The model used a Simplex Method for linear programming. This model involves 7 different crops, namely: rice, cassava, corn, mungbean, peanut, sweet potato, and taro/gabi. The crops were chosen for the primary reason that they can thrive under drought condition except for rice (paddy). Rice was included to have a reference point. One crop may have more advantages offered than the others when drought conditions may be exacerbated by climate change. It was assumed that among the 7 alternative crops, one or a combination of such would give an optimal solution that could maximize the farmers' income.

In this model, the objective function was defined as a single objective of profit maximization expressed as a product of profit gained and the number of hectares planted (area). The constraints such as availability of funds, availability of land, target harvest for each crop, amount of water to irrigate the farm, available time for planting, and yield decrease due to water deficit are defined as linear relationships. Having in mind the nature of the problem for resource allocation, a linearity of both, the objective function and constraints, the linear programming technique, in particular, simplex Method, was considered to be an efficient technique for providing a satisfactory solution (Buzarovska, 2012). This technique is a useful tool for decision-making problems that require a resource allocation problem (Lee & Olson as cited Buzarovska, 2012).

Assumptions

The analysis employed the following considerations and requirements:

1. Choose the crop which was the most optimal.
2. The area allotted to each crop should be equal to or not exceed to the land available (with respect to available budget cost).
3. The cost of producing each crop should be equal to or not exceed to the average funds available.
4. The target revenue for each crop should be equal to or exceed the average target revenues.
5. The available water to irrigate each crop should be equal to or not exceed the maximum amount of water to irrigate the whole farm.
6. The yield decrease due to water deficit for each crop should be equal to or not exceed to the maximum yield decrease of the farm.

Parameters

Let: i = i: i=1, 2, . . . , n
where:
1 = Cassava (Manihot escculenta)
2 = Corn (Zea mays)
3 = Mungbean (Vigna radiata)
4 = Peanut (Arachis hypogea)
5 = Rice (Oryza sativa)
6 = Sweet Potato (Ipomoea batatas)
7 = Taro (Colocasia esculenta)
R_i = revenue generated from producing crop i per hectare per year (PhP)
C_i = costs incurred from planting crop i per hectare per year (PhP)
P_i = profit gained from planting crop i per hectare per year (PhP)
W_i = water required/used to irrigate crop i farm per hectare per year (m3)
Y_i = yield decrease due to water deficit of crop i farm per hectare per year (%)
a = total available land area devoted for farming based on the available budget of farmers (ha)
b = total available cost budget per hectare per year (PhP)
d = target revenue per hectare per year (PhP)
e = total available water (based on mean annual rainfall) under drought condition per year (m^3)
f_i = allowable decrease in revenue in relation to cost for crop i per hectare per year (%)

Decision Variable

H_i = number of hectares planted with crop i in a year

Objective Function:

$$Maximize \sum_{i=1}^{7} P_i H_i$$

Maximize $P_1H_1 + P_2H_2 + P_3H_3 + P_4H_4 + P_5H_5 + P_6H_6 + P_7H_7$

Constraints:

1. Availability of land $\sum_{i=1}^{7} H_i \leq a$ $H_1 + H_2 + H_3 + H_4 + H_5 + H_6 + H_7 \leq a$
2. Availability of fund $\sum_{i=1}^{7} C_i H_i \leq b$ $C_1H_1 + C_2H_2 + C_3H_3 + C_4H_4 + C_5H_5 + C_6H_6 + C_7H_7 \leq b$
3. Target revenue for each crop per hectare per year $\sum_{i=1}^{7} R_i H_i \geq d$ $R_1H_1 + R_2H_2 + R_3H_3 + R_4H_4 + R_5H_5 + R_6H_6 + R_7H_7 \geq d$
4. Amount of water (m^3) to irrigate the farm (dependent on mean annual rainfall) $\sum_{i=1}^{7} W_i H_i \leq e$
$W_1H_1 + W_2H_2 + W_3H_3 + W_4H_4 + W_5H_5 + W_6H_6 + W_7H_7 \leq e$
5. Yield decrease due to water deficit $Y_iH_i \leq f_i$ all $_i$ $Y_1H_1 \leq f_1, Y_2H_2 \leq f_2, Y_3H_3 \leq f_3, Y_4H_4 \leq f_4, Y_5H_5 \leq f_5, Y_6H_6 \leq f_6, Y_7H_7 \leq f_7$

Table 1: *Annual cost, revenue, profit and number of cropping season per hectare annually.*

Crop	No. of Cropping Season[2]	Cost (PhP)	Revenue (PhP)	Profit (PhP)
Cassava	1	22, 349.00[3]	66, 256.00[3]	43, 907.00
Corn	2	44, 046.00[3]	72, 202.00[3]	28, 156.00
Mungbean	3	53, 574.00[3]	138, 486.00[3]	84, 912.00
Peanut	3	97, 149.00[3]	200, 364.00[3]	103, 215.00
Rice	1[1]	29, 230.00[3]	44, 908.00[3]	15, 678.00
Sweet Potato	2	61, 230.00[3]	181, 076.00[3]	119, 846.00
Taro	1	47, 983.50[4]	105, 000.00[4]	57, 016.50

[1] *Only one cropping for rice annually due to scarcity of water,* [2] *Based on the standard total length of planting periods under normal condition from FAO Irrigation and Drainage Paper No. 24 (1977),* [3] *Source: Philippine Statistics Authority (PSA) (2015), 4Source: VSU PhilRootcrops (2016)*

Data Used and Analysis

Objective Function. The objective function was a single objective of profit maximization expressed as a product of profits gained and the number of hectares planted (area). Profit (see Table 1) is derived from subtracting costs to revenues (Equation 1).

$$P = R – C \quad (1)$$

where:
P profit gained from planting crop i per hectare per year (PhP)
R revenues generated from producing crop i per hectare per year (PhP)
C costs incurred from producing crop i per hectare per year (PhP)

Constraint 1. The left hand side (LHS) was developed only as the summation of the decision variable ($H_i = H_1 + H_2 + H_3 + H_4 + H_5 + H_6 + H_7$) to enable equal opportunity of each crop in the distribution of area in the farm. The right hand side (RHS) which is 1.00 hectare was related to the maximum cost budget (see Table 2) per hectare per year. Thus, 1 hectare was used for it to be in line with the estimated available funds of farmers per hectare in a year. The latter was the amount of money that a farmer allocated for farming activities in a hectare annually, hence, the former must be equal to one.

Constraint 2. The costs (see Table 1) in the left hand side was a secondary data taken from the CountryStat-Cost and Returns of PSA (PSA, 2015) except for taro which was taken from the VSU PhilRootcrops due to nil of data from the PSA. Secondary data were chosen to be used in the study so as to facilitate uniformity of the standard average costs incurred in planting each crop. The right hand side (RHS) is the annual average budget cost per hectare of marginal farmers who served as respondents of the study. This is the amount of monetary resources available that the farmers spent in their farming activities. *Constraint 3.* The left hand side (LHS) which comprises the revenues were also taken from the CountryStat-Cost and Returns of PSA (PSA, 2015) except for taro which was taken from the VSU PhilRootcrops due to dearth of data from the PSA. RHS of the third constraint was generated from the responses of the farmers regarding the average target revenue (PhP 84, 581.00) per hectare of land, yearly. Target revenue was used instead of break-even point for the reason that the second designates profit equivalent to zero and thus is inconsistent with the generated revenues for each crop in the LHS.

Constraint 4. The LHS (see Table 3) of constraint 4 is the total water use (m^3/yr) for each crop production in the country calculated by multiplying the standard global water footprint (m^3/ton) with the average

Table 2: *Global average water footprint of crops included in the study (1996-2005).*

FAOSTAT Crop	Crop	Global Average Water Footprint (m^3/ton)			
		Green	Blue	Grey	Total
125	Manioc (Cassava)	550	1	13	564
56	Maize (Corn)	947	81	194	1222
414	Beans, green[1]	320	54	188	561
242	Groundnuts[2]	2469	150	163	2782
27	Rice, paddy	1146	341	187	1673
122	Sweet Potatoes	324	5	53	383
136	Taro (Coco Yam)	587	3	15	606

[1] *Due to unavailable data which is mungbean-specific, beans (green) was used. Mungbean is also called as green gram globally,* [2] *Peanut is also known as groundnut globally, Source: Derived from Mekonnen and Hoekstra (2010)*

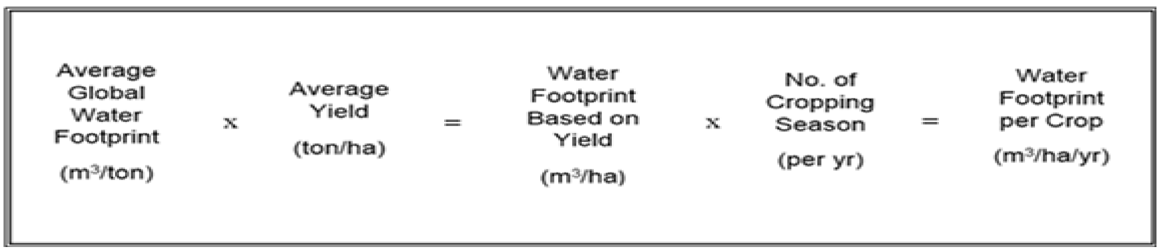

Figure 2: *Diagram for the computation of water footprint per crop in this study.*

yield (ton/ha). Afterward, the product was then again multiplied to the number of cropping season in a year, and it was assumed that rice had only 1 cropping due to drought, which resulted in scarcity of water (Figure 2).

The concept of "water footprint" was introduced by Hoekstra (2003) and subsequently elaborated by Hoekstra and Chapagain (2008) provides a framework to analyze the link between human consumption and the appropriation of the globe's freshwater (see Table 2). The water footprint is the volume of water used to produce a particular good, measured at the point of roduction (Hoekstra & Chapagain, 2008). It is defined as the total volume of freshwater that is used to produce the product (Hoekstra et al. as cited by Mekonnen & Hoekstra, 2010). The blue water footprint refers to the volume of surface water and groundwater consumed (evaporated) as a result of the production of a good; the green water footprint refers to the rainwater consumed. The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Mekonnen & Hoekstra, 2010). Average yield per hectare was taken from the CountryStat-Cost and Returns of PSA (PSA, 2015) except for taro which was taken from the VSU PhilRootcrops. Consistency of data used was again considered in using the mentioned sources.

Otherwise, the RHS of the fourth constraint was calculated considering the least amount of mean annual rainfall. The mean annual rainfall of the Philippines varied from 965 to 4,064 mm annually (PAGASA, 2016). Thus, 965 mm was used taking a conservative view of the rainfall pattern in the country. It was calculated by deducting sixty percent of 965 mm giving 386 mm of rainfall yearly. This is in line with the drought situation focused by the study underpinned with the definition of drought given by PAGASA (2016), which defined drought as 3 consecutive months of way below normal rainfall condition—greater

Table 3: *Water footprint used in the LHS of Constraint 4.*

Crop	**Total Global Average Water Footprint (m^3/ton)**	**Average Yield (ton/ha)**	**No. of Cropping Season (Per Year)**	**Water Footprint per Crop (m^3/ha/yr)**
Cassava	564	12.157	1	6856.55
Corn	1222	2.935	2	7173.55
Mungbean	561	0.812	3	1366.60
Peanut	2782	1.643	3	13712.48
Rice	1673	2.745	1	4592.39
Sweet Potato	383	6.244	2	4782.90
Taro	606	7.000	1	4242.00

than 60% reduction from average rainfall. (In this study, drought was assumed to prevail whole-year round.)

Aimed at consistency of units used, millimetres was then converted to cubic meters (386 mm to 3860 m^3/ha/yr) sourced from FAO (2006) and Buzarovska (2012).

$1mmday^{-1} = 10m^3ha^{-1}day^{-1}$ *Or* $1mmyear^{-1} = 10m^3ha^{-1}year^{-1}$

Constraint 5. The last constraint was all about yield decrease due to water deficit. FAO addressed the relationship between crop yield and water use in the late 70s proposing a simple equation where relative yield reduction was related to the corresponding relative reduction in evapotranspiration (FAO, 2012). When water supply does not meet the crop water requirements, the ETc will decrease. Under this condition, water stress will develop in the plant, which will adversely affect crop growth and, ultimately, crop yield. The effect of water stress on crop growth and yield depends on the crop species and variety on one hand and the magnitude and the time of occurrence of water deficit on the other. The effect of the magnitude and the timing of water deficit on crop growth and yield is of major importance in scheduling available but limited water supply over growing periods of the crops, and in determining the priority of water supply amongst crops during the growing season (FAO cited by Savva & Frenken, 2002).

The concept of “water footprint” was introduced by Hoekstra (2003) and subsequently elaborated by Hoekstra and Chapagain (2008) provides a framework to analyze the link between human consumption and the appropriation of the globe’s freshwater (see Table 2). The water footprint is the volume of water used to produce a particular good, measured at the point of roduction (Hoekstra & Chapagain, 2008). It is defined as the total volume of freshwater that is used to produce the product (Hoekstra et al. as cited by Mekonnen & Hoekstra, 2010). The blue water footprint refers to the volume of surface water and groundwater consumed (evaporated) as a result of the production of a good; the green water footprint refers to the rainwater consumed. The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Mekonnen & Hoekstra, 2010). A simple, linear crop-water production function was introduced in the FAO Irrigation and Drainage Paper No 33 (1979) to predict the reduction in crop yield when crop stress was caused by a shortage of soil water as shown in equation 2:

$$[1 - \frac{Y_a}{Y_m}] = k_y x[1 - \frac{ET_{cadj}}{ET_c}] \tag{2}$$

Where ky relates relative yield decrease $[1 - \frac{Y_a}{Y_m}]$ to relative evapotranspiration deficit $[1 - \frac{ET_{cadj}}{ET_c}]$.

Table 4: *Water footprint used in the LHS of Constraint 4.*

Crop	Yield Decrease Factor (k_y)	E_{tcadj}	E_{tc}
Cassava	1.0	6,856.55 – 2,996.55 (3,860)	6,856.55
Corn	1.25	7,173.14 – 3,313.14 (3,860)	7,173.14
Mungbean	1.15	1,366.60 – (-2,493.40) (3,860)	1,366.60
Peanut	0.70	13, 712.48 – 9852.48 (3,860)	13, 712.48
Rice	1.15	4, 592.39 – 732.39 (3, 860)	4, 592.39
Sweet Potato	1.0	4,782.90 – 922.9 (3, 860)	4,782.90
Taro	1.0	4,242.00 – 382 (3, 860)	4,242.00

k_y = Yield response factor (-)
Y_a = Actual crop yield
Y_m = Maximum crop yield when there is no water stress and $ET_{cadj} = ET_c$
ET_c = Crop evapotranspiration for standard conditions (mm d^{-1})
ET_{cadj} = Adjusted (actual) crop evapotranspiration
(mm d^{-1})

There are k_y values in FAO Irrigation and Drainage paper No 33 for only about 23 crops (FAO, 2006). K_y values are crop specific and may vary over the growing season. When water deficit occurs during a particular part of the total growing period of a crop, the yield response to water deficit can vary greatly depending on how sensitive the crop is at that growth stage. In general, the decrease in yield due to water deficit during the vegetative and ripening period is relatively small, while during the flowering and yield formation periods, large (Savva & Frenken K., 2002). Accordingly, FAO (2012) provided the following:

$k_y > 1$: crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress.

$k_y < 1$: crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use.

$k_y = 1$: yield reduction is directly proportional to reduced water use.

For many crops, the seasonal ky is nearly 1. For crops where k_y is unknown, the user may use $k_y = 1$ in Equation 2 or may select the k_y for a crop type that has similar behavior (FAO, 2006).

Subsequently, the LHS of the last constraint was arrived using Equation 2. Ky values used are presented in the preceding table (Table 4), whereas the ET_c and ET_{cadj} used were derived from the previous constraint which is the water footprint for each crop and the available water or water supply (based on mean annual rainfall under drought condition), respectively.

Consider the green maize grown close to Mahalapye climatic station in Botswana with a water requirement of 820 mm. What is the yield reduction, if: 1. The water supply is 10% less than the total water requirements with the deficit equally spread over the total growing period (150 days)? ANSWER:

1. If the water supply is 10% less than the total water requirement of 820, this means a deficit of 82 mm
$[1 - \frac{ET_{cadj}}{ET_c}] = [1 - \frac{820-82}{820}] = 0.1$
$[1 - \frac{Y_a}{Y_m}] = kyx[1 - \frac{ET_{cadj}}{ET_c}] = 1.05x0.1 = 0.105$
*The yield reduction is 10.5%. This means that the actual yield Ya is 100 − 10.5 = 89.5% of maximum crop yield Y_m.
Sample computation for this study was presented below (for cassava only).
$[1 - \frac{ET_{cadj}}{ET_c}] = [1 - \frac{3860}{6856.55}] = 0.44$
$[1 - \frac{Y_a}{Y_m}] = kyx[1 - \frac{ET_{cadj}}{ET_c}] = 1.0x0.44 = 0.44$
*The yield reduction is 44%. This means that the actual yield Ya is 100 - 44 = 56% of maximum crop yield Y_m

On the other hand, the RHS (see Table 5)

Table 5: *Coefficients used for constraint 5 (LHS and RHS).*

Crop	LHS Coefficient (%)	RHS Coefficient (%)
Cassava	44.0	66.27
Corn	57.5	39.00
Mungbean	01	61.31
Peanut	50.4	51.51
Rice	18.4	34.91
Sweet Potato	19.0	66.19
Taro	9.0	54.30

[1] *It is assumed that there is no yield decrease for mungbean since there is a glut of available water as compared to the water requirement of the crop each year (see Constraint 4).*

Table 6: *Derived values of the coefficients of the left hand side (LHS) and right hand side (RHS) of Constraints 1 to 5 based on the primary and secondary data gathered.*

Crop	Constraint 1		Constraint 2		Constraint 3		Constraint 4		Constraint 5	
	LHS (ha)	RHS(ha)	LHS(PhP)	RHS(PhP)	LHS(PhP)	RHS(PhP)	LHS(m^3)	RHS(m^3)	LHS(%)	RHS(%)
Cassava	1.00	1.00	22349.00	32000.00	66256.00	65000.00	6856.55	3860.00	44.0	66.27
Corn	1.00	1.00	44046.00	32000.00	72202.00	65000.00	7173.14	3860.00	57.5	39.00
Mungbean	1.00	1.00	53574.00	32000.00	138486.00	65000.00	1366.60	3860.00	0.0	61.31
Peanut	1.00	1.00	97149.00	32000.00	200364.00	65000.00	13712.48	3860.00	50.4	51.51
Rice	1.00	1.00	29230.00	32000.00	44908.00	65000.00	4592.39	3860.00	18.4	34.91
Sweet Potato	1.00	1.00	61230.00	32000.00	181076.00	65000.00	4782.90	3860.00	19.0	66.19
Taro	1.00	1.00	47983.50	32000.00	105000.00	65000.00	4242.00	3860.00	9.0	54.30

[1] *Due to unavailable data which is mungbean-specific, beans (green) was used. Mungbean is also called as green gram globally,* [2] *Peanut is also known as groundnut globally, Source: Derived from Mekonnen and Hoekstra (2010)*

originated from the gap between revenue and cost from planting each crop per hectare annually (LHS coefficients of constraints 2 & 3). The difference between revenue and cost (which is basically the profit) was divided by the total revenue and then multiplied by 100 to get the percentage. This percentage indicates the allowable decrease in yield for the farmer to achieve break-even point (cost = revenue; profit = 0). Any decrease in yield higher than the computed value primarily designates that the revenues generated is not enough and/or cannot cover the costs incurred in planting crop *i* per hectare yearly. Sample computation for cassava is presented below.

$$\frac{P}{R}x100 \tag{3}$$

where: P profit gained from planting crop i per hectare per year (PhP), R revenues generated from producing crop i per hectare per year (PhP)

$Cassava = \frac{43907}{66256}x100 = 66.27\%$

Data were analyzed and run using the LINDO Software.

Results and Discussion

Linear Programming Results

The model comprised of the objective function which was subjected to its constraints and is presented below. The values of the coefficients were derived based from primary and secondary data as presented in Table 6.

The Model

Maximize Z = $43907H_1 + 28156H_2 + 84912H_3 + 103215H_4 + 15678H_5 + 119846H_6 + 57016.50H_7$

Subjected to:

$$H_1 + H_2 + H_3 + H_4 + H_5 + H_6 + H_7 \leq 1$$

(land available)

$$29230H_5 + 61230H_6 + 47983.50H_6 \leq 32000$$
(Funds available)
$$66256H_1{+}72202H_2{+}138486H_3{+}200364H_4{+} 44908H_5 + 181076H_6 + 105000H_7 \geq 65000$$
(Target revenues)
$$6856.55H_1 + 7173.14H_2 + 1366.60H_3 + 13712.48H_4 + 4592.39H_5 + 4782.90H_6 + 4242H_7 \leq 3860 \text{ (water available)}$$
$$44H_1 \leq 66.27$$
$$57.5H_2 \leq 39$$
$$0H_3 \leq 61.31$$
$$50.4H_4 \leq 51.51$$
$$18.4H_5 \leq 34.91$$
$$19H_6 \leq 66.19$$
$$9H_7 \leq 54.30$$

In order to have a non-negative result in the optimal solution, the following parameters were included in the model:

$$H_1 \geq 0$$
$$H_2 \geq 0$$
$$H_3 \geq 0$$
$$H_4 \geq 0$$
$$H_5 \geq 0$$
$$H_6 \geq 0$$
$$H_7 \geq 0$$

The formulated problem consisted of 6 decision variables and 18 constraints including the non-negativity constraints. Figure 3 shows the results of the analysis from LINDO software. Optimality was attained after 2 iterations. Result of the analysis showed that the objective function value was 62,67.29. This was the annual maximum profit obtained for a farmer owning 1 hectare of land devoted for crop production given the climate change conditions and constraints. The result also suggested that farmers should plant 0.27 hectares of cassava and 0.43 hectares of sweet potato to achieve the highest possible profit based on the value of the decision variables. There was a gap (0.31 ha) between the available land area (1 ha) and the recommended area to be planted (0.69 ha) due to the available cost budget allocated for farming (P32, 000) that was just enough to cover the expenses of 0.69 ha of land annually. The profit would be raised if the production was extended on the total available area (1 ha) given the optimal crop mix. Cassava and sweet potato were selected relatively because of their lower costs (P22, 349.00 and P61, 230.00, respectively) and higher revenues (P66, 256.00 and P181, 076.00, respectively) than other crops. Hence, net returns were higher for the selected crops. Also, water used (6, 856.55 m^3 and 4, 782.90 m^3, correspondingly) for the recommended crops were way lower than others reflecting lower yield decrease due to water deficit (44% and 19%, individually) with respect to the percentage of costs to revenues for each of the crop. Mungbean, albeit its low water use and having no yield decrease due to glut of water was not chosen because of comparably higher cost and lower revenue than the remaining crops. As depicted from the reduced cost of the decision variables, corn, mungbean, peanut, rice, and taro must increase their profit by P58, 174.73; P19, 858.90; P87, 131.01; P41, 607.82; and P881,105.31, respectively, before it would be possible for the corresponding crops to assume a positive value in the optimal solution. Only Constraint 2 (funds available) and Constraint 4 (water available) had a dual price greater than and not equal to zero. This means that for every Php1.00 added to the farmer's budget, there would be an increase of optimal profit by Php1.95; and for every one (1) m^3 added to the total water available to irrigate the farm, there would be an increase in the optimal profit (P62, 677.29/ha/yr) by Php0.03. For the remaining constraints, the dual price was equivalent to zero which indicated that the optimal profit would not increase even if additional units of it would be added. Given the drought condition brought by climate change and the farmer's capacity, the farming operation and production were greatly constrained with the available cost budget intended for farming activities and water available to irrigate the farm. These factors play a vital role in achieving high farm productivity and income.

LP OPTIMUM FOUND AT STEP 2

OBJECTIVE FUNCTION VALUE

1) 62677.29

VARIABLE	VALUE	REDUCED COST
H1	0.266175	0.000000
H2	0.000000	58174.734375
H3	0.000000	19858.900391
H4	0.000000	87131.007812
H5	0.000000	41607.824219
H6	0.425466	0.000000
H7	0.000000	881105.312500

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.308360	0.000000
3)	0.000000	1.95481
4)	29677.289062	0.000000
5)	0.000000	0.031915
6)	54.558311	0.000000
7)	39.000000	0.000000
8)	61.310001	0.000000
9)	51.509998	0.000000
10)	34.910000	0.00000
11)	58.106152	0.000000
12)	54.299999	0.000000
13)	0.266175	0.000000
14)	0.000000	0.000000
15)	0.000000	0.000000
16)	0.000000	0.000000
17)	0.000000	0.000000
18)	0.425466	0.000000
19)	0.000000	0.000000

NO. ITERATIONS= 2

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
H1	43907.000000	36013.207031	163.112122
H2	28156.000000	58174.738281	INFINITY
H3	84912.000000	19858.900391	INFINITY
H4	103215.000000	87131.007812	INFINITY
H5	15678.000000	41607.824219	INFINITY
H6	119846.000000	446.881561	18452.166016
H7	57017.000000	881105.312500	INFINITY

		RIGHTHAND SIDE RANGES	
ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	1.000000	INFINITY	0.308360
3	32000.000000	17415.166016	10043.703125
4	65000.000000	29677.289062	INFINITY
5	3860.000000	2481.831055	1360.362549
6	66.269997	INFINITY	54.558311
7	39.000000	INFINITY	39.000000
8	61.310001	INFINITY	61.310001
9	51.509998	INFINITY	51.509998
10	34.910000	INFINITY	34.910000
11	66.190002	INFINITY	58.106152
12	54.299999	INFINITY	54.299999
13	0.000000	0.266175	INFINITY
14	0.000000	0.000000	INFINITY
15	0.000000	0.000000	INFINITY
16	0.000000	0.000000	INFINITY
17	0.000000	000000	INFINITY
18	0.000000	0.425466	INFINITY
19	0.000000	0.000000	INFINITY

Figure 3: *Output result of the model generated using the LINDO software.*

The objective function coefficients can be altered as long as the ranges of optimality permit. Increase and decrease of profit for each crop as long as it is allowable indicates that any change in the optimal solution will not be possible. Similarly, the values of the right hand side (RHS) can range variably without changing the value and interpretation of the dual prices. This means that dual prices are still valid even if the values of the RHS increases or decreases in an allowable manner. Values of the objective coefficient and the right hand side may increase infinitely and vice versa.

Marketability of the Selected Crops (Cassava and Sweetpotato)

In Region 8, many different food products are produced from cassava and sold in the market. For instance, tubers are being processed into fried rolls, cassava cake, and steamed or cooked tubers. Among all products, cassava chips and cassava roll/ball are reported to be highly saleable (Oxford Committee for Famine Relief [OXFAM] & VSU, 2016). Fresh tubers are normally purchased by households, local processors, and bakeries. Most of the buyers are households and local processors, while only very few middlemen/traders and bakeries are buying fresh tubers. In recent years, cassava production in Region 8 has increased due to expanded use for feeds and the emerging markets for health foods. In 2014, a new feeds plant of San Miguel Foods, Inc. (SMFI) has been established in Ormoc City with a projected daily capacity of 80–100 tons dried cassava chips in 2016–2017, or about 15 hectares daily harvest (OXFAM & VSU, 2016). This does not include other small processors of cassava-based food products. There is a huge potential market where Albuera and Baybay, Leyte cassava producers can link with.

Meanwhile, the value chain analysis conducted by the VSU PhilRootcrops (2016) in Leyte and Samar showed that sweet potatoes are sold in either raw (fresh roots) or processed form. Raw sweet potatoes or fresh roots are most frequently utilized after boiling until they become soft and mealy. In addition, roots are also utilized for chips, fries, noodles, catsup, jam, or beverage processing. Along identified value chains, sweet potato is commonly processed into fried chips coated with sugar. The result of the assessment identified some of sweet potato enterprises. This included San Agustin RIC (Baybay, Leyte), CMV Food Enterprises and another private business owned by Charity Concon (Ormoc, Leyte), Uswag Kababaehan Association (UKA), Tinago Farmers Association (TIFA) and Palompon Chamber of Commerce (Palompon, Leyte), Dolongan Rural Improvement Club (Basey, Samar), Sta. Rita Food Processors Association (Sta. Rita, Samar), Arado Rural Improvement Club (Palo Leyte), and Hilongos, LGU w/ Magnangoy Women's Association (Hilongos, Leyte) (VSU-Philrootcrops, 2016). This represents market for sweet potato in Leyte and Samar that can be satisfied with its high volume of production, 111,874.21 MT in Eastern Visayas and 52,447.30 MT in Leyte (PSA, 2016). This does not include other sweet potato enterprises that were not included in the assessment.

Conclusion and Recommendation

Given the constraints under climate change condition and capacity of the farmers, farmers are recommended to plant cassava or sweet potato to attain the highest possible farm income. Cassava and sweet potato nowadays are known to have an already established market. Developed market for cassava and sweet potato roots and derived products is conducive for the uplifting of farmers' income. Ever increasing trend in the Philippine population (as well as the world) means a highly ascending demand for food. Awakening the sleeping development of native root crops in the market and processing sector can be used to supply the chase to solve the ever unresolved hunger in the country and to satisfy the enormous demand for food locally and internationally. It is also highly recommendable to undertake adaptation and mitigation measures considering the agriculture sectors' vulnerability toward climate change. In the national level, the government should focus more on researches relating to climate change, develop policies and programs (laws, if necessary), and finance public organizations to take an essential step on informing and guiding Filipinos especially farmers on the undesirable effects of climate change. Reduction of the susceptibility of the agriculture sector means improved weather based programs, state-of-the-art weather information systems and technology, development of highly resistant crops, proper water management and improved water efficiency use, rehabilitation and construction of new irrigation techniques and systems, among others. In the farm level, farmers are recommended to change the cropping pattern with a larger share of less water-demanding crops, introduction of more resistant crop varieties, changing of the timing of field operations, diversification of farm enterprise, and the like.

Policy on financial assistance for farmers must be passed especially those on their procurement of farm inputs as this serves as hindrance to farmers especially those marginalized in increasing their farm income. Once budget is increased, ultimately farm income will be raised based on the result of the analysis. As findings of the study revealed, planting cassava and sweet potato is optimal. To be able to put these two crops on a competitive advantage together with the products derived from them (by-products), special attention on its development must be vitally devoted. Appropriate actions should be done nationally and at the farm level. This includes a need for the government to prioritize production and processing programs of the above-mentioned crops (cassava and sweet potato) across Philippine locations. In relation to this, it is not enough to undertake only extension-cum-credit programs to improve farm production systems. These programs must be accompanied by the development of institutional arrangements that facilitate transactions between farmers and end-users or processors.

Exploitation of the potential of cassava-and sweet potato-based processing depends on developments at the farm level. To improve farm production systems, clear policies and programs that develop farm production must be put in place. Though, specific programs addressing the problems concerning market failure need to be undertaken. The challenge is how to equip farmers and processors with the knowledge and tools needed to provide products that meet the requirements of growth markets. Crops must be improved genetically to be more resistant to severe pest infestations and serious diseases and to tolerate water deficiency. Thus, cassava and sweet potato yields can increase desirably making surpluses of production and resulting to favorable economic incentives. An immediate need to promote processing is to make financing facilities available so that the private sector will be encouraged to invest in processing activities. In the long run, the government must provide incentives to the private sector to continue improving the state of technology in processing. Improving the production system in order to reduce the cost of raw material while maintaining reasonable profit margins for farmers, adding post-harvest value by the development of new products and more efficient processes, and stimulating higher demand for cassava-based products by market development. To be fruitful, research streams should not work independently, but coordinate activities closely, collaborate between institutions, and build strong partnership between the public and the private sector.

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