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Mapping Suitable Areas of Central Luzon, Philippines for Aerobic Rice Production Using GIS-Based Land Suitability Analysis

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ABSTRACT

Aerobic rice technology is a production system which involved drought-tolerant rice varieties grown in non-flooded and non-puddled soil in water-scarce areas with appropriate cultural management practices aiming at yield level up to 6.0 tons ha. The study presented suitability maps and spatial data to aerobic rice under different production environments of the Central Luzon Region, Philippines. Simple limitation approach (SLA) was used to derive the overall suitability of aerobic rice production in these areas. Spatial datasets gathered from official sources were likewise used. Of the seven provinces, Nueva Ecija had the biggest potential area of 547,735.80 hectares with 11.49% marked as highly suitable to aerobic rice technology, followed by Bulacan which had a potential area of 255,022.52 hectares with 6.15% marked as highly suitable. Pampanga, Tarlac, Zambales, Aurora and Bataan followed with 6.15 %, 5.88 %, 2.65 %, 1.59 %t and 1.56%, respectively, of their corresponding potential areas suitable for aerobic rice production. The total land area in Central Luzon which was found to be highly suitable for aerobic rice production was 126,959.91 hectares. On the assumption that ART could give an average yield of 4.5 tons per hectare, Central Luzon can supply an additional 571,319.59 metric tons of aerobic rice annually.

***Keywords* —** Geographical Information System, Agroecological Requirements, Simple Limitation Approach, Philippines

INTRODUCTION

Intensification of rice production and other staples has been the top priority of the Philippine government in addressing the prevailing and even aggravating problem of the country on food security which is also a global challenge. Water is a critical requirement for rice production. At present, the world is faced with the increasing scarcity of water that has become a serious threat for traditional rice cultivation practices (Tuong & Bouman 2003). Irrigation water for agriculture consumes 2/3 of the fresh water, and in Asia, rice alone exhausts more than 50 percent of the water used. Tuong and Bouman reported that by 2025, it is expected that 2 million ha of Asia's irrigated dry season rice and 13 million ha of its irrigated wet season rice will experience "physical water scarcity," and most of the 22 million ha of irrigated dry season rice in South and Southeast Asia will suffer "economic water scarcity".

With the decreasing water resources for rice cultivation, researchers, plant breeders and development workers prompted to develop water-efficient aerobic rice varieties by combining the drought-resistant characteristics of upland varieties with the high-yielding traits of lowland varieties (Belder, Spiertz, Bouman, Lu,& Tuong, 2005). Aerobic rice technology (ART) is a new cropping system involving the growing of rice variety in non-flooded and non-puddled soil using supplementary irrigation.

The ART is said to be appropriate in the different environments, namely: (1) water-short irrigated areas (irrigation system tail-ends); (2) favorable uplands, rainfed areas, with or without supplementary irrigation; (3) areas where the dry and wet seasons transition is not too abrupt, thus allowing establishment in dry moist soil; and (4) soils where percolation rate is very high.

Rice and Population Situations, and the Road to Rice Self-sufficiency

According to the Bureau of Agricultural Statistics, for the same period between 2008 and 2012, the average *palay* production in the Philippines was at 16,714,154 metric tons annually. Production bottomed out in 2010 at

15,772,319 metric tons from a previous high of 16,815,548 metric tons in 2008, but steadily increased since then to reach 18,032,422 metric tons in 2012.

Region III is considered as the “Philippine Rice Granary.” It cradles the Central Luzon plain which is a contiguous area that produces almost a fifth of the total volume of *palay* production in the country. The provinces of Nueva Ecija and Tarlac contribute, more or less, 2 million metric tons of rice annually and the remaining four provinces with less than half million each annually. In 2012, the region reached an annual production of 3.2 million metric tons of palay.

Rice is the staple food among Filipinos. In 2008 alone, rice consumption for each person stood at 128.1 kilograms. It dipped to 114.81 kg two years later but rebounded slightly to 117.14 kg in 2012. For the 5-year period between 2008 and 2012, the per capita rice consumption averaged 119 kilograms annually. Using the 2008-2012 annual per capita rice consumption average, which is 119 kg, we can then estimate the amount of rice consumed per province for the entire country in 2014. Metro Manila, Cebu, the provinces in Central Luzon and CALABARZON, Pangasinan, Iloilo, and Negros Occidental lead the list of provinces that require large quantity of rice supply to feed their population.

In 2010, the Philippine population was recorded at 92,337, 852 (BAS, 2014). Based on the 2000-2010 growth rate, which is 1.90 percent at the national level, but varies per province, the Philippine population is estimated to be just under 100 million people in 2014, a year before the next round of national census is conducted in 2015. Metro Manila, the most populous region in the country, is expected to have topped the 12-million mark.

The population in Region 3 reached 10,137,737 in 2010, growing at a rate of 2.14 percent annually. Bulacan and Pampanga are seen to exhibit faster population growth and land use conversion from agriculture to non-agriculture uses because of Metro Manila’s northward urban expansion. Consequently, demand for rice for consumption is highest in Pampanga and Bulacan while deficit in locally produced rice supply is expected to be observed in Zambales, Bataan, Pampanga, and Bulacan as these provinces do not produce much rice to feed the growing population.

Assuming that utilization of *palay* production goes entirely to consumption and that the rice milling recovery rate is pegged at 65%, existing data show that although the provinces of Nueva Ecija, Isabela, Cagayan, Iloilo and Pangasinan have rice surpluses under these assumptions, their rice stocks can easily be pulled down by over a million metric tons rice deficits in Cebu and Metro Manila as well as those provinces in yellow.

The Philippine population has been increasing at around 2% per annum, but the geography has not changed, that is, relatively small tracts of land and the absence of vast and fertile river deltas for rice farming. The Philippines, being an island nation, is battling a formidable force of nature in trying to achieve rice self-sufficiency.

These, coupled with irrigation infrastructure not properly maintained or insufficient to cover more potentially productive areas, and lack of quality transportation infrastructure which hinders efficient rice trade, are pointed out as the bottlenecks which conspire to offer a bigger challenge to attaining rice self-sufficiency.

Research Efforts to Address Rice Insufficiency

Given all these challenges facing the rice sector which has direct impact on food security, local and international experts, fortunately, have not been remiss to search for answers.

Among the technologies that were developed as a response to this looming problem include hybrid rice. Casiwan (2007) reported that hybrid rice, which is a product of cross-pollinating two uniquely superior rice lines, could offer an increased farmers' yields and income more than what could be achieved by other modern varieties. However, data showed that yields of hybrid rice varied across season and location. Production area of hybrid rice, therefore, should be targeted geographically and seasonally.

Farm mechanization is another means to improve rice yield. In a study conducted by the International Rice Research Institute in 1999, Montoya and Dawe (2007) noted that rice production costs in the Philippines were higher compared to those of the neighboring countries. Costs of machinery and labor accounted for most of the difference. Adopting the combination of harvester-thresher and direct seeding was seen to lower the cost of rice production.

Likewise, improved Nitrogen management is also employed to address the problem. Dawe, Moya, Gascon, Valencia, and Jamora (2007) observed that Filipino farmers used insufficient amounts of nitrogen especially during the dry season when it would be beneficial to use more nitrogen fertilizer because of abundant sunlight which provides energy required for plant growth.

The Need for Spatiotemporal Targeting

Casiwan (2007) remarked that hybrid rice production was more profitable than inbred variety during the dry season provided that location was suitable.

Thus, there is a need to systematically locate areas whose agro-ecological conditions are suited to hybrid rice production. Furthermore, E. C. Godilano maintained that programs in agriculture and natural resources management would be more effective in the future if they were geographically targeted (personal communication, October 19, 2005).

Land Evaluation

In the broader context, land evaluation concerns with determining the present land performance for specific land use. Climate, soil, vegetative cover, and other information are assessed in terms of the requirements of a range of alternative land uses (FAO, 1977).

Within the confine of agriculture, this means assessing a piece of land for its ability to provide optimum conditions required for maximum crop growth and development. Land suitability is the fitness of land for defined crops types: rice, corn, vegetable, etc. Specification of agro-ecological requirements of crops is scaled and matched with land suitability rating.

With the advent of GIS and Remote Sensing technology, identification of these different production environments could now be possible and be done in more systematic and scientific manner even with limited financial resources.

It is in this context to facilitate the identification and production of maps on the production of aerobic rice in the different production environments that this undertaking was conceived.

OBJECTIVE OF THE STUDY

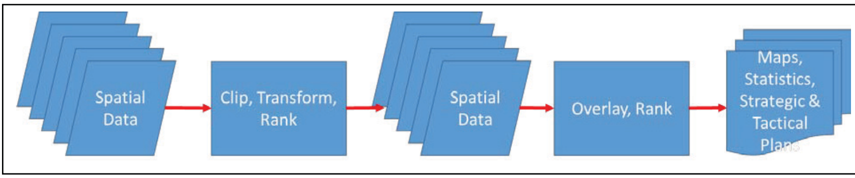
The study was conducted to determine the suitable areas of Central Luzon for aerobic rice production using the GIS-Based Land Suitability Analysis. Specifically, the aimed to show in two-dimensional map all potentially suitable areas for aerobic rice production in Region III.

METHODOLOGY

Simple Limitation Approach and Geoprocessing Model

The simple limitation approach (SLA) was used in deriving the aerobic rice suitability of Region 3. This means that instead of assigning qualitative grade such as “Moderately Suitable”, “Highly Suitable”, etc., which could mean different things to different people, limiting factors that were present in specific geographic location are listed and adopted for that location.

The following graphic (Geoprocessing Model) summarized the steps undertaken.



The SLA framework involves three steps (Godilano & Abunda, 2004):

1) Development of strategic options using expert criteria to identify the desirable ranges of conditions that would most favor successful commodity domain;
2) Integration and convergence of thematic maps and databases that determine suitability limitations; and
3) Coordination of conditions that exhibit spatial dependency against the similarly characterized spatially-referenced databases.

The first step in conducting the land suitability analysis for aerobic rice production in Region 3 involved the identification of the agro-ecological requirements of aerobic rice for optimum production based on repeated observations across experimental stations and experiences from adopters of the technology from around the world. In general site suitability analysis, these requirements are called *criteria*.

Spatial datasets were gathered from different government agencies and official sources. Each dataset was assessed for fitness in the analysis and relevance to the specified criteria. Necessary data transformations were carried out on each dataset.

Overlay of datasets was performed to determine coincidence and proximities. Geoprocessing tasks were executed within ArcGIS environment.

Agro-ecological Requirements

Aerobic rice varieties are grown in well-drained, non-puddled, and non-saturated soils. The following conditions are appropriate management practices of aerobic rice which can bring about a yield of up to four to six tons per hectare (IRRI, 2009):

- Soil: well-drained and coarse-textured, loam soil;
- Slope: Flat to undulating;
- Irrigation: insufficient water to keep lowland rice fields flooded for a substantial period of time but just enough to bring moisture content to or close to field capacity. Tail-end part of large-scale surface irrigation system qualifies;
- Groundwater potential (for supplemental irrigation): Deep groundwater table;
- External input: access to fertilizer is necessary.

Spatial Datasets Used

This study utilized the following spatial datasets to achieve its objectives. These included: (1) rice ecosystem; (2) land classification; (3) soils texture; (4) groundwater potential; and (5) terrain/slope. These land characteristics are attributes of land that can be measured or estimated (FAO, 1977). The suitability of aerobic rice is not determined by rice ecosystem alone but by the interaction between the above mentioned land characteristics and other agro-ecological parameters.

Land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of land use (FAO, 1977).

Land suitability is defined as the fitness of a given type of land for a defined use. The qualitative rating "**Highly Suitable**" which reflects the degree of sustainability, was not used. Instead, to characterize the fitness of a given type of land characteristics for ART, the "**No Limitation**" qualitative rating was employed to mean that a particular area within the given province satisfactory meets all suitability criteria for ART. However, to be more comprehensive, the GIS Experts also indicated "**with Limitation**" to reflect what criterion or land characteristic(s) is absent or lacking.

The following were the spatial data used in the land suitability analysis for ART:

Rice Ecosystem

The rice ecosystem data delineates the irrigated from non-irrigated rice areas. This dataset came from the Bureau of Soil and Water Management (BSWM) of the Department of Agriculture (DA). It suffers the problem of currency as this dataset reflects with justifiable certainty only the conditions of the ground in the 1990s. It is, however, assumed that the true ground conditions have not changed much since then.

As shown below in Figure 1, not all rice ecosystem types in Region III qualify for aerobic rice technology (ART) production site.

To avoid conflict with paddy rice production, the NIA-irrigated areas along with candidate areas for NIA irrigation, were excluded. Based on this criterion, there are 423,755 hectares in Region 3 available for ART production under rice ecosystem as presented in Table 1.

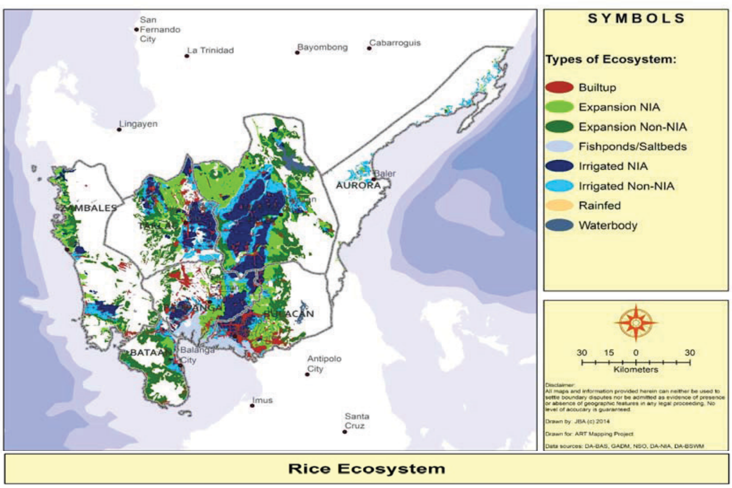


Figure 1. Rice ecosystem types in Region 3

Table 1: Rice ecosystem statistics in Region 3

Rice Ecosystem	*Not suitable ART	*Suitable ART ecosystem	***Grand Total**
Expansion NIA	182,978	0	*182,978*
Expansion Non NIA	0	268,468	*268,468*
Irrigated NIA	209,399	0	*209,399*
Irrigated Non NIA	0	154,946	*154,946*
Rainfed	0	341	*341*
Grand Total	***602,800***	***423,755***	***816,132***

**Values are in hectare*

Land Classification

According to Article XII, Section 2 of the Philippine Constitution, "all lands of the public domain, waters, minerals, coal, petroleum, and other mineral oils, all forces of potential energy, fisheries, forest or timber, wildlife, flora, and fauna, and other natural resources are owned by the State. With the exception of agricultural lands, all other natural resources shall not be alienated."

Under the Land Classification, the Alienable and Disposable land classes are used for ART production. The "No Data" classification should be verified with the DENR to determine their appropriate suitability. A total of 1,054,726 hectares lands classified suitable for ART assuming that all other three factors are presents. Figure 2 shows the land classification for Region III, while Table 2 presents the land classification statistics in the Region.

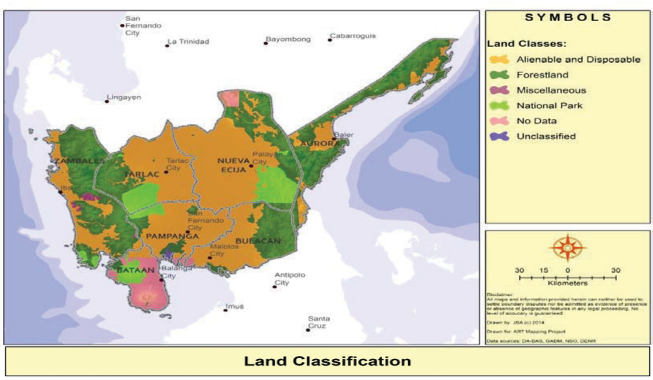


Figure 2. Land Classification in Region III

Table 2. Land classification statistics for Region 3

Land Classes	*Not suitable ART land class	*Suitable ART land class	*Grand Total*
Alienable and Disposable	0	1,054,726	*1,054,726*
Forestland	791,730	0	*791,730*
Miscellaneous	8,611	0	*8,611*
National Park	154,792	0	*154,792*
No Data	111,135	0	*111,135*
Unclassified	87	0	*87*
Grand Total	***1,066,355***	***1,054,726***	***2,121,081***

**Values are in hectare*

Soil Texture

Based on agro-ecological requirements for ART production, coarse-textured, loamy soils favor aerobic rice.

The soil data was sourced from BSWM. It shows the different soil texture categories. From this data, loamy or loamy sand soils for ART production were selected.

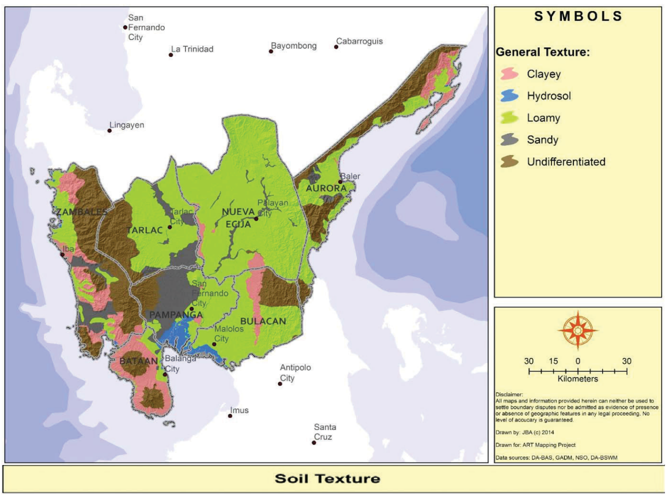


Figure 3. Classification of soil texture in Region III

There are five (5) soil classes in Region III, of which sandy and loam soils are considered best suited for ART production. There are a total of 1,148,746 hectares of land in the Region that possess that land characteristics, as seen in Table 3.

Table 3: Soil texture statistics in Region 3

Soil Texture	*Not suitable ART soil	*Suitable ART Soil	*Grand Total*
Clay	239,018	0	*239,018*
Hydrosol	38,522	0	*38,522*
Loam	0	1,148,198	*1,148,198*
Sand	195,213	548	*195,761*
Undifferentiated	489,141	0	*489,141*
Grand Total	***961,894***	***1,148,746***	***2,110,640***

Values are in hectare

Terrain Slope

Figure 4 shows the terrain slopes in Region III. The level to nearly level (0-3%), and gently sloping to undulating types of slope are land characteristics included in the assessment for ART production in Region III.

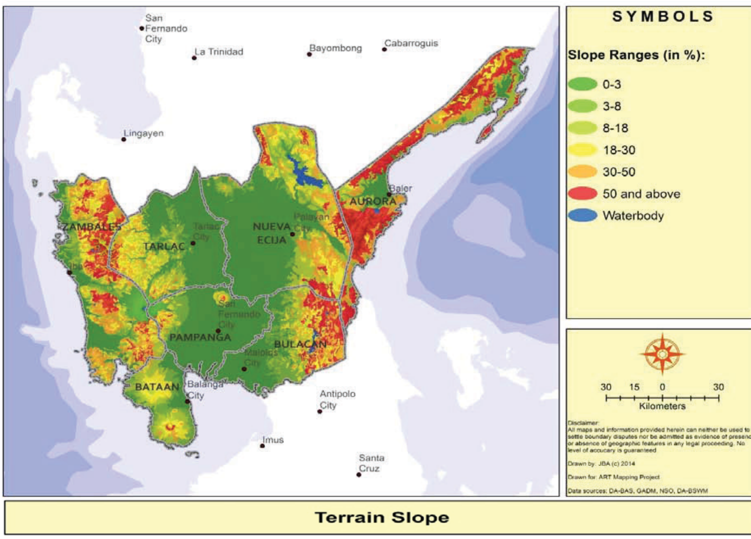


Figure 4. Slope ranges in Region III

Table 4: Slope statistics in Region 3. Values are in hectares

Slope Categories	*Not suitable ART slope	*Suitable ART slope	*Grand Total*
Gently sloping to undulating	0	170,550	*170,550*
Level to nearly level	0	875,939	*875,939*
Rivers	16,871	0	*16,871*
Rolling to moderately steep	243,397	0	*243,397*
Steep	260,803	0	*260,803*
Undulating to rolling	274,630	0	*274,630*
Very Steep	280,222	0	*280,222*
Grand Total	***1,075,922***	***1,046,489***	***2,122,412***

**Values are in hectare*

The desirable slope for ART production ranges from flat to undulating terrain. As shown in Table 4, there are about 1,046,489 hectares suitable for ART production in Region 3.

Groundwater Potential

Groundwater potential determines how hard it is to extract groundwater for supplemental irrigation. More often, aerobic rice needs supplemental irrigation mostly when hair-like forming crack on the rice field started to manifest and water is insufficient to frequently bring the soil water content close to field capacity. Experiments have shown that water requirement of ART ranges from 470 mm to 650 mm for the entire growing period.

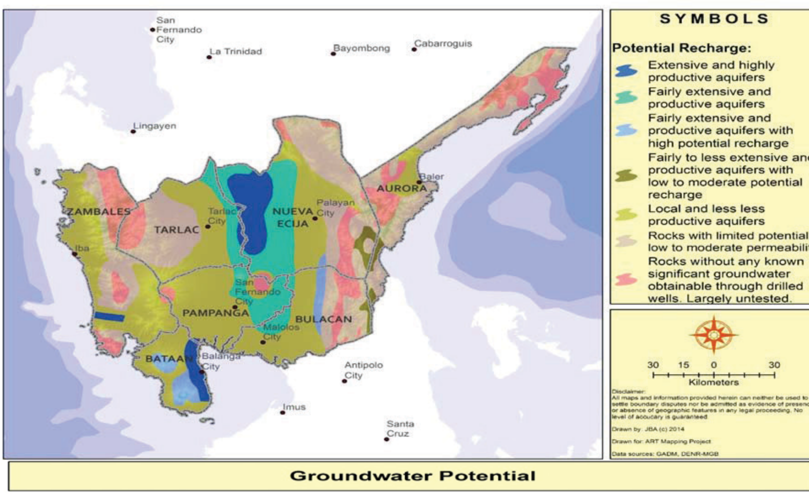


Figure 5. Groundwater potential in Region III

Table 5. Groundwater potential in Region III

Categories	*Not suitable ART GWP	*Suitable ART GWP	*Grand Total*
Extensive and highly productive aquifers		114,962	*114,962*
Fairly extensive and productive aquifers		237,498	*237,498*
Fairly extensive and productive aquifers with high potential recharge		51,127	*51,127*
Fairly to less extensive and productive aquifers with low to moderate potential recharge		29,580	*29,580*

Categories	*Not suitable ART GWP	*Suitable ART GWP	*Grand Total
Local and less productive aquifers		822,037	*822,037*
Rocks with limited potential, low to moderate permeability	571,803		*571,803*
Rocks without any known significant groundwater obtainable through drilled wells. Largely untested	292,221		*292,221*
Grand Total	***915,150***	***1,255,204***	***2,119,228***

**Values are in hectare*

As presented in Table 5, there were about 1,255,204 hectares of land in Region III with groundwater potential highly suitable for ART.

RESULTS AND DISCUSSION

This portion summarizes the results of land suitability analysis and mapping to aerobic rice cultivation in the provinces of Aurora, Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac and Zambales.

Figure 6 shows the map of Region 3 with reference to the provinces' level of suitability to ART.

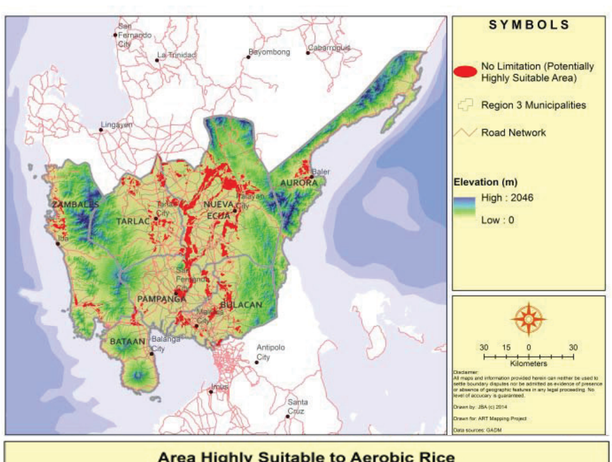


Figure 6. Two-dimensional Maps of Aurora, Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac and Zambales Highly Suitable to Aerobic Rice

ART Suitability in the Province of Aurora

The Province of Aurora registered with a total area of 302,547.83 hectares suitable for ART. However, only 4,817.17 or 1.59 percent of this figure were found to be highly suitable (No Limitation) for ART production. These 4,817.17 hectares were located and distributed in the five (5) municipalities of the province, namely: Baler, Dingalan, Dipaculao, Maria Aurora and San Luis (Table 6). Among the five municipalities, Dipaculao registered to have the biggest area with no limitations with a total aggregate area of 1,990.12 hectares while Dingalan shared the least with only 83.66 hectares that could be cultivated for ART.

At the barangay level, Laboy and Buenavista in the Municipality of Dipaculao, registered with the largest area with no the limitations, with 529.81 and 303.95 hectares, respectively, and Barangay Calabuanan in the Municipality of Baler, ranked second to the biggest portion with a total area of 471.38 hectares.

Given the assumption that ART could obtain a yield between 4-6 ton/hectare, and Aurora with an area of 4,817.17 hectares, this will translate an additional production of 21,677.25 tons of rice in Region III.

ART Suitability in the Province of Bataan

The province of Bataan has a total of 130,776.27 hectares suitable for ART. However, only 2,039.28 or 1.56 percent were found to be highly suitable (No Limitations) to ART production. These 2,539.04 hectares are located in the municipalities of Dinalupihan and Hermosa (Table 6). The municipality of Dinalupihan has an aggregate area of 1,662.30 hectares while Hermosa shared the least with only 876.746 hectares that could be cultivated to ART.

At the barangay level, San Simon in the Municipality of Dinalupihan registered with the largest area with no the limitations with 320.89 hectares. The second biggest area is in Barangay Bacong, Hermosa with 266.73 hectares.

On the assumption that ART could obtain a yield between 4-6 ton/hectare, and Bataan has an area of 2,539.04 hectares, this may translate an additional production of 11,425.70 metric tons of rice in Region III.

ART Suitability in the Province of Bulacan

Bulacan province registered to have a consolidated potential area of about 255,022.52 hectares to ART. From this figure, however, only 15,677.06 hectares or 6.14 percent were found to be highly suitable (No Limitations) to aerobic rice production. The Municipality of San Ildefonso and Bustos contributed the biggest share with 3,615.92 and 2,014.05 hectares respectively, while Municipality of Dona Remedios marked to have the smallest area with only 13.86 hectares suited to ART (Table 6).

Barangay Upig in San Ildefonso marked as the biggest area which is highly suitable to ART with a total of 679.77 hectares, followed by Barangay Camachilican in Bustos with 435 hectares.

With total area of 15,677.06 hectares highly suitable to aerobic rice production, the Province of Bulacan will be able to produce and contribute a total 70,546.79 metric tons of rice to Region III total rice production.

ART Suitability in the Province of Nueva Ecija

Among the seven provinces, Nueva Ecija emerged with the biggest potential area to aerobic rice production. It has a total of 547,735.80 hectares and 62,987.18 hectares or 11.5 percent of this is highly suitable (No Limitations) to ART (Table 6). San Jose City and the municipality of Rizal registered the biggest number of hectares for ART with 6,636.57 and 6,074.17, respectively, while the municipality of Gabaldon registered the least area for ART with 13.79 hectares.

At the barangay level, Luyos in the municipality of San Antonio had the biggest area for ART with 1,229.51 hectares, followed by Barangay Papaya also in the Municipality of San Antonio with 1,116.98 hectares.

With an aggregate area of 62,748.74 hectares, and assuming 4.5 ton/ha production, Nueva Ecija province would have an additional production of 282,369.33 metric tons of aerobic rice annually as its contribution to Region III rice supply.

ART Suitability in the Province of Pampanga

Pampanga province registered to have a consolidated potential area of about 224,952.58 hectares for ART. From that figure, only 13,841.26 hectares or 6.15 percent were found to be highly suitable (no limitations) for aerobic rice production. The municipalities of Candaba and Arayat contributed the biggest areas with 3,963.82 and 2,399.45 hectares, respectively. The municipality of Minalin gave the lowest number of hectares suitable for ART at 7.28 hectares.

At the barangay level, Candaba Swamps marked with the biggest suitable area for ART with a total of 2,338.67 hectares, followed by Barangay Lapaz in Arayat with 693.55 hectares.

On the assumption ART would give 4.5 ton/ha on the average, Pampanga province may be expected to contribute an additional 61,954.47 metric tons of rice in the Region to feed its growing population.

ART Suitability in the Province of Tarlac

Tarlac province registered to have a consolidated potential area of about 301,817.87 hectares to ART. From this figures, however, only 17,740.85 hectares or 5.88 percent appeared to be highly suitable (No Limitations) to aerobic rice production. Tarlac City and the municipality of Victoria contributed the biggest share with 2,446.19 and 3,578.13 hectares, respectively, while the municipality of Pura marked to have the smallest area suitable for ART with 4.19 hectares.

At the barangay level, Talimunduc in Concepcion town marked as the biggest area highly suitable to ART with a total of 527.11 hectares, followed by Barangay Lawy in Capas with 501.03 hectares.

With Tarlac having a total area of 17,740.85 hectares that are highly suitable to aerobic rice production, and assuming 4.5 ton/ha production, the province will be able to produce and contribute a total of 79,833.84 metric tons of rice to Region III annually.

ART Suitability in the Province of Zambales

For the Province of Zambales, a total of 9,699.39 hectares of land were found to be suitable to ART with No Limitation (Table 6). However, this is only 2.65 percent of the total potential area for ART with an equivalent of 365,320.27 hectares. The municipalities of Palauig and Masinloc contributed the biggest areas with 2,803.81 and 1,750.65, respectively, while San Felipe registered the smallest area of hectare with11.93 hectares.

At the barangay level, Tapuac in the municipality of Masinloc has the biggest area with 922.70 hectares, followed by Barangay San Agustin in Iba with 857.42 hectares.

With an aggregate area of 9,699 hectares, and assuming 4.5 ton/ha production, Zambales province would have an additional production of 43,647 metric tons of aerobic rice annually.

Based on the overall results of the analysis, the Province of Nueva Ecija had the biggest potential area of 547,735.80 hectares with 11.49% marked as highly suitable to aerobic rice technology, followed by Bulacan which had a potential area of 255,022.52 hectares with 6.15% marked as highly suitable. Pampanga, Tarlac, Zambales, Aurora and Bataan followed with 6.15 %, 5.88 %, 2.65 %, 1.59 %t and 1.56%, respectively, of their corresponding potential areas suitable for aerobic rice production. With 126,959.91 hectares of highly suitable areas for aerobic rice production and on the assumption that ART could give an average yield of 4.5 tons per hectare, Central Luzon can supply an additional 571,319.59 metric tons of aerobic rice annually.

According to a related study in the Tana delta, Kuria, Ngari and Waithaka (2011), found the number of hectares available to each suitability class in the Tana delta area to be distributed as follows: 67% is "highly to moderately" suitable, 14% is moderately suitable, and 10% is marginally suitable. About 9% of the study area classified as Eutric Fluvisol was found to be currently unsuitable for rice cultivation, due to some limitation factors such as partly sandy clay texture, saline, low water retention, and high hydraulic conductivity.

Moreover, in a related study by Ayehu and Besufekad (2015), more than 70% of the total study area were found to be highly and moderately suitable for rice crop production. The relationship between suitability map and current vegetation cover of the study area has also been computed and the result predicts the inverse relationship between the density of vegetation cover and rice land suitability. Overall, the results indicate that the study area has a huge potential for rice production. Therefore, economic levels of agricultural production can be achieved by cultivating rice crop in highly and moderately suitable areas, and practicing diversification of marginally suitable areas to crops other than rice.

Geographic Information System (GIS) has demonstrated itself as a very powerful tool in agricultural research and natural resource management. Samanta, B. Pal and D. Pal (2011), examine multi-criteria decision approach to determine land suitability for rice cultivation based on different variables, like topography (slope and aspect of the land), physical (texture, water holding capacity and depth) and chemical (pH, nitrogen, potassium, phosphorus) soil properties, climate (temperature and rainfall) and land accessibility that are mandatory inputs to land suitability model. The province of Morobe has been classified into five categories of rice suitability. The result indicates that only four percent (4%) land can be demarcated as 'high' and twenty-one percent (21%) as 'medium-high' suitability categories in the study area and the spatial expanse of all the five categories within the province are mapped and displayed.

Table 6. Summary table of the seven provinces of Region 3 with No Limitations for Aerobic Rice Technology

PROVINCE	No.	CITY_MUN	AREA_HA	Est. Production
	1	Maria Aurora	1662.29	7,480.34
	2	Baler	876.74	3,945.36
Aurora	*3*	Dinggalan	83.66	376.48
	4	Dipaculao	1,990.12	8,955.55
	5	San Luis	204.33	919.53

PROVINCE	No.	CITY_MUN	AREA_HA	Est. Production
Province Total			***4,817.16***	**21,677.25**
Bataan	*1*	Dinalupihan	1662.29	7,480.34
	2	Hermosa	876.74	3,945.36
Province Total			***2539.04***	**11,425.70**
Bulacan	*1*	Angat	994.36	4,474.66
	2	Balagtas	31.74	142.84
	3	Baliuag	38.21	171.99
	4	Bocaue	92.16	414.75
	5	Bulacan	499.91	2,249.62
	6	Bustos	2,014.05	9,063.24
	7	Calumpit	1,027.87	4,625.44
	8	Dona Remedios	13.86	62.38
	9	Guiguinto	44.55	200.50
	10	Hagonoy	944.69	4,251.15
	11	Malolos	336.29	1,513.31
	12	Meycauyan	887.19	3,992.39
	13	Norzagaray	421.71	1,897.72
	14	Obando	185.18	833.32
	15	Pandi	351.46	1,581.58
	16	Paombong	320.37	1,441.69
	17	Plaridel	216.47	974.16
	18	San Ildefonso	3,615.92	16,271.66
	19	San Jose del Monte	1,028.07	4,626.36
	20	San Miguel	998.70	4,494.16
	21	San Rafael	1,506.65	6,779.94
	22	Sta Maria	107.54	483.95
Province Total			***15,677.06***	**70,546.79**

PROVINCE	No.	CITY_MUN	AREA_HA	Est. Production
	1	Aliaga	1,658.79	7,464.58
	2	Bongabong	1,898.30	8,542.39
	3	Cabanatuan City	3,814.25	17,164.16
	4	Cabiao	2,684.37	12,079.70
	5	Caranglan	190.76	858.46
	6	Cuyapo	2,312.92	10,408.16
	7	Gabaldon	13.78	62.05
	8	Gapan City	2,306.74	10,380.37
	9	Gen M. Natividad	642.98	2,893.42
	10	Gen Tinio	268.43	1,207.95
	11	Guimba	306.27	1,378.22
	12	Jaen	170.69	768.14
	13	Licab	2,765.66	12,445.51
	14	Llanera	3,288.46	14,798.08
	15	Munoz City	5,744.20	25,848.94
Nueva Ecija	*16*	Lupao	1,794.37	8,074.69
	17	Nampicuan	209.98	944.94
	18	Palayan City	1,501.12	6,755.05
	19	Pantabangan	835.05	3,757.76
	20	Penaranda	850.20	3,825.92
	21	Rizal	6,074.17	27,333.80
	22	Quezon	2,836.06	12,762.27
	23	San Antonio	5,725.67	25,765.52
	24	San Isidro	270.86	1,218.87
	25	San Jose City	6,636.57	29,864.60
	26	San Leonardo	491.73	2,212.83
	27	Sta Rosa	2,691.63	12,112.35
	28	Sto Domingo	676.13	3,042.60
	29	Talavera	711.61	3,202.28
	30	Talugtog	571.82	2,573.20
	31	Zaragosa	2805.00	12,622.50
Province Total			***62,748.73***	**282,369.31**

PROVINCE	No.	CITY_MUN	AREA_HA	Est. Production
Pampanga	*1*	Apalit	73.59	331.19
	2	Arayat	2,399.44	10,797.51
	3	Candaba	3,963.82	17,837.23
	4	Floridablanca	682.09	3,069.42
	5	Guagua	210.19	945.87
	6	Lubao	191.45	861.55
	7	Macabebe	930.98	4,189.45
	8	Magalang	175.55	789.98
	9	Masantol	583.27	2,624.73
	10	Mexico	1,129.55	5,083.02
	11	Minalin	7.28	32.77
	12	San Fernando City	1,393.41	6,270.35
	13	San Luis	32.59	146.67
	14	San Simon	362.73	1,632.31
	15	Santa Ana	1,267.98	5,705.93
	16	Santo Tomas	363.66	1,636.49
Province Total			***13,767.66***	**61,954.48**
Tarlac	*1*	Anao	1584.43	7,129.97
	2	Bamban	304.93	1,372.19
	3	Camiling	2237.50	10,068.78
	4	Capas	1345.46	6,054.61
	5	Concepcion	2377.65	10,699.46
	6	Gerona	517.728	2,329.78
	7	La Paz	380.61	1,712.78
	8	Moncada	802.26	3,610.20
	9	Paniqui	100.46	452.09
	10	Pura	4.19	18.87
	11	Ramos	460.50	2,072.26
	12	San Clemente	642.08	2,889.38
	13	San Manuel	474.26	2,134.19
	14	Sta Ignacia	484.40	2,179.83
	15	Tarlac City	3578.13	16,101.60
	16	Victoria	2446.19	11,007.86
Province Total			***17,740.85***	**79,833.84**

PROVINCE	No.	CITY_MUN	AREA_HA	Est. Production
Zambales	*1*	Castillejos	712.37	3,205.71
	2	Candelaria	612.80	2,757.61
	3	Iba	1,088.00	4,896.00
	4	Masinloc	1,750.64	7,877.92
	5	Olongapo City	43.19	194.37
	6	Palauig	2,803.81	12,617.17
	7	San Antonio	658.05	2,961.27
	8	San Felipe	11.92	53.68
	9	San Marcelino	423.60	1,906.21
	10	San Narciso	582.83	2,622.77
	11	Sta Cruz	350.64	1,577.92
	12	Subic	661.48	2,976.66
Province Total			***9,699.39***	**43,647.255**
Region 3 Total			**126,959.91**	**571,319.59**

CONCLUSIONS

The areas identified to be highly suitable to aerobic rice system without limitation relative to the agro-ecological requirements to optimum ART production is 126,959 hectares in Region 3. However, these areas should be validated on the ground to determine current land use and performance, available technical and institutional support, and social acceptability of ART.

Based on the results of the analysis, there were identified areas that presented only one or two limitations to ART production. Finding appropriate technological interventions to these areas is necessary to make them suitable to aerobic rice production.

Areas identified as highly suitable or without limitation, can have a higher production potential per unit of inputs. These areas may then serve as sites for technology demonstration farms for aerobic rice production. It is incumbent that delivery of technological and institutional support to ART be maximized on these areas.

The size of the suitable areas to ART and access of these areas to available inputs including the market, among other considerations, should become the bases in crafting the budget and financial plan to aerobic rice program of Region 3.

Generated maps should be reproduced, disseminated and used as tool in planning, implementation, monitoring and evaluation of projects/programs on rice production.

Partner institutions such as LGUs, NGOs, NGAs, POs, other SUCs and farmers should be oriented and taught on the utility of suitability maps of ART.

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