A Soil Analysis Approach to Assessing Potential Loss of Productive Lands Under Agricultural Land Conversion

Jordan G. Calura[1], Rodrigo B. Badayos[2], Jessica Villanueva-Peyraube[3], and Jocelyn D. Labios[2]

[1]Bureau of Soils and Water Management, Quezon City, Philippines; [2]Agricultural Systems Institute-College of Agriculture and Food Science, University of the Philippines Los Baños (UPLB), Laguna, Philippines; [3]School of Environmental Science and Management, UPLB

ABSTRACT

Land provides physical space and is usually required for various sectoral developments needed to meet the needs of increasing population. Land is a finite natural resource; thus, conflict arises over land use and development.

The strategic location of the municipality of Pura in Tarlac province, Philippines within the urban beltway of Central Luzon and the recent opening of the Tarlac–Pangasinan–La Union Expressway provide Pura excellent opportunities for urban and industrial development. However, the precursor to this is agricultural land conversion (ALC), which can change or reduce the area of productive lands.

This paper assessed the degree of productivity of the agricultural lands in the study area that are predisposed to ALC using FAO's land suitability framework and the revised Storie index for soil productivity. Soil survey and composite soil sampling at 20 cm depth in the selected 34 sampling points were done to analyze the relevant soil physical and chemical properties. Five soil mapping units (SMU) were grouped based on the soil surface texture. The results show that the SMUs are only *marginally suitable* (*S3f*) for producing rice and other crops due to their current low soil organic carbon content. However, these SMUs can be highly suitable (*S1*) for crop production with appropriate soil management. Using the Storie index, the entire tract of land of Pura has an index rating of 58 percent, which corresponds to a grade 3 soil suitable for planting a number of crops with expected good results. The results of the land suitability evaluation and soil productivity assessment further show that the land in the municipality of Pura is productive, and thus can benefit both agricultural production and ALC. As such, whichever spatial strategy or policy direction for ALC that the municipal government chooses to adopt, the municipality of Pura will lose productive land.

Keywords: agricultural land conversion, land suitability, soil productivity
JEL codes: Q150

Contact Jordan G. Calura jgcalura@up.edu.ph https://doi.org/10.37801/ajad2023.20.2.6

INTRODUCTION

The increasing population requires higher volume and improved mode of food production. The same is true with the requirement for improving and enhancing other economic sectors such as the services, industrial, residential, and commercial sectors. Accordingly, all these sectors often require physical space—land—in order to develop.

According to FAO (2017), should global population reach 9.73 billion by 2050, the world needs to produce 50 percent more food, feed, and biofuel. As such, the ever-increasing demand for agricultural products will put great pressure on finite natural resources such as land, water, and genetic potential (Alexandratos and Bruinsma 2012).

Agricultural lands are perceptibly diminishing due to rapid urban expansion and to the continuous demand for goods and other services resulting from population growth. In developing countries, agricultural land loss is more intense, with an estimated farm loss of 2.2 ha per capita every 12 years. Thus, the agriculture sector in developing countries experiences growth and transition in their economic structure (Azadi, Ho, and Hasfiati 2011).

Urban growth is the precursor of agricultural land conversion (ALC) in developing countries (Azadi, Ho, and Hasfiati 2011). Accordingly, rural urbanization can accelerate through infrastructure development such as highway construction (Song et al. 2016) and through the proximity of rural areas to mega urban areas such as metropolitan Manila (Estacio et al. 2021).

The municipality of Pura in Tarlac province, Philippines, is a rural area within the central plains of Luzon. Most of the land in the municipality is agricultural, with 91.6 percent of the total land area of the municipality (approximately 2,878.10 ha) composed of agricultural lands. The municipality is approximately 19 km from the provincial capital (Tarlac City), 78.5 km from the regional center (San Fernando City, Pampanga), 55 km from the Clark Special Economic Zone (Angeles City, Pampanga), and 144.9 km north of Manila.

According to the Comprehensive Land Use Plan (CLUP) of the municipality of Pura for the planning period 2013–22, the population in the municipality is projected to reach 26,500 individuals by 2022 from 22,949 individuals in 2010; this means that the residential area in the municipality would need to expand. Moreover, the CLUP also cited that the municipal government may opt to adopt a low-density or high-density residential land use that would require 289 ha or 89 ha, respectively. A "concentrated linear development plan" was then proposed to accommodate the needs of the growing population and its related economic and sectoral development. The spatial strategy involves reclassifying agricultural lands along the national roads that connect the two central cores for mixed built-up development areas and supporting smaller development nodes. Controlled or uncontrolled land conversion may then expand along the perimeters of their spatial development plan.

The proximity of Pura municipality to urban areas and the construction of highways, i.e., the Tarlac–Pangasinan–La Union Expressway (TPLEx), traversing the stretch of the municipality from south to north, provide a haven for urban and economic growth in the study area. However, the most frequent repercussion of ALC is the loss of productive lands.

As such, this study attempts to assess the degree of productivity of the agricultural lands predisposed to ALC in the municipality of Pura. Such analysis can help policymakers assess the costs and benefits of alternative uses of the agricultural lands being considered for conversion. Such study would help to guide local government units in the Philippines in developing their respective CLUPs for future development. This approach could also be adopted by other localities for rational land use planning.

MATERIALS AND METHODS

The Study Area

The municipality of Pura is a lowland ecological zone geographically situated in the alluvial plain of Central Luzon. It is within the northeastern boundary of Tarlac province, with coordinates 15°37’29.28” north latitude and 120°38’52.8” east longitude.

The municipality has 16 barangays, has a total land area of 3,142 ha, and is the fourth-smallest local government unit of Tarlac province. Agriculture is the primary land use in the municipality, with 91.6 percent (2,878 ha) of the municipality’s total land area composed of agricultural lands. Paddy rice farming predominates agricultural land use in Pura, with 74.5 percent of the total agricultural land area (2,145 ha) allocated to rice production. The built-up area accounts for only 8.4 percent (262.7 ha) of the municipality’s total land area. The remaining 1.3 ha are characterized as swamps. Other agricultural production (e.g., commercial livestock production) is not very prominent in the area.

Methods

The research team conducted primary data gathering in September 2021, specifically soil survey, soil sampling collection, and land use validation. The team followed the grid sampling scheme to collect soil samples for laboratory analysis of the soil physical and chemical properties. Figure 1 shows the location map of the study area, whereas Figure 2 shows the soil sampling grid scheme adopted in this study. Figure 3 shows the schematic diagram of the methods used in this study to assess the land productivity in the study area and the potential loss of productive lands due to ALC.

Five composite soil samples were randomly collected from each representative sampling point area. The final soil sample representative was then obtained by mixing thoroughly the composite samples collected from each sampling point. Houlong et al. (2016) cited that unlike in the simple random sampling method, minor errors may occur when the grid sampling scheme is used in an interpolation technique like the Kriging method. Data interpolation techniques are used to estimate values of unknown data points from a set of known data points.

Figure 1. Location of the study area

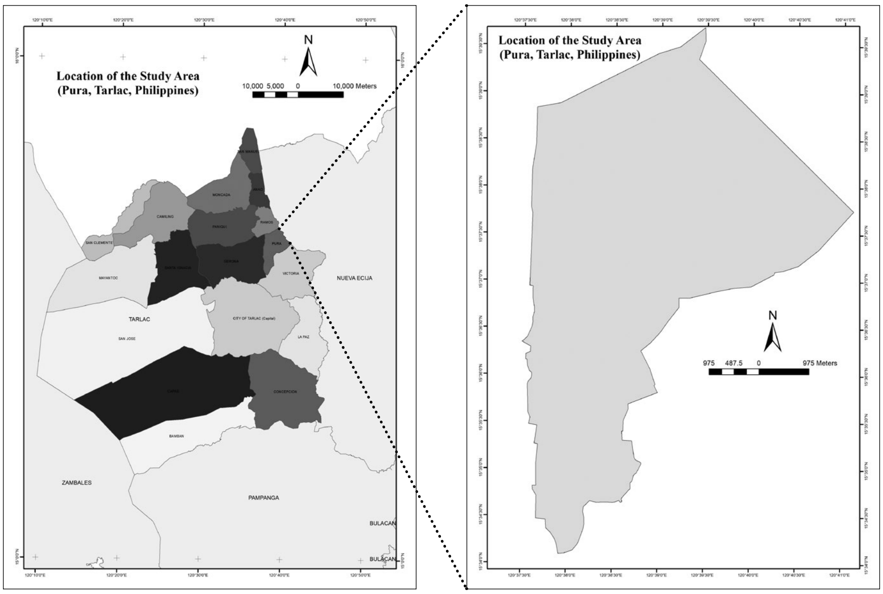
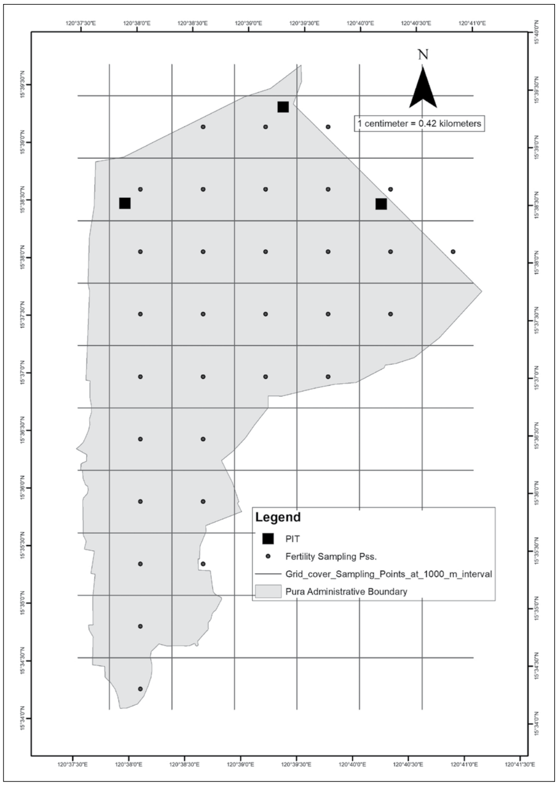


Figure 2. The soil sampling grid scheme for Pura, Tarlac, Philippines

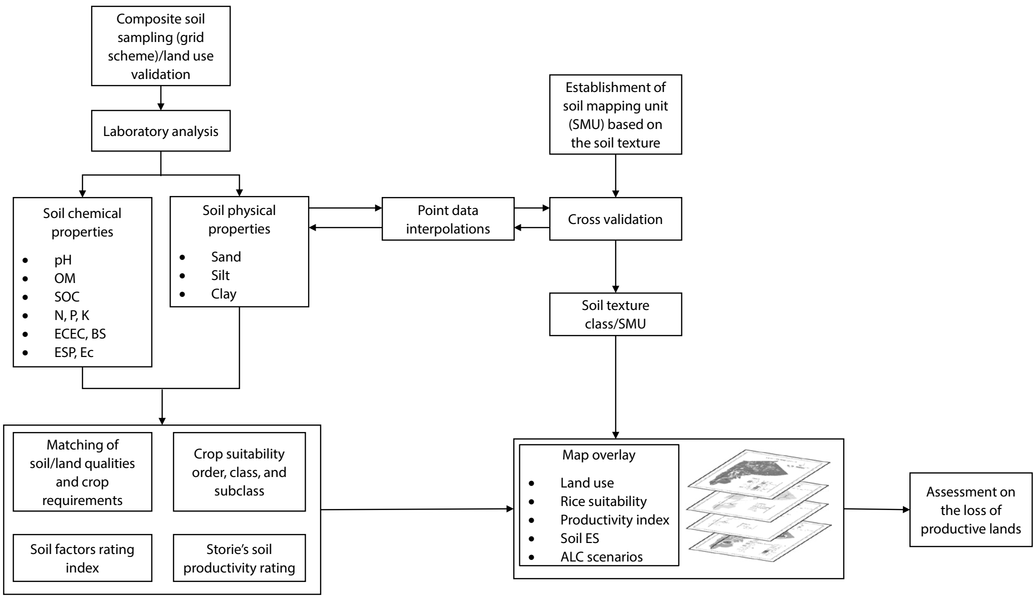


This study deals with a semi-detailed soil survey with a mapping scale of 1:25,000; thus, the sampling points must have at least vertical and horizontal distances of 1 km to fit within the minimum mappable area of 6–36 ha (Carating et al. 2008). This means that one sampling point represents approximately 25 ha. The grid sampling scheme in this study was then inputted into a QGIS software based on the identified mapping dimensions for the semi-detailed soil survey. A total of 31 sampling points were established within the municipality.

A semi-detailed soil survey approach deals with the following: detailed landforms and elements; slope units to demonstrate the geomorphology; series, complexes, or associations; soil phases and selected parameters to demonstrate the soil; plant associations and distribution to demonstrate the vegetation; land use and farming systems; specific parameters; and cropping patterns to demonstrate the land use (Landon 1991).

Soil samples were collected at a plow depth of 20 cm. The collected soil samples were air-dried and subsequently sent to a soil laboratory to analyze the following parameters: soil texture, nitrogen, phosphorus, potassium, magnesium, pH,

Figure 3. Schematic diagram of the study



effective cation exchange capacity, base saturation, electrical conductivity, exchangeable sodium percentage, soil organic carbon (SOC), and percent organic matter (OM).

Soil grouping was done to have a better representation of the land evaluation vis-á-vis its spatial distribution. Groupings are usually through landforms or other easily observable land features. Since the study area has a relatively flat relief, a soil surface texture of 0–20 cm was used in this paper for the land groupings. In relation to the spatial analysis, SMUs were used to denote the soil groupings.

Land productivity can be measured using various approaches. This study used the Storie index and FAO land suitability evaluation. Both methods focus on determining the productivity and suitability of land based on its soil characteristics.

The Storie index is a soil rating system that is based on the soil features governing the potential utilization and productive capability of the land; it is not affected by other physical and economic considerations (Storie 1932). It utilizes four factors: *factor A* rates the degree of soil profile development, *factor B* rates the surface texture, *factor C* rates the slope, and *factor X* rates the other soil and landscape properties.

In this study, each factor was rated based on the revised rating matrix of O'Geen and Southard (2015). Storie's soil productivity index rating for each SMU was computed using equation 1, whereas the productivity rating for the entire tract of land of the municipality of Pura was computed using equation 2.

Equation (1)

$$Stories\ Index\ Rating = \left[\left(\frac{Factor\ A}{100}\right) \times \left(\frac{Factor\ B}{100}\right) \times \left(\frac{Factor\ C}{100}\right) \times \left(\frac{Factor\ X}{100}\right)\right] \times 100$$

Equation (2)

$$\begin{matrix} Index\ rating\ for \\ the\ entire\ track \\ of\ land \end{matrix} = \frac{[(SMU\ 1\ index\ rating\ \times area) + \cdots + (SMU\ 5\ index\ rating\ area\ \times area)]}{100}$$

The land suitability in the study area was evaluated using the FAO framework. The framework utilizes various land characteristics: *topography* (percent slope); *wetness* (flooding and drainage); *soil physical characteristics* (surface texture, presence of coarse fragment, soil depth); *soil chemical characteristics* (apparent cation exchange capacity, base saturation, sum of basic cations, pH, organic carbon); and *salinity and alkalinity* of the soil.

These land characteristics were matched with the agronomic requirements (optimum and marginal range) of each crop that is commonly grown in the municipality (e.g., rice, corn, sugarcane, and other vegetables). The single limiting factor approach was implemented using the matrix table of Sys et al. (1991) to determine the degree of suitability of the crops. The land was rated up to the subclass category to denote the specific limiting factors.

Other soil information was gathered via a field survey following the procedures prescribed in the USDA Soil Survey Manual (USDA 2017). The survey results and results of the laboratory analysis were used as inputs to the Storie index and FAO suitability framework.

RESULTS AND DISCUSSIONS

GIS Mapping and Cross-Data Validation

Using a training set, the most accurate interpolation techniques were determined and used in this study to estimate the three soil separates (i.e., sand, silt, and clay), and subsequently generate the soil texture class map. The relative proportions of the soil separates classify soil textural classes based on the USDA's soil texture triangle.

This qualitative classification aims to simplify the classification of soil texture when conducting land evaluation.

Robinson and Metternicht (2006) recommended using ordinary kriging (OK), inverse distance weighting (IDW), and splines (SPL) as the spatial prediction method to interpolate the soil properties. The OK approach uses information about the area around the estimation location to estimate a value at a particular place in a region where a variogram is known (Wackernagel 1995). In the same manner as the OK method, the IDW approach directly implements the assumption that an attribute value at an unsampled location is a weighted average of known data points within a nearby local neighborhood (Robinson and Metternicht 2006). On the other hand, the points generated from the SPL method are fitted together to form smooth connections; the method also generates polynomials that describe lines or surface segments (Webster and Oliver 2007).

The accuracy of the chosen interpolation methods was then evaluated by estimating the coefficients of determination (R^2) and the root-mean-square error (RMSE) of all the interpolated raster. For the purpose of evaluating the interpolation results of the soil parameters, these statistical values are regarded as supplementary (Radocaj et al. 2020; An et al. 2016). The RMSE was used to evaluate the variation in the data based on absolute fit, whereas the R^2 measures the fit of the interpolated values to the regression line. A linear regression model was used to determine the R^2 values. A higher R^2 and a lower RMSE indicate a better model (Radocaj et al. 2020).

Table 1 shows the descriptive statistics of the training sets for the *sand*, *silt*, and *clay* separates. The highest *combined* (sand, silt, and clay) mean R^2 was obtained in the IDW and SPL techniques, with both having values computed at 0.19; the OK method provided the lowest value of 0.15. Meanwhile, the lowest combined RMSE was obtained in OK, with a value of 3.79. The IDW obtained a comparative value of 5.87, while SPL obtained the highest combined RMSE of 13.83. Based on the results, the OK and IDW interpolation techniques provide more accurate values than the SPL approach. The accuracy of using OK and IDW in interpolating soil separates was also manifested in the study of Radocaj et al. (2020).

Figure 4 shows the soil textural class of the ground-truth data using the soil texture triangle prescribed by the USDA. It shows that when using the IDW technique, 94.1 percent of the ground-

Table 1. Descriptive statistics for the five training sets used in cross validation of various interpolation techniques

Training Set No.	Statistical Value	IDW			OK			SI		
		Clay	Silt	Sand	Clay	Silt	Sand	Clay	Silt	Sand
Set 1	R2	0.38	0.13	0.23	0.32	0.02	0.15	0.38	0.23	0.25
	RMSE	3.67	9.04	9.36	1.03	8.82	8.37	3.67	15.15	16.99
Set 2	R2	0.04	0.01	0.19	0.07	0.10	0.34	0.04	0.30	0.15
	RMSE	5.79	3.05	3.88	0.96	2.92	3.52	5.79	17.64	24.06
Set 3	R2	0.13	0.00	0.26	0.23	0.00	0.38	0.13	0.04	0.17
	RMSE	8.33	5.72	6.98	1.47	4.78	4.84	8.33	19.59	25.48
Set 4	R2	0.52	0.23	0.34	0.01	0.20	0.20	0.52	0.22	0.20
	RMSE	4.30	4.51	4.83	1.50	1.73	4.98	4.30	12.27	14.47
Set 5	R2	0.14	0.15	0.09	0.01	0.07	0.15	0.14	0.04	0.02
	RMSE	4.35	6.46	7.78	1.98	2.49	7.37	4.35	15.58	19.75
Mean	R2	0.24	0.10	0.22	0.13	0.08	0.24	0.24	0.17	0.16
	RMSE	5.29	5.76	6.57	1.39	4.15	5.82	5.29	16.04	20.15

Notes: IDW = inverse-distance weighting; OK = ordinary kriging; RMSE = root mean square error; SPL = splines

Figure 4. Soil texture class of the ground truth data in Pura, Tarlac, Philippines

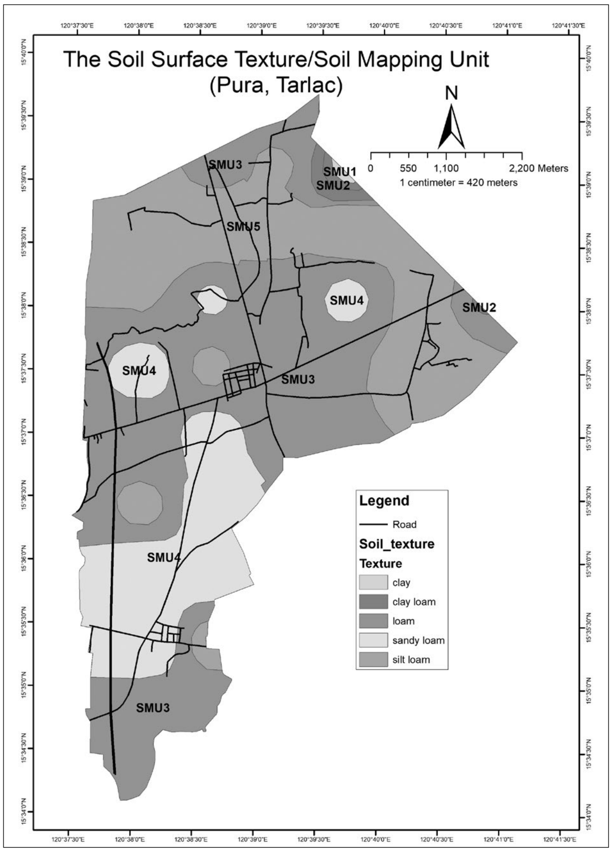
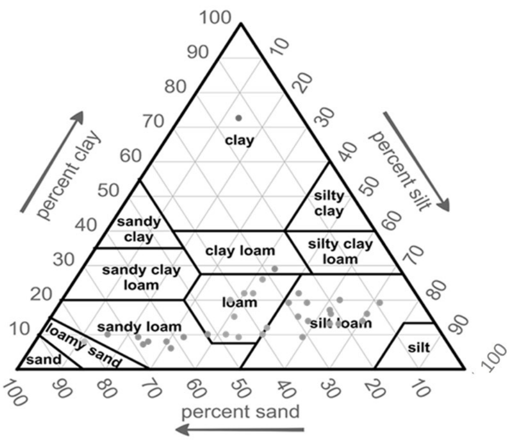


Figure 5. Soil mapping unit of Pura, Tarlac, Philippines



truth data matched the interpolated textural classification; when using the OK approach, on the other hand, more than half (55.9%) of the ground-truth data were mismatched with the interpolated textural classification. Thus, IDW was adopted in generating the soil texture class map of the municipality of Pura. Accordingly, five SMUs were established using the soil surface texture. Figure 5 shows the resulting SMU based on soil surface texture while using the IDW technique. Table 2 shows the descriptive statistics of the physical and chemical properties of the 34 sampling points, while Table 3 shows that of the combined attributes of the 34 sampling points based on their SMU groupings.

Land Characteristics

Table 4 shows the summary of land characteristics of each SMU. Each characteristic was used as input in assessing the soil productivity of the SMUs based on the revised Storie index and in determining the suitability of the land to various crops, following the FAO land suitability framework.

Topography

Yield and crop nutrient concentration have significant relationship with topography (Kumhalova et al. 2011). The FAO land suitability framework utilizes slope to group the landform according to classes. Based on the topographic map sheet 3132-III of the National Mapping and Resource Information Authority, the municipality of Pura has *<1 percent slope*. Accordingly, the FAO slope classification identifies this as flat or almost flat, which is highly suitable for the crops commonly grown in the municipality.

Wetness

In this paper, *soil drainage* and *flooding* were used as the parameters to characterize the soil wetness that affects crop production. The suitable crops that can be best grown in an area may be determined by

Table 2. Descriptive statistics for some physical and chemical soil properties of the 34 sampling points of Pura, Tarlac, Philippines

Soil Properties	Mean	Standard Deviation	%CV
Sand (%)	38.53	19.16	49.74
Silt (%)	44.64	16.61	37.21
Clay (%)	16.84	11.62	69.02
pH	6.60	0.70	10.66
moisture content (%)	2.90	1.97	67.97
OM (%)	1.13	0.55	48.36
Available P (ppm)	19.12	17.60	92.07
EA (cmol/kg)	5.47	3.19	58.28
EC (mS/cm)	0.22	0.24	108.09
Ca (cmol/kg)	5.13	2.64	51.49
Mg (cmol/kg)	2.83	1.93	68.26
Na (cmol/kg)	0.44	0.62	141.30
K (cmol/kg)	0.19	0.09	48.86
Sum Bases (cmol/kg)	8.58	4.71	54.93
ECEC (cmol/kg)	14.05	5.35	38.09
Base Saturation (%)	58.38	17.08	29.26
SOC (%)	0.66	0.32	48.35
ESP (%)	2.77	3.71	133.90
Nitrogen (%)	0.06	0.03	48.36

Notes: CV = coefficient of variation; EA = exchangeable acidity; EC = electrical conductivity; ECEC = effective cation exchange capacity; ESP = exchangeable sodium percentage

the quality of soil drainage (Abd-Elmabod et al. 2017). Good soil drainage is a requisite to improve or sustain production or to manage water supplies (Haroun 2004 as cited in Abd-Elmabod et al. 2017). Accordingly, the data show that Pura has *imperfect drainage*. This kind of drainage moderately limits the land for corn and sugarcane production and marginally limits the use of land for citrus and mango production.

Flood tolerance varies for most crops; in some cases, it seriously limits crop production (Sys, Van Ranst, and Debaveye 1991). The study area was characterized to have a flooding class of *F1 – slight*, which means that the land surface is higher than the mean highest water level albeit the occasional high floods may affect the land for a short period of time (not longer than 1–2 months). This flooding characteristic poses no limitation to the crops commonly grown in Pura municipality.

Soil physical characteristics

Soil characteristics directly and indirectly affect land qualities such as moisture availability, availability of oxygen, and availability of foothold for root development (Sys, Van Ranst, and Debaveye 1991). Accordingly, this paper used the following soil characteristics to determine the degree of suitability of land to crop production: *soil surface texture*, *coarse fragment*, and *soil depth*.

Soil texture

The results of the laboratory analysis and interpolation identify that the soil in the municipality of Pura has five textural classes: *clay*, *clay loam*, *loam*, *sandy loam*, and *silt loam*. These classes correspond to the soil grouping SMU 1, SMU 2, SMU 3, SMU 4, and SMU 5, respectively. *Sandy loam* makes SMU 4 a marginal land for irrigated rice production. Based on the study of Dou et al. (2016), rice grain yield in *clay soil* is 46 percent higher than in *sandy soil*. The authors further cited that during the grain development of rice, sandy soil may not meet the demands of the crop due to the nature of the aggregation of the sand that provides easier passage, thereby retaining less water and nutrients.

Coarse fragments

Coarse fragments composed of gravels and cobbles at the surface and up to 20 cm soil depth influence the tillage and the capacity of the soil to retain nutrients and water (Sys, Van Ranst, and Debaveye 1991). In the survey area, the team did not observe such coarse fragments; thus, the land is highly suitable for producing crops that would thrive on soils that do not have coarse fragments.

Soil depth

One important criterion in evaluating land productivity is the depth of the soil. Soil depth indicates how deep plant roots can anchor on and penetrate the soil (Sys, Van Ranst, Debaveye, 1991), which is very critical for plant growth

Table 3. Descriptive statistics for the combined attributes of the 34 sampling points based on their SMU groupings

Soil Parameters	SMU1	SMU2	SMU3			SMU4			SMU5		
			Mean	SD	%CV	Mean	SD	%CV	Mean	SD	%CV
Clay (%)	73.80	29.80	16.24	6.30	38.81	8.80	1.26	14.37	16.86	3.44	20.40
Silt (%)	12.60	42.60	42.24	4.32	10.22	24.10	7.51	31.16	60.51	6.49	10.72
Sand (%)	13.60	27.60	41.52	5.97	14.39	67.10	7.15	10.66	22.63	6.44	28.48
pH	6.37	7.55	6.41	0.42	6.55	6.20	0.41	6.58	6.90	0.86	12.49
Nitrogen (%)	0.14	0.04	0.06	0.02	33.58	0.03	0.01	32.45	0.06	0.02	37.71
Phosphorus (ppm)	21.00	5.00	29.40	22.61	76.90	16.13	13.21	81.90	14.36	14.55	101.36
Potassium (cmol kg-1)	0.39	0.14	0.18	0.07	38.23	0.24	0.14	56.25	0.16	0.05	31.91
OC (%)	1.57	0.49	0.70	0.23	33.42	0.35	0.12	32.65	0.74	0.28	37.71
OM (%)	2.69	0.84	1.21	0.40	33.44	0.61	0.20	32.67	1.28	0.48	37.72
ECEC (cmol/kg)	24.89	24.95	14.61	4.78	32.71	7.36	1.48	20.12	15.93	2.45	15.37
Base Saturation (%)	13.49	78.75	57.28	15.29	26.69	45.36	10.19	22.46	68.36	11.13	16.28
Sum of Bases (cmol kg-1)	3.36	5.14	8.80	4.66	52.99	3.39	1.31	38.64	10.98	2.47	22.48
ESP (%)	2.69	7.54	1.48	0.77	51.92	0.93	0.30	32.29	4.41	5.15	116.58

Notes: ECEC = effective cation exchange capacity; ESP = exchangeable sodium percentage; SD = standard deviation; SMU = soil mapping unit

Table 4. The land characteristics for the five SMUs, Pura, Tarlac

Land Characteristics	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5
Topography (t)					
Slope (%)	< 1	< 1	< 1	< 1	< 1
Wetness (w)					
Flooding	Occasional	Occasional	Occasional	Occasional	Occasional
Drainage	Imperfect	Imperfect	Imperfect	Imperfect	Imperfect
Physical Soil Characteristics(s)					
Surface texture	clay	clay loam	loam	sandy loam	silt loam
Coarse fragment (vol%)	none	none	none	none	none
Soil depth (cm)	134	134	134	134	134
CaCO3	no data	no data	no data	no data	no data
Gypsum (%)	no data	no data	no data	no data	no data
Soil Fertility Characteristics (f)					
Apparent CEC (cmol/kg clay)	24.89	24.95	14.61	7.36	15.93
Base saturation (%)	13.49	78.75	57.28	45.36	68.36
Sum of basic cations (cmol/kg soil)	3.36	5.14	8.80	3.39	10.98
pH	6.37	7.55	6.41	6.20	6.90
Organic carbon (%)	1.57	0.49	0.70	0.35	0.74
Salinity and Alkalinity (n)					
Ec (dS/m)	0.67	0.67	0.67	0.67	0.67
ESP	2.69	7.54	1.48	0.93	4.41

Note: CEC = cation exchange capacity

(Abd-Elmabod, et al. 2017). Based on the soil survey report of Alicante et al. (1940), two soil series have been mapped in the study area: the La Paz and Zaragosa series. These two-soil series were validated during the soil survey. They have an effective rooting depth of 112–150 cm, which indicates that the soil depth in the research site is highly suitable for growing various crops.

Fertility Characteristics

The following soil fertility characteristics were used in the study to evaluate the degree of suitability of the land to various crops: *effective cation exchange capacity*, *percent base saturation*, *pH*, and *organic carbon*.

Cation exchange capacity (CEC)

CEC influences the suitability of the land to crop production as it defines the presence or absence of mineral reserves and the capacity of the soil to retain nutrients and water, which are all crucial for crop growth and development (Sys, Van Ranst, and Debaveye 1991). In terms of soil development, they cited that a CEC of >24 centimole per kilogram clay (cmol/kg clay) is optimum for the recent soil group and 16–24 cmol/kg clay is the optimum range for intermediate soils.

As earlier mentioned, the survey team identified and validated two soil series in the study area: the La Paz and Zaragosa series. The former belongs to the soil order Entisol, whereas the latter belongs to Inceptisols. These soil orders, with respect to soil profile development, belong to the recent- to intermediate soil groups. The apparent CEC of the study area ranges from 7.36 cmol/kg clay to 24.95 cmol/kg clay. The lowest apparent CEC is a characteristic of SMU 4; thus, SMU 4 is moderately limited to most of the crops grown in the municipality.

Percent base saturation

Percent base saturation pertains to the percentage of CEC occupied by bases such as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}. Specifically, it denotes the ability of the soil to provide such cations to plants (Havlin 2005). The optimum level of base saturation varies among crops. A percent base saturation of >20 percent is sufficient to develop the land for irrigated rice production; soils with a base saturation lower than this would not be suitable for planting this crop (Sys et al. 1993). Accordingly, the 13.5 percent base saturation of SMU 1 implies that the soil in that area is not suitable for irrigated rice production.

Soil pH

Soil acidity is considered one of the most relevant factors affecting plant uptake of trace elements (Abd-Elmabod et al. 2017). Likewise, this parameter informs on the probable soil toxicities that adversely affect crop development (Sys, Van Ranst, and Debaveye 1991). Accordingly, results show that the soil in Pura has a relatively near-neutral to neutral soil pH, with pH ranging from 6.20 to 7.55; this indicates that the soil pH in the municipality poses no limitation for crop production.

Organic carbon

In highly weathered tropical soils, the organic carbon (OC) content under natural vegetation often expresses the natural fertility of the soil (Sys, Van Ranst, and Debaveye 1991). The results of this study show that the relatively low OC in the study area of 0.35–1.57 percent makes the land moderately to marginally suitable for producing various crops.

Salinity and exchangeable sodium percentage

Salinity can be considered one of the most limiting factors in agricultural development, especially in arid valleys and basins (Sys, Van Ranst, and Debaveye 1991). Excessive plant uptake of salts may accumulate, thus causing premature senescence and reduced yields (Abd-Elmabod et al. 2017). Based on the weighted average of the three pedons, the soil of Pura has significantly low salinity levels at 0.67 decisiemens per meter (dS/m). This level poses no limitation to the production of various crops.

The *exchangeable sodium percentage* is another factor to consider in land evaluation since it highly affects soil structure and permeability (Sys, Van Ranst, and Debaveye 1991). Tolerance for sodium saturation varies among crops. Based on the results, the study area has a relatively very low exchangeable sodium percentage, thereby making the research site highly suitable for most crops.

Crop Suitability

Table 5 summarizes the suitability ratings of each crop in each SMU. Note that a common limiting factor among the SMUs is their very low soil organic carbon (SOC) content ranging from 0.35 percent to 1.6 percent.

The SOC capacity is a function of texture, climate, topography, and land use management (Patrick et al. 2013). According to the European Communities (2009), coarse-textured soils tend to have lower OM than fine-textured soils. Relative to the SOC characteristic of each SMU in Pura, *SMU 1* has a fine soil texture and has the highest SOC level of 1.57 percent. *SMU 2* has a moderately fine soil texture and has a relatively low SOC level of 0.49 percent. SMUs 3 and 5 have the same soil textural grouping as medium textured soil with SOC levels of 0.70 percent and 0.74 percent, respectively. *SMU 4* has a moderately coarse soil texture and has the lowest SOC level of 0.35 percent.

Another factor that affects the level of SOC is altitude. The increase in altitude affects climatic variables such as rainfall and temperature that control soil processes, properties, and development; hence, SOC increases along with the increase in altitude (Choudhury et al. 2016; Sinoga et al. 2012; Ramesh et al. 2019). The inverse relationship between altitude and level of SOC, in which soils at lower elevations have significantly lower carbon than soils at higher elevations, was demonstrated by Saeed et al. (2019). Pura is situated at a low altitude, between 20–30 meters above sea level; hence, attaining a relatively low SOC range of 0.35–1.8 percent. Moreover, Pura farmers practice conventional tillage, which decreases SOC capacity due to the loss of OM (Doran and Smith 1987; Patrick et al. 2013).

Table 5. Summary of current and potential crop suitability ratings of Pura, Tarlac, Philippines

Crop	Suitability Rating									
	SMU 1		SMU 2		SMU 3		SMU 4		SMU 5	
	Current	Potential	Current	Potential	Current	Potential	Current	Potential	Current	Potential
Rice (irrigated)	N1f	S1	S3f	S1	S3f	S2s	S3sf	S3s	S3f	S2s
Rice (upland)	S3f	S1	S2f	S1	S2f	S1	S2f	S1	S2f	S1
Corn	N1f	S1	S3f	S1	S2wf	S1	S3f	S1	S2wf	S1
Onion	S3f	S1	S3f	S1	S3f	S1	S3f	S1	S3f	S1
Sweet potato	S3f	S1	S3f	S1	S3f	S1	S3f	S1	S3f	S1
Tomato	S3f	S1	S3f	S1	S3f	S1	S3f	S1	S3f	S1
Cowpea	S3f	S1	S3f	S1	S3f	S1	S3f	S1	S3f	S1
Sugarcane	S3f	S2s	S3f	S2s	S2wsf	S2s	S3f	S1	S2wsf	S2s
Citrus	S3w	S2s	S3w	S2s	S3w	S2s	S3w	S2s	S3w	S2s
Mango	S3wf	S2s	S3wf	S1	S3wf	S1	S3wf	S1	S3wf	S1

Notes: N1f = currently not suitable due to limitations in soil fertility characteristics; S1 = highly suitable; S2s = moderately suitable due to limitations in soil physical characteristics; S2wf = moderately suitable due to limitations in soil wetness and fertility characteristics; S3f = marginally suitable due to limitations in soil fertility characteristics; S3w = marginally suitable due to limitations in soil wetness; S3wf = marginally suitable due to limitations in soil wetness and fertility characteristics

Soil Productivity Index

Factor A

Factor A rates the soil based on the degree of soil development. Alluvial soils that are relatively young when it comes to soil development (i.e., Entisols and Inceptisols) have higher ratings compared with soil with intermediate to advanced development characterized by Bt horizon (soil subsurface layer with an increased amount of clay relative to the overlying layer) or with cemented subsurface layers that restrict root penetration (O'Geen and Southard 2015). Based on the soil survey report of Alicante et al. (1940) and on the field validation conducted in this study, Pura is characterized with Zaragosa and La Paz series. These are characterized as Inceptisol and Entisol, respectively, under the USDA soil order. Both soil orders have minimal soil development and are characterized as young soil. Thus, all SMUs received the highest rating of 100 percent for this factor.

Factor B

Factor B rates the land based on soil surface texture. Soil texture such as loam receives the highest rating while clay-rich and sandy soils have lower ratings (O'Geen and Southard 2015). Based on the GIS-assisted textural grouping performed in this study, *SMUs 3, 4,* and *5*, which are characterized by medium to moderately coarse soil textural group, have the highest rating of 100 percent. *SMU 1*, on the other hand, has clay soil surface texture and has the lowest rating of 50 percent.

Factor C

Factor C rates the land based on its slope (O'Geen and Southard 2015). The relative level, <1 percent slope of Pura corresponds to a rating of 100 percent for all SMUs.

Table 6. Summary table of Storie's soil productivity index rating for Pura, Tarlac, Philippines

Factor	SMU 1	SMU 2	SMU 3	SMU 4	SMU 5
Factor A (%)	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Effective rooting depth	100.00	100.00	100.00	100.00	100.00
Factor B (%)	**50.00**	**90.00**	**100.00**	**100.00**	**100.00**
Surface textural class	50.00	90.00	100.00	100.00	100.00
Factor C (%)	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Slope	100.00	100.00	100.00	100.00	100.00
Factor X (%)	**58.14**	**58.14**	**58.14**	**58.14**	**58.14**
pH	100.00	100.00	100.00	100.00	100.00
Ec (dS/m)	100.00	100.00	100.00	100.00	100.00
Drainage class	90.00	90.00	90.00	90.00	90.00
Erosion class	100.00	100.00	100.00	100.00	100.00
Flooding frequency	85.00	85.00	85.00	85.00	85.00
Flooding duraion	95.00	95.00	95.00	95.00	95.00
Flooding interaction	80.00	80.00	80.00	80.00	80.00
Storie index rating (%)	**29.07**	**52.33**	**58.14**	**58.14**	**58.14**
Soil grade	**Grade 4 (Poor)**	**Grade 3 (Fair)**	**Grade 3 (Fair)**	**Grade 3 (Fair)**	**Grade 3 (Fair)**

Factor X

Factor X rates the dynamic properties of soil such as drainage, alkalinity, fertility, acidity, erosion, and microrelief (O'Geen and Southard, 2015). All SMUs received a uniform rating of 58.1 percent as the product of subfactor soil pH, salinity, drainage class, erosion class, flooding frequency, flooding duration, and flooding interaction.

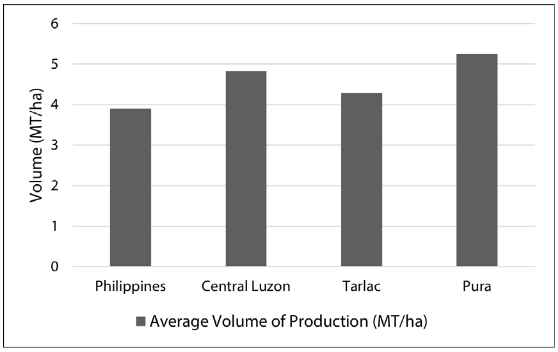
The Storie index rating of the soil in Pura was determined using equation 1. Table 6 summarizes the ratings of each factor in each SMU. The lowest Storie index rating of 29 percent was obtained from *SMU 1*, with a soil grade of *grade 4 (poor)*. This soil grade has a narrow range of agricultural possibilities; although it may be good enough for rice production, it may not be sufficient for producing other crops (Storie 1932).

The major factor affecting the soil productivity of *SMU 1* is its clay surface texture. Consistent with the suitability subclass of this SMU, the clay surface texture has *moderate limitations* for crops like sugarcane, citrus, and mango.

The rest of the SMUs have an index rating of >40 percent but <60 percent. This index range characterizes *grade 3 (fair)* soils, which are generally of fair quality but have a narrower range of suitability than the higher soil grades (Storie 1932). As a whole, the soil productivity rating of Pura is 58 percent, a *grade 3* soil suitable for producing some crops that would yield good results.

When the average yield of rice in Pura, which is the major crop grown in the study area, is compared with that at the provincial and national levels, the yield of Pura is 11 percent and 22 percent higher, respectively; however, it is 1 percent lower than the regional level (Figure 6). Based on this production volume, the adverse effect of a relatively low level of SOC did not manifest since other important agronomic requirements such as slope, wetness, soil physical characteristics, and other soil fertility indicators such as pH, base saturation, and apparent CEC (Sys et al. 1993) provide a favorable level for rice production in Pura (see Table 4). However, there is still a need to address such limitations for the sustainability of rice production in the area.

Figure 6. Comparison of the mean volume of rice production at municipal, provincial, regional, and country-wide level



Sources of basic data: (1) Data for Philippines, Central Luzon, and Tarlac from 2010–20 are extracted from Philippine Statistics Authority (PSA)-OpenStat (2022); (2) Data for Pura from 2016–20 are combined data from the Pura Municipal Agricultural Office (2010) and the Bureau of Soils and Water Management (2023)

Note: Discrepancies in the average yield of production might be attributed to the spatial coverage of the sampling population and the methodology of PSA and the Municipal Agriculture Office of Pura in data gathering.

According to Yost and Hartemink (2019), in sandy soils utilized for agriculture, the level of SOC can be enhanced through soil amendments combined with irrigation; in effect, this increases the CEC of the soil.

Fan et al. (2014) conducted a 20-year study to determine the effectivity of increasing the SOC stock to enhance crop yield by adding nitrogen (N), phosphorous (P), and potassium (K) at rates of 150 kg/ha, 32.7 kg/ha, and 124.5/kg for wheat and 150 kg/ha, 26.2 kg/ha, and 124.5 kg/ha for corn, respectively. Their results showed an increase in SOC stock of 15.6 megagram carbon per hectare (Mg C/ha) at 20 cm soil depth and at a rate of 0.05 Mg C/ha per year rate. Meanwhile, the results of Arunrat, Pumijumnong, and Hatan (2017) showed that applying NPK at an average rate of 88.74 kg/ha, 31.06 kg/ha, and 14.45 kg/ha, respectively, was positively correlated with rice yield in irrigated areas. Fan et al. (2014) also determined that applying manure every year and every other year was positively correlated to rice yield in irrigated areas. The findings of Fan et al. (2014) and Arunrat, Pumijumnong, and Hatan (2017) imply that the combined application of inorganic and organic fertilizer is effective in increasing crop yield and SOC sequestration (Bi et al. 2009;Yan et al. 2013).

Rice production can increase by 10–50 kg/ha per year for every 1 Mg C/ha (Lal 2006). The data in Table 4 shows that the level of SOC (except for *SMU 1*) in the study area is less than 0.74 percent, which makes the land marginally suitable for rice production. If this level is raised to at least 0.8 percent (Sys et al. 1993) and considering that the other land characteristics in Pura are favorable, all SMUs (except *SMU 1*) has the potential to optimize rice production as shown in potential suitability rating in Table 5. The exception of *SMU 1* is due to its severe limitation in the level of base saturation (13.5%). Moreover, all SMUs were found to be productive lands based on the results of the land suitability evaluation, the soil productivity assessment, and on the rice production data shown in Figure 4.

Farm size, farm slope, and distance to the nearest cities and highways are the primary driving forces of ALC (Levia and Page 2000). The results of this study show that the indicative soil productivity and crop suitability of the land in Pura, its relatively flat surface level (< 1% slope), and its proximity to urban cities and major roads (i.e., TPLEx and national and provincial roads) make the lands in Pura conducive to ALC.

Other factors predispose the lands in Pura to ALC. For one, productive lands, such as those in Pura, command higher prices than less productive lands in the market (Irawan 2008); thus, landowners are more inclined to sell their lands. Drozd and Johnson (2004) cited that landowners are willing to fragment their lands because highly productive lands command higher prices in the market. For another, Pura is mostly composed of flatlands, which are more conducive for residential, commercial, and industrial development than those lands with higher slopes. The cost of construction on flatlands is typically lower than that on uneven lands (Nelson 1990) due to the high cost of leveling; thus, it is less profitable to develop infrastructure on farmlands with slopes >15°. Hence, most ALCs occur in farmlands with relatively flat surfaces (Azadi, Ho, and Hasfiati 2011).

Agricultural Land Conversion Scenario

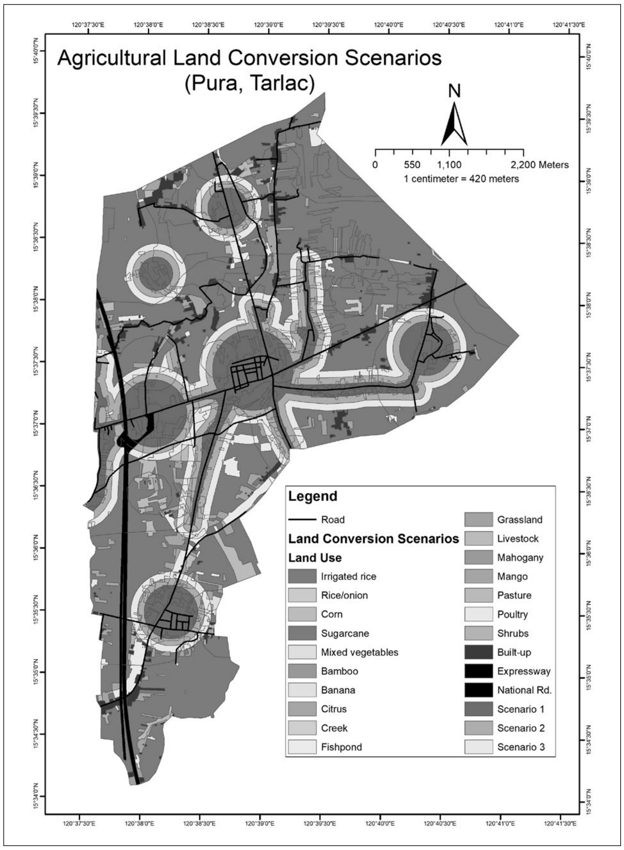
This study developed three scenarios to measure the potential loss of productive land in the municipality of Pura. *Scenario 1* is the business-as-usual scenario, which assumes the full implementation of the proposed spatial development strategy in the existing CLUP 2013–22 of the municipality of Pura. *Scenario 2* assumes that land conversion will be expanded by the end of 2032, with an additional 100 m of land to be converted in areas beyond the spatial development area cited in *scenario 1*. Lastly, *scenario 3* assumes that land conversion will further be expanded by the end of 2042, with an additional 100 m of land to be converted in areas beyond the spatial development area cited in *scenario 2*.

According to Karlen (2005), soil productivity, in general, is measured by comparing the inputs (any production requirement) with the output, which typically refers to the crop yield. FAO (1976) defines the suitability classes as follows:

1. *Highly suitable (S1) land*. This land class has no significant limitation or minor limitations relative to the physical and chemical characteristics of the land important for crop development (Sys et al. 1993) and will not significantly increase the inputs above the acceptable level when used. Likewise, the productivity or the benefits gained from the land will not decrease over time in its usage.
2. *Moderately suitable (S2) lands*. Moderately suitable lands are those with moderately severe limitations in their usage and require additional inputs to be productive. The output from this type of land is notably inferior to that from S1 land, albeit still attractive.
3. *Marginally suitable (S3) lands*. This type of land has severe limitations in its usage to the extent that the input level marginally justifies the output.

Following the definitions of suitability classes, *S1* and *S2* are used to indicate land productivity (see Table 5). The potential suitability of the land was used in assessing the land in Pura since the low SOC level of soil in the municipality can be easily

Figure 7. Spatial extent of the assumed ALC scenarios for Pura, Tarlac, Philippines

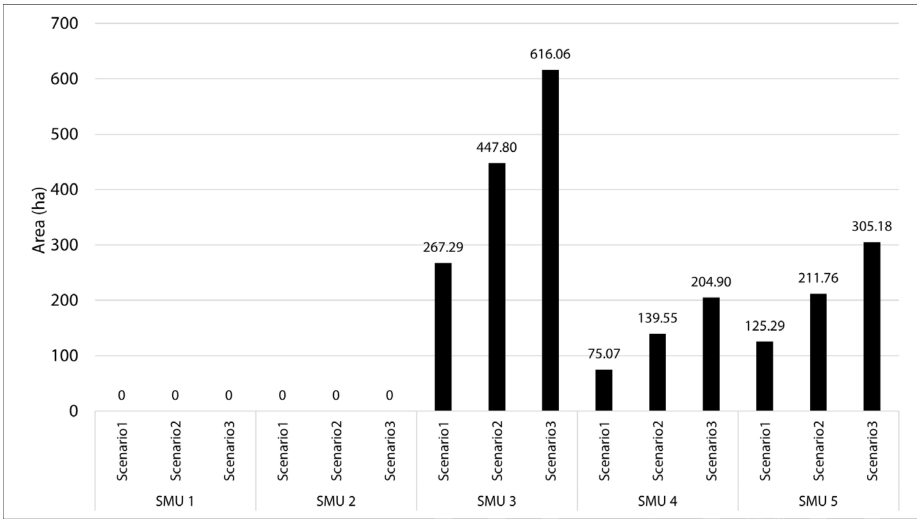


managed. Considering all these, the results show that *SMU 3* would incur the highest loss of productive agricultural land among all three scenarios.

The maps of the three land conversion scenarios were then superimposed on the potential suitability map and the soil productivity index map that had been earlier developed such that the potential loss of productive lands in Pura can be assessed (Figure 7). Based on this map overlay, in *SMUs 3, 4,* and *5*, the predisposed productive land is high to moderately suitable for crops such as rice, corn, onion, sweet potato, tomato, cowpea, sugarcane, citrus, and mango. Also, the predisposed productive land has a *soil productivity index rating* of 58.1, and a *grade 3 soil (fair soil)*.

Further, Figure 8 shows the expected loss of productive lands in the municipality should the planned ALC be implemented. By the end of *scenario 1* (2022), an approximate aggregate area of 468 ha would be lost if the linear spatial development plan of the municipality pushes through. By the end of *scenario 2* (2032), an additional 331 ha

Figure 8. Estimated loss of productive land per SMU per scenario due to ALC in Pura, Tarlac, Philippines



Note: The spatial location and extent of SMUs 1 and 2 in the northeastern part are outside of the spatial coverage of the three scenarios. Thus, no data is reflected.

Table 7. Potential environmental implication of SOC management

Soil Parameter	Degree of Limitation	Management[1]	Environmental Implication[2]
Soil organic carbon	Marginal (S3) for most crops grown in Pura.	• Soil mulching, green-manure crops (legumes or forage grasses) should be incorporated into the topsoil. • Crop residues (e.g. rice straw) should be retained in the field where the crop has grown. • Crop residues should not be burned to avoid loss of carbon in the form of carbon dioxide. • Use of minimum or zero-tillage	• Less irrigation water needed • Less fertilizer and pesticide application • Increased water recharge • Decreased water pollution • Land degradation is lesser • Increased plant production • Increased carbon sequestration

Sources: [1]Moody and Phan (2008; [2]Weil and Brady (2017)

would be lost, and by the end of *scenario 3* (2042), another 327 ha of productive lands would be lost due to ALC.

Environmental Implications

The 2013–20 CLUP of Pura reported that the municipality has three cropping seasons. Most barangays practice rice production during the main cropping season; rice, corn, or sugarcane are planted during the second cropping season; and lastly, either root crops or corn are planted during the third cropping season. As such, mulching, as a crop residue management, can be a cheap and effective way to enhance the soil fertility associated with low SOC. According to studies, mulching modifies the soil moisture and temperature regimes and can impact the soil flora and fauna. These ultimately enhance the SOC pool (Duiker and Lal 1999; Sharma and Acharya 2000; Ramesh et al. 2019). Legumes like cowpea and mung bean are recommended as either cover crop or catch crop during the third cropping season. Also, rice straw or corn stover from the previous cropping seasons should be used as soil mulch.

Rice straw has an average carbon-to-nitrogen ratio of 50.57 C/N (Jusoh, Manaf, and Latiff 2013; Qiu et al. 2012; IRRI 2019), and corn stover has a C/N ratio of 57 (USDA NRCS 2011). On the other hand, the leaf and branch of mung bean have a mean C/N ratio of 18 (Algan and Celen 2011), whereas the average C/N ratio of cowpea is 17 (USDA NRCS 2011). Accordingly, rice straw and corn stover have slower decomposition rates than the leguminous substrate based on their C/N ratio. The sequencing of high and low C/N ratio is ideal such that nutrients will be available to the next cropping season. In the long run, this practice can enhance various soil characteristics and qualities. However, fertilizers should be used judiciously, and irrigation should be provided during the initial stage of this practice to enhance biomass production.

Addressing or managing the low SOC of Pura could lead to various positive environmental consequences. Weil and Brady (2017) demonstrated that adding plant and animal residues to the soil will eventually lead to less volume of irrigation water needed, less use of fertilizers and pesticides, increased water recharge, decreased water pollution, less land degradation, increased plant production, and increased carbon sequestration. Table 7 shows the degree of limitation, recommended management, and environmental implications in addressing/managing SOC.

Significance of Soil Productivity and Crop Suitability in Policymaking

Various laws, issuances, and guidelines have already been issued to protect and rationalize land use reclassification and agricultural land conversion in the Philippines. One prominent law that has been passed several decades ago is the Agriculture and Fisheries Modernization Act of 1997 (Republic Act No. 8435). This law mentions the Network of Protected Areas for Agricultural and Agri-Industrial Development (NPAAAD), within which are Strategic Agriculture and Fisheries Development Zones (SAFDZ). The former are areas classified within the alienable and disposable land (A&D land) of the country with various land uses. The latter are zones delineated as prime for agriculture within the NPAAAD.

Either one of the results from the crop suitability evaluation or from Storie's soil productivity assessment in this study could justify that the entire tract of land of Pura, with the exemption of SMU 1, is indeed viable and sound for agricultural purposes. Thus, the remaining agricultural lands of Pura mapped within SMUs 1–5 could be delineated as part of the NPAAAD and ultimately (except for SMU 1), a SAFDZ. Through this, the remaining agricultural lands of the municipality could be protected from ALC.

Notwithstanding the above, ALC is inevitable due to the growing population. The municipality must then have strong and rational CLUP or zoning ordinances to secure the needs of its localities while advancing and modernizing its agriculture sector. One way to attain this is to integrate SAFDZ into the municipality's CLUP.

CONCLUSION

Using IDW as the spatial prediction model, five SMUs were established in the municipality of Pura that corresponds to varying degrees of soil chemical and physical properties. These properties were then used as the inputs to FAO's crop suitability and Storie index of soil productivity.

The results show that the soil in Pura municipality was determined to be currently not suitable and only marginally suitable for crop production due to its low SOC. However, this issue can be easily addressed through soil amendments and through proper irrigation. Hence, the potential suitability of the soil of Pura indicates promising productivity for crops such as rice, corn, onion, sweet potato, tomato, cowpea, sugarcane, citrus, and mango.

The problem of low SOC can be easily addressed or managed through irrigation and through a combination of organic and inorganic fertilization. Using organic fertilizer can be practical since the sources would not be costly and the raw materials/litters are readily available every cropping season. Raising the SOC level will not only enhance the suitability and productivity of the soil but will also lead to various environmental benefits.

Most of the remaining agricultural land of Pura, except those within SMU 1, has been assessed to have *grade 3 soil (fair soil)*. Using equation 1, the soil productivity index rating is estimated to be between 52.3 percent and 58.1 percent. Meanwhile, although SMU 1 has *grade 4 soil (poor soil)*, the entirety of Pura's remaining agricultural lands has *grade 3 soil*. Using equation 2, the soil productivity index rating of Pura is calculated to be 58 percent. This is because the 5 ha area of SMU 1 is insignificant to the overall productivity rating in relation to its spatial extent.

The soil productivity and suitability of Pura, its relatively flat surface (<1% slope), and its proximity to cities and major roads are drivers of ALC in the municipality. Furthermore, ALC in Pura is inevitable due to the increasing population. The existing CLUP of the municipality proposes to implement a concentrated linear development plan, which is a spatial strategy that will carry out the development goals and vision. Accordingly, three scenarios were constructed in this study based on the assumption that the land area that will be converted will continue to expand by an additional 100 m by 2032 and another 100 m by 2042 for residential, industrial, and commercial areas that skirt Pura's basal (2013–22) spatial strategy. Accordingly, it is projected that SMU 3 would incur the highest loss of productive lands in the next two decades.

The remaining agricultural lands of the municipality of Pura, especially those within SMUs 2–5, can be justified as part of the SAFDZ since they are viable and sound for agricultural purposes. The productivity of the land in the municipality could benefit both agriculture and ALC; however, whichever spatial strategy or policy direction for ALC that the municipality of Pura pursues, the municipal government should best be informed through carefully evaluating the opportunity costs of conversion. This study has demonstrated a technical approach to making such an assessment based on soil quality analysis. In the case of the municipality of Pura, formulating strong and rational land use plans or zoning ordinances would best include integrating the SAFDZs into its CLUP.

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