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LAND SUITABILITY ASSESSMENT FOR GARLIC IN REGION I

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Abstract

Garlic, known as the white gold of Ilocos, relies on factors like day-length, temperature, relative humidity, and topography for its productivity. With the decreasing areas devoted to garlic due to climate variability, it is imperative to identify suitable areas for possible expansion to increase production volume and reduce importation.

Soil samples were gathered throughout Region 1 to characterize the physical and chemical properties of the soils and identify suitable areas for garlic production. Four factors were used to delineate suitable areas: soil properties, climate, water availability, and topography.

Agroclimatic analysis indicates that only 15,687ha are highly suitable for garlic in Region 1, and Ilocos Norte shares about 97%. About 233,980ha are moderately suitable, while 708,266ha are marginally suitable.

Scenario analysis indicates that the climatic suitability for garlic in the current and future (2030 and 2050) will drastically change from the current to 2050 due to increased temperature. In the regional context, a total of 34,800ha are highly suitable for garlic, mostly in Ilocos Norte (78%), 187,300ha are moderately suitable, 325,000ha are marginally suitable, and 679,300ha are unsuitable in the current scenario. However, a decrease of about 89% and 33% of the highly suitable and moderately suitable areas, respectively, will be observed in 2030. An increase of 12.4% and 7.6% in marginally suitable and unsuitable regions, respectively, will be observed in the same year.

Keywords: agroclimatic condition, garlic, geographic information system, suitability assessment

Introduction

Garlic, locally known as *bawang,* is considered the white gold of the Ilocos. Ilocos Region is the country's primary garlic producer, owning 6589 percent (Philippine Statistics Authority [PSA], 2020) of the average total production volume from 2015 to 2019. This is mainly due to its favorable conditions, i.e., short days, long cold nights, low temperatures, and low rainfall.

Garlic is affected by four main factors: planting time, soil, water, and climate (Food and Agriculture Organization [FAO], 2001). It is usually grown as a dry season crop but is more productive during cool months and short days where bulb formation occurs

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during these periods (Galacgac, 2015). The crop needs cool weather during the early stage of growth. A comparative dry soil, dry atmosphere, and moderately high temperature are important at the pre-harvest stage. Garlic grows best in medium-textured and well-drained fertile soils with high organic matter content. Incorporating organic fertilizer and soil amendments or well-decomposed manure into heavy soils such as clay and silty clay will make them friable and suitable for garlic production. Malformation and difficulty when harvesting bulbs may result when garlic has been planted in heavy, clay soils (Department of Agriculture, Forestry, and Fisheries of South Africa). Garlic is moderately tolerant of acidity and will grow in pH ranges from 5.5 to 6.8 (Garlic Production Guide, 2007), but the ideal is 6.5 to 7.

Garlic production continues to decline from 11,348mt in 2008 to 7,256.32mt in 2019 (Bureau of Agricultural Statistice [BAS], 2020), down by about 36 percent. This decline was attributed to the decreasing area planted in garlic due to the infestation of diseases caused by climate change. Historical data show that in 1990, a total area of 6,406ha was devoted to garlic nationwide, which increased to 7,912ha in 1997 but started to decline in 1998 (5,185ha) and decreased to only 2,591ha in 2012 (BAS, 2013). Specifically, Ilocos Norte has greatly influenced national garlic production since it devoted the most expansive area of 5,761ha in 1997 to only 2,612.15ha in 2019 (BAS, 2020).

Garlic yield per hectare varied across the growing areas of the country. Among the top five regions obtaining the highest yield per hectare (BAS, 2013) are Region 4B (4.31t ha^{-1}), Region 6 (4.21t ha^{-1}), Region 8 (4.0t ha^{-1}), Region 3 (3.52t ha^{-1}), and Region 1 (2.87t ha^{-1}). Soil and climatic conditions are the two major factors causing the yield variations across regions. With climate change, temperature variability greatly affects bulb formation and the incidence of pests and diseases of garlic.

With the declining area and volume of garlic production in the Philippines, there is a need to characterize the growing areas and identify possible expansion areas to supply and meet the increasing garlic demand. Boonyanuphap et al. (2004) used a multifactor spatial analysis and effectively assessed the environmental suitability of areas for a banana plantation. This approach used the Geographic Information System (GIS), a combination of five environmental factors with nineteen variables, to express land suitability in five classes. One site was chosen for site assessment. This site fell into a range of categories from highly suitable (S1) to not suitable (N1).

Land-use suitability mapping and analysis is one of the most worthwhile uses of GIS for planning and management (Malczewski, 2004). Land-use suitability analysis aims to classify or identify the most suitable use of the land following specific requirements of some crops (Hopkins, 1977; Collins et al., 2001). The GIS-based land-use suitability analysis has been applied in a wide variety of situations, including the suitability of land for agricultural activities (Cambell et al., 1992 and Kalogirou, 2002), landscape evaluation and planning (Miller et al., 1998), environmental impact assessment (Moreno & Seigel, 1988), selecting the best site for the public and private sector facilities (Eastman et al., 1993 and Church, 2002), and among others.

Soil degradation has been observed in most agricultural areas in the country due to improper land management. Since soil is one of the most essential natural resources due to its outright influence on food production, it is important to know its nature and present characteristics to correct its degraded condition, optimally manage, and conserve. Hence, there is a need to characterize the soils in the region to improve the productivity of garlic and identify possible areas for expansion to meet the needed garlic requirements of about 164,881 mt annually, mainly supplied through importation. The research generally assessed land suitability for garlic production in Region I. Specifically, it characterized the physical and chemical properties of the soils in Region I, assessed their suitability based on soil properties, topography, climate, and water availability affecting garlic production, identified suitable areas for garlic production in Region I, and determined the scenario analysis on the climatic suitability of garlic in the years 2030 and 2050.

Methodology

Site Description

The study was conducted in Region I, where cropping practices are dominantly rice-based due to its climatic type. Region I is under Type I climate, having two pronounced seasons: dry from November to April and wet during the rest of the year. However, it has three agroclimatic conditions: cool tropics, warm, humid tropics, and warm subhumid tropics. Based on the climatic data of the different weather stations, the average annual rainfall ranges from 2020 mm (La Union) – to 2719 mm (Pangasinan), and the mean annual temperature ranges from 26.8 °C (Ilocos Sur) – to 27.8 °C (Pangasinan).

Ilocos Region has about 23 soil series with various soil types, mostly from alluvial and calcareous limestone parent materials. Fig. 2 presents the different soil types and the sampling sites where soil samples were gathered for analyses. Samples were grouped according to soil series for easier data manipulation and better visualization of results.

Data collection

Five soil samples were collected per location from the garlic growing areas in Ilocos Norte and the different soil series in

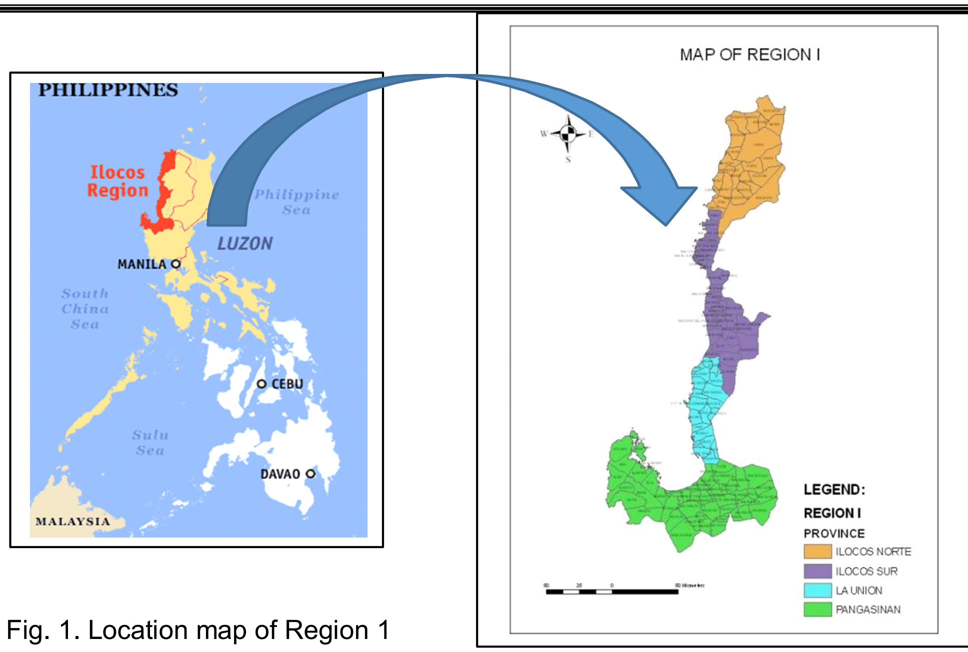

Fig. 1. Location map of Region 1

Ilocos Sur, La Union, and Pangasinan provinces in 2018. Soil samples were processed and analyzed for soil pH, organic matter, available phosphorus, and exchangeable potassium. Cation exchange capacity (CEC) of the soil samples was estimated based on the soil samples' percentage of OM, clay, and silt contents using the online CEC calculator (Soil Doctor - weebly.com). Soil physical characteristics such as slope, texture, adequate rooting depth, and stoniness from the surface and subsurface were determined. Secondary data were also gathered, such as climatic data (30 -year data), groundwater-specific capacity (Alibuyog, 2002), and productivity of aquifer (Alibuyog, 2002), drainage, flooding characteristics. Fourteen variables adopted from Boonyanuphap et al. (2004) were grouped into four environmental factors based on their specific relationship with the land suitability assessment for garlic: climate, soil property, topography, and water availability. These four environmental factors were essentially different in their requirement for land suitability.

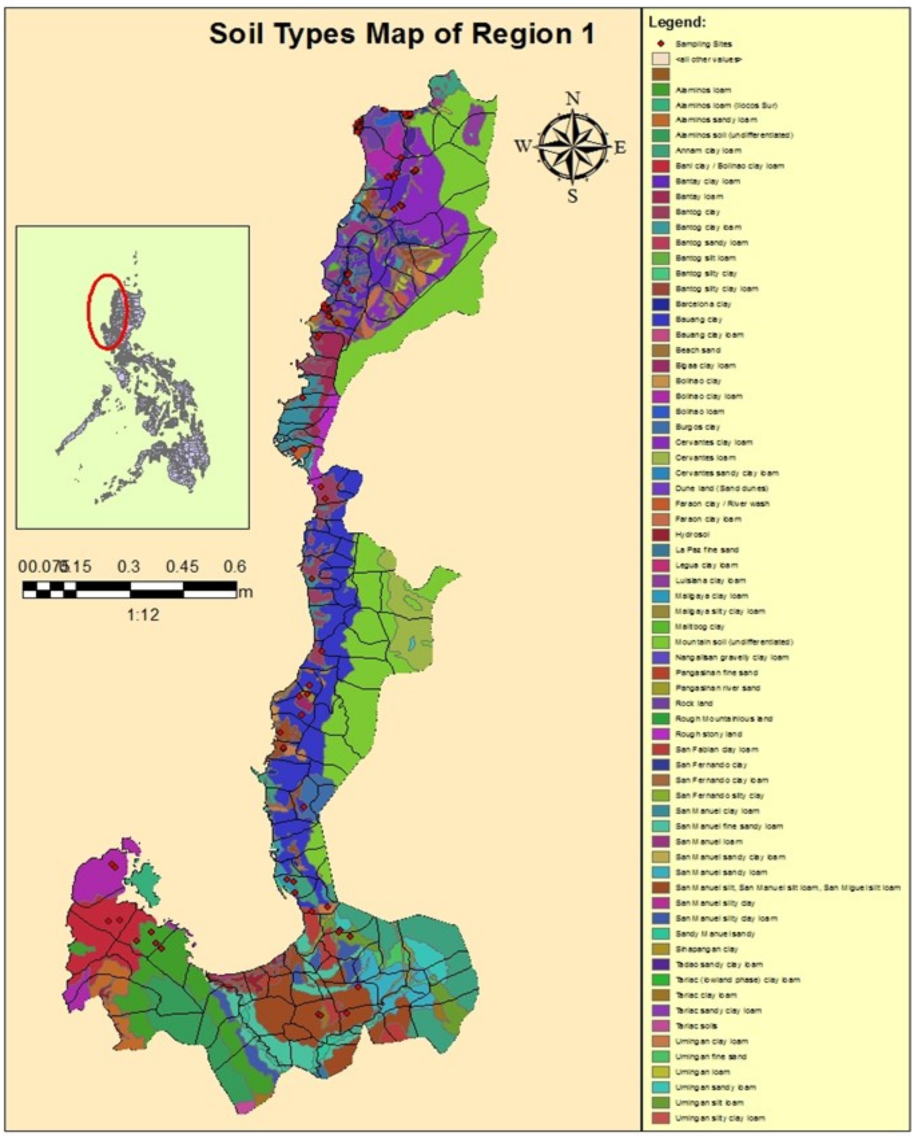

Fig. 2. Sampling sites with their respective soil types

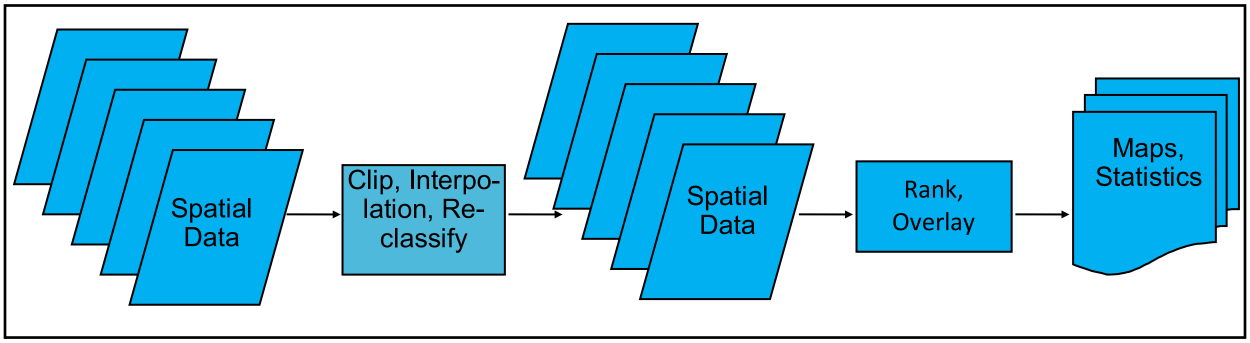

Fig. 3. Geoprocessing Model Used in the Study.

Suitability Mapping

The geoprocessing model used in the study is shown in Fig. 3. Different operations such as clip, interpolation, reclassification, and weighted overlay from the Arc Tool Box were used.

Interpolation. Point data on the different soil properties, such as pH, Organic Matter (OM), and Soil Depth, were spatially analyzed and interpolated using the kriging tool of the ArcGIS software.

Clip. Generated surface maps for Region 1 were clipped and masked to the desired boundary.

Reclassify. Clipped and masked generated surface maps for the different soil properties were reclassified using the reclassify tool according to suitability rating criteria (Table 1). Clipped-generated surface maps for the climatic factors were also reclassified using the suitability rating criteria. Secondary data such as elevation, soil depth, texture, and slope were also reclassified according to the desired suitability rating criteria.

Overlay. Reclassified maps, such as climatic factors, soil properties factors, land cover, and slope, were overlaid. The climatic factor was given the highest weight at 55%, while soil properties, slope, and groundwater availability were given 15% each. The generated map was masked with a land cover map (2010) utilizing only the areas planted with annual crops.

Extraction of suitability rating areas. Areas for the different suitability ratings were computed using a field calculator, and a tabulated area was done using a zonal spatial analyst tool.

Scenario Analysis. Suitable areas for garlic production as affected by climatic conditions were determined using the MaxEnt model. The model utilizes crop occurrence data with nine precipitation and 11 temperature-related variables (Fig. 4). Two hundred eighty-eight occurrence data were determined throughout the region for garlic. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation), and extreme or limiting environment factors (e.g., temperature of the coldest and warmest months, and precipitation of the wettest and driest quarters). To determine the effect of climate change on crop climatic suitability, future climatic conditions (years 2030 and 2050) were compared to the current or baseline condition (Fig. 5). The relative concentration pathway (RCP 8.5) was used (IPCC, 2013).

Table 1. Criteria for the suitability of garlic production (Boonyanuphap et al.,2004)

Factor	Class	Suitability Rating
Climatic Factors (55%)		
Mean annual temperature (°C)	≥ 27	Unsuitable
	24 – 26	Marginally Suitable
	21 – 23	Moderately Suitable
	18 – 20 or below	Highly Suitable
Relative Humidity (%)	≥ 88	Unsuitable
	85 – 87	Marginally Suitable
	82 – 84	Moderately Suitable
	≤ 81	Highly Suitable
Soil Property Factors (15%)		
Texture	Heavy clay or sandy	Unsuitable
	SiC or C	Marginally Suitable
	SC or LS or SL or SiCL	Moderately Suitable
	L or SiL or SCL or CL	Highly Suitable
Depth (cm)	< 15	Unsuitable
	16 – 35	Marginally Suitable
	36 – 50	Moderately Suitable
	> 50	Highly Suitable
Drainage	Very poor or very excessive	Unsuitable
	Poor – excessive	Marginally Suitable
	Fair	Moderately Suitable
	Good	Highly Suitable
pH	<4.5 or >8.5	Unsuitable
	4.5 – 5.5 or 8.0 – 8.5	Marginally Suitable
	5.6 – 6.5 or 7.6 – 8.1	Moderately Suitable
	6.6 – 7.5	Highly Suitable
OM	< 2.0	Unsuitable
	2.1 – 3.5	Marginally Suitable
	3.6 – 4.5	Moderately Suitable
	> 4.50	Highly Suitable
Exchangeable K	<100	Unsuitable
	100-175	Marginally Suitable
	175-250	Moderately Suitable
	>250	Highly Suitable
Available P	<11	Unsuitable
	11.5-20.0	Marginally Suitable
	20.0 -30.0	Moderately Suitable
	>30.0	Highly Suitable

Note: SiC – silty clay; C – clay; SC – sandy clay; S – sand; LS – loamy sand; SL – sandy loam; L – loam; SiL – silty loam; SCL – sandy clay loam; CL – clay loam; and SiCL, silty clay loam

Table 1...Continued.

Factor	Class	Suitability Rating
Supplementary Factor (15%)		
Quantity of groundwater (m^3/ day)	< 500	Unsuitable
	500 – 1500	Marginally Suitable
	1500 – 3000	Moderately Suitable
	> 3000	Highly Suitable
Topographic Factor (15%)		
Slope (%)	> 30	Unsuitable
	18 – 30	Marginally Suitable
	8 – 18	Moderately Suitable
	0 – 8	Highly Suitable

Note: SiC – silty clay; C – clay; SC – sandy clay; S – sand; LS – loamy sand; SL – sandy loam; L – loam; SiL – silty loam; SCL – sandy clay loam; CL – clay loam; and SiCL, silty clay loam

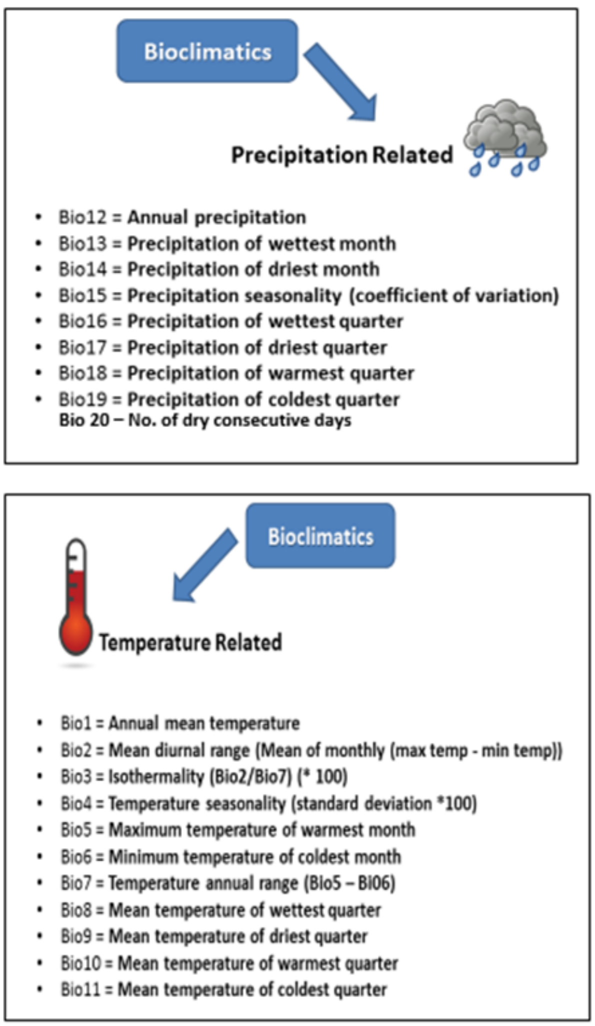

Fig. 4. Precipitation and temperature-related variables from MaxEnt Model.

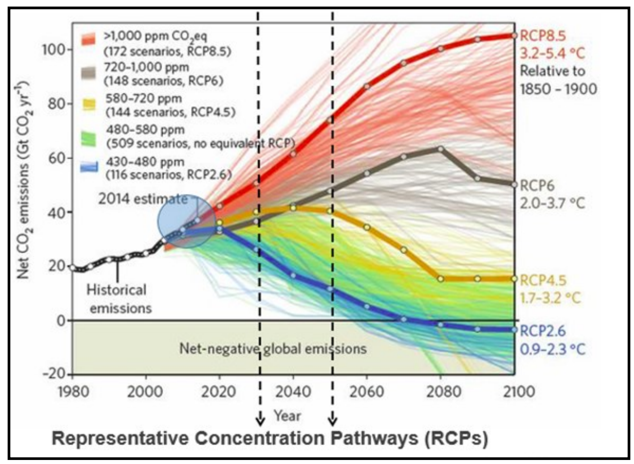

Fig. 5. Representation Concentration pathway 8.5 as affected by net carbon dioxide emissions (Source: IPCC ARS, 2013).

Results and Discussion

Physical and chemical characteristics of soils of Region 1

Results of the measurements on the physical characteristics (Table 2) of the soils considered indicate that the majority of the soils have 0-3% slope (42%), followed by 8-18% (31.58%); 3-8% (21.05%), and 18-30% slope with only 5.26%. These indicate that the soils are mostly located in the lowlands, which are commonly alluvial soils and usually have poor drainage both at the surface and internally. The poorly drained soils are usually flooded during rainy seasons. Most of the soils have clay loam texture at the surface and clay at the subsurface. However, the soils have fine sandy loam to clay texture and moderate depth, which is favorable for garlic production. Heavy clay soils have poor to very poor drainage on both the surface and subsurface due to their smaller soil particles.

On the contrary, very light soils have excessive to very excessive drainage due to their very coarse particles. These conditions affect garlic production, for these will affect aeration, moisture retention, and irrigation frequency, which are crucial to the growth and development of the garlic plant. Among the deep soils are Bantay, Bantog Bigaa, San Manuel, Sinaangan, and Umingan. The stones in the subsurface would impede root penetration and absorption of nutrients in the lower horizons.

The chemical characteristics of the major soils in Region 1 are presented in Table 3. All of the major soils are acidic. Soil acidity is the main growth-limiting factor for plants (Foy, 1984). Elucidations of poor plant growth on acid soils have comprised Al^{3+} toxicity (Barcelo et al., 1996; Kinraide, 1993), Mn^{2+} toxicity (Foy, 1984), low N supply (mainly NH_4^+-N rather than NO_3^--N) (Foy, 1984), P deficiency (Foy, 1984), Mo deficiency particularly in legumes; Hafner *et al*., 1992) and toxic concentrations of phenolic acids (Baziramakenga et al., 1995; Vaughan & Ord, 1991; Whitehead et al., 1981). The hydrogen (H^+) ion itself has been identified as the primary cause of poor growth of plants relatively in seeming deference to Arnon and Johnson (1942) who concluded that the poor growth observed in lettuce, tomato, and Bermuda grass when grown in solutions of low pH was the result of a low Ca supply (Kid & Proctor, 2000). The OM contents of most of the soils observed are unsuitable and marginally suitable for crop production. This indicates that the soils or farms in Region 1 are already degraded. Organic matter affects the chemical and physical properties of the soil and its overall health, including soil structure, moisture holding capacity, diversity, and activity of soil organisms, both beneficial and harmful to crop production and nutrient availability (Bot & Benites, 2005). Soil organic matter accumulates to higher levels in cool and humid regions compared to warm and arid climates (Lal, 2000). Besides, SOM is associated with different soil fractions, sand, silt, and clay, which will differ in susceptibility to decomposition.

Likewise, the analysis results on the available P content show that 61.11% of the soils in Region 1 are very low, which is marginally suitable for garlic production. Phosphorus is crucial for converting solar energy into food, fiber, and other plant products. It plays a vital role in the metabolism of sugars, energy storage and transfer, cell growth, and the transfer of genetic information (Wyant et al., 2013).

For K, about 39% of the soil series are unsuitable in which the exchangeable K reading fell below 100 ppm, and these soils are located in Pangasinan, namely: Alaminos, Bani, Bolinao, San Fabian, and Tarlac series. Soils in Ilocos Sur and La Union, such as Annam, Umingan, Bauang, and Burgos, have available P content of > 100 ppm,s categorized as marginally suitable. Ilocos Norte's Soils, including San Manuel, San Fernando, Cervantes, Bantog, Bantay, and Tadao, are highly suitable, meaning their K content is > 250 ppm.

The cation exchange capacity (CEC), which is the total sum of exchangeable cations that a soil can hold (Brady & Weil, 2004) of most of the soils in Region 1, is high (Table 3). CEC determines the ability of the soil to hold positively charged nutrients such as NH4+, K+, Ca_2+, Mg_2+, and Na+. As CEC increases, more nutrients are attached to soil particles, and fewer remain in the solution. Since the nutrients in the soil solution are available to plants, this means that while there are plenty of nutrients in the soil, the plants may not be able to take advantage of them. At the same time, they are less likely to leach. The addition of cations to the soil, through acidification, liming, or fertilization, will release cations into the soil solution as the new cations exchange places on the CEC.

Suitability Analysis of Individual Factor

Soil Property Factor. Soil quality greatly affects crop production. These include texture, soil depth, pH, organic matter content, available P, exchangeable K, and CEC. In terms of texture, most of the farms in the region are moderately suitable. This suggests that these farms are characterized by medium-textured soil (sandy or silty clay loam). A wider portion of the highly suitable areas is located in Pasuquin and Vintar, characterized by light-textured soil and minimal stoniness. Heavy clay soils impede the formation and growth of garlic bulbs and make harvesting difficult.

Soil depth also affects bulb growth and garlic yield. The optimum soil depth for garlic is 50cm. Most of the soils in the region are deep (> 50cm) and thus highly suitable for garlic production. Areas rated moderately suitable and marginally suitable are characterized by relatively shallow soil with a depth ranging from 36 – 50cm and 16 – 35cm. At this condition, root penetration is obstructed by the presence of stones, boulders, or the parent materials and thus affects the absorption of nutrients by the plants. Also, shallow soil limits the availability of nutrients due to its limited capacity to store and hold nutrients.

Soil pH affects the availability of nutrients in the soil. At neutral pH 7, the availability of nutrients in the soil is not fixed, and thus, they are readily absorbed by the plants. In Region 1, however, most soils are slightly acidic to acidic. Most of these soils are located in Pangasinan, Ilocos Sur, and Ilocos Norte, with a pH of 5.6 – 6.5. Almost all the soils in La Union have pH readings ranging from 4.5 to 5.5, which are acidic to very acidic. Most of the soils in the central lowlands of Ilocos Norte are characterized by slightly neutral to neutral to slightly basic (6.6 – 7.5).

Regarding the suitability of the OM content of soils in Region 1, results show that most of the farms are marginally suitable with only 2.1 – 3.5%, and most of the soils in La Union are currently not suitable for garlic with only < 2%. The soil's low OM content in the region indicates that these are already in their degraded state. This might be due to the increased mineralization rates brought about by the heavy application of synthetic fertilizers and pesticides and tillage practices or the removal of crop residues (Bot and Benites, 2005). Only soils from Burgos and Pasuquin are rated moderately suitable for garlic production, with OM content ranging from 3.6 to 4.5%. This might be one of the reasons why Pasuquin and Burgos have larger garlic bulbs than the other growing areas in the region.

Combining all the soil properties, results show that most of the soils in the region are marginally suitable for garlic production, and some are unsuitable, particularly in Pangasinan. Some areas in the northern and southern parts of Ilocos Norte and the southern part of Ilocos Sur are moderately suitable. These are the growing areas for garlic (Fig. 6).

Water Availability Factor. Water is indispensable in crop production. The availability of irrigation water dictates the kind

Table. Physical Characteristics of the major soils in Region 1.

Soil Series	Slope %	Drainage		Flooding	Texture		Effective Depth (cm)	Stoniness	
		Surface	Internal		Surface	Subsurface		Surface	Subsurface
Alaminos	0.3	Good	Good	0	Clay	Clay loam	60	0	0
Annam	8-18	Good	Fair	0	Clay loam	Clay loam	80	0	0
Bani	3-8	Good	Good	0	Clay loam	Sandy clay loam	65	0	1
Bantay	3-8	Good	Fair	0	Loam	Clay loam	94	0	1
Bantog	0-3	Poor	Very poor	1	Clay loam	Clay	90	0	1
Bauang	8-18	Good	Excessive	0	Clay	Clay	60	0	0
Bigaa	0-3	Poor	Poor	1	Clay loam	Clay loam	100	0	0
Bolinao	3-8	Good	Poor	0	Clay loam	Clay	45	0	1
Nurgos	8-18	Good	Excessive	0	Clay loam	Clay	45	0	1
Cervantes	8-18	Good	Good	0	Clay loam	Clay	80	0	0
Faraon	8-18	Good	Fair	0	Clay loam	Clay	40	0	1
San Fabian	8-18	Good	Fair	0	Clay loam	Clay loam	45	0	1
San Fernando	0-3	Good	Poor	1	Clay loam	Clay	88	0	0
San Miguel	0-3	Good	Good	0	Silt loam	Silt loam	100	0	0
Sinapangan	0-3	Poor	Poor	1	Clay	Clay	100	0	0
Tadao	18-30	Good	Good	0	Sandy clay loam	Sandy clay loam	70	0	0
Tarlac	0-3	Poor	Poor	1	Clay loam	Clay loam	85	0	0
Umingan	3-8	Good	Good	0	Loam	Fine sandy loam	100	0	0

Table 3. Chemical Characteristics of the major soils in Region 1.

Soil Series	pH	OM %	Available P, ppm	Exchange K, ppm	CEC, cmol kg^{-1} soil
Alaminos	5.92	1.18	22.91	61.93	6
Annam	5.30	1.44	21.95	133.65	25
Bani	5.43	2.13	12.63	81.06	25
Bantay	5.91	2.12	9.96	367.80	37
Bantog	5.65	1.84	12.56	408.46	43
Bauang	4.60	3.68	18.26	149.99	40
Bigaa	5.24	0.57	30.94	97.71	45
Bolinao	5.50	3.75	23.55	73.89	20
Burgos	5.07	0.32	4.34	124.09	20
Cervantes	4.89	1.24	13.48	474.36	14
Faraon	5.56	0.79	19.82	90.62	71
San Fabian	5.30	0.79	14.41	31.65	40
San Fernando	6.26	1.31	14.24	304.16	71
San Manuel	5.56	1.81	20.52	331.49	40
Sinapangan	5.25	0.46	25.43	116.91	45
Tadao	4.99	3.80	18.59	276.89	25
Tarlac	5.39	0.83	2.71	23.68	40
Umingan	4.97	0.98	13.86	100.18	45

of crops to be planted. For Region 1, the most productive aquifers are found mainly in Pangasinan and some in Ilocos Norte particularly in Bangui with a specific capacity from 2,448.78 – 7,065.04m^3/m-day (Fig. 7). On the contrary, La Union, Ilocos Sur, and most of the municipalities of Ilocos Norte have very low specific capacity ranging only from 18.22 – 2,448.78 m^3/m-day.

The specific capacity of the aquifer to produce groundwater affects the availability of irrigation water and the suitability of the area for tubewell installation. It is evident in Fig. 8 that Pangasinan, the southern part of La Union, and the northern part of Ilocos Norte are suitable for tubewell installation. Most areas in Ilocos Norte and Ilocos Sur are moderately suitable for tubewell installation supporting garlic production. Also, a large area in Ilocos Norte is unsuitable for tubewell production due to an unproductive aquifer.

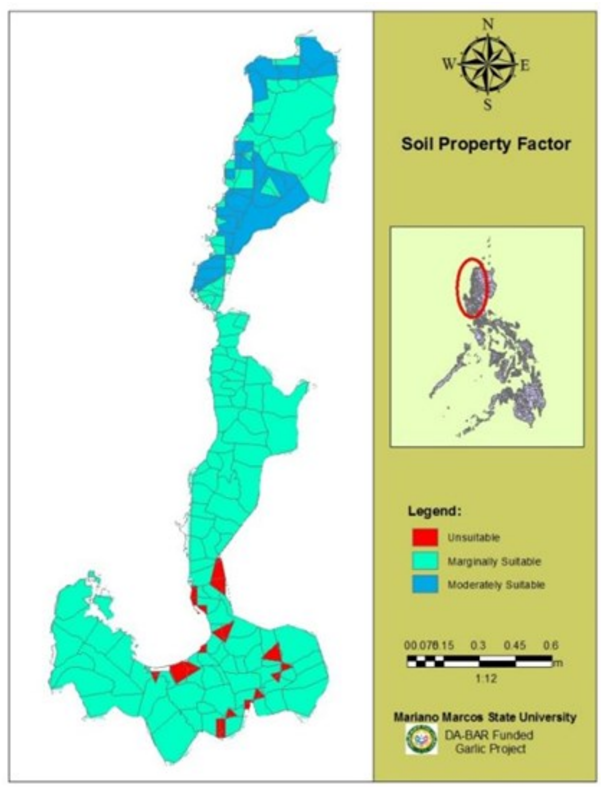

Figure 6. Suitability class for garlic concerning soil property factor

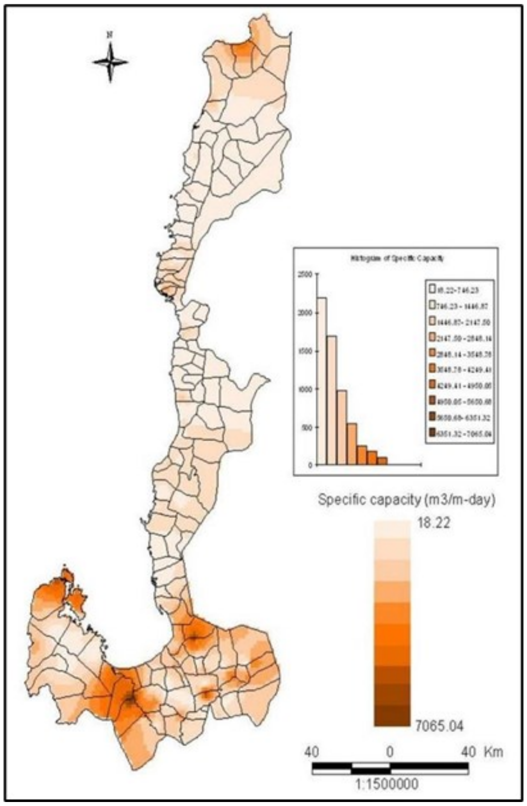

Fig. 7. Specific capacity of aquifers in Region 1.

Topographic Factor. Topography also affects garlic production, particularly slope. Caution is imposed on areas with slopes 18 – 30% or rolling to moderately steep for erosion risk, such as Tadao Ilocos Norte, which is considered marginally suitable (Fig.9). Undulating to rolling or moderately suitable are areas with slopes 8 – 18%. Meanwhile, 0 – 3% (level to nearly level) and 3 – 8% (gently sloping to undulating) are the areas that are highly suitable for garlic production.

Land Suitability Classification of Garlic in Region 1

Figure 10 and Table 4 present the suitability map of garlic and the total area covered per suitability classification, respectively. The results of the analyses show that 58.13% (190,823 ha) of the total cultivated land area of Ilocos Norte is marginal, 32.61% (107,076 ha) is moderately suitable, and only 4.62% (15,192 ha) is highly

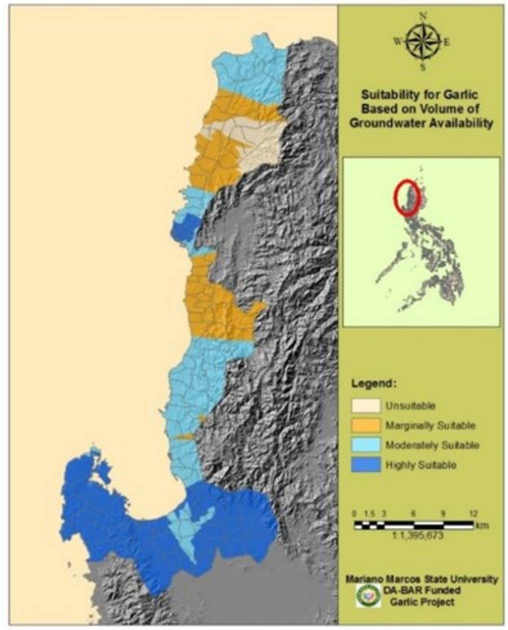

Figure 8. Suitability of aquifers for tubewell installation based on specific capacity.

suitable. For Ilocos Sur, about 41.29% (102,655 ha) of its areas are unsuitable for garlic production, followed by marginally suitable with 38.88% (96,665 ha), moderately suitable 19.80% (49,222 ha), and only 0.02% (58 ha) are highly suitable. In La Union, 41.55% (58,844 ha) of its total agricultural lands are marginally suitable to garlic, 31.73% (44,936 ha) are unsuitable, 26.49% (37,383 ha) are moderately suitable and only 0.31% (437 ha) are highly suitable. In Pangasinan, about 71.26% (361,934 ha) are marginally suitable, and 20.80% (105,671 ha) are unsuitable. Only 9.73% (40,299 ha) are moderately suitable, and no highly suitable areas for garlic. Agroclimatic analysis indicates that only 15,687 ha are highly suitable for garlic in Region I, and Ilocos Norte shares about 97%. About 233,980 ha are moderately suitable, while 708,266 ha are marginally suitable.

Scenario Analysis

Based on RCP 8.5, the temperature will increase with time, and thus, the growth and

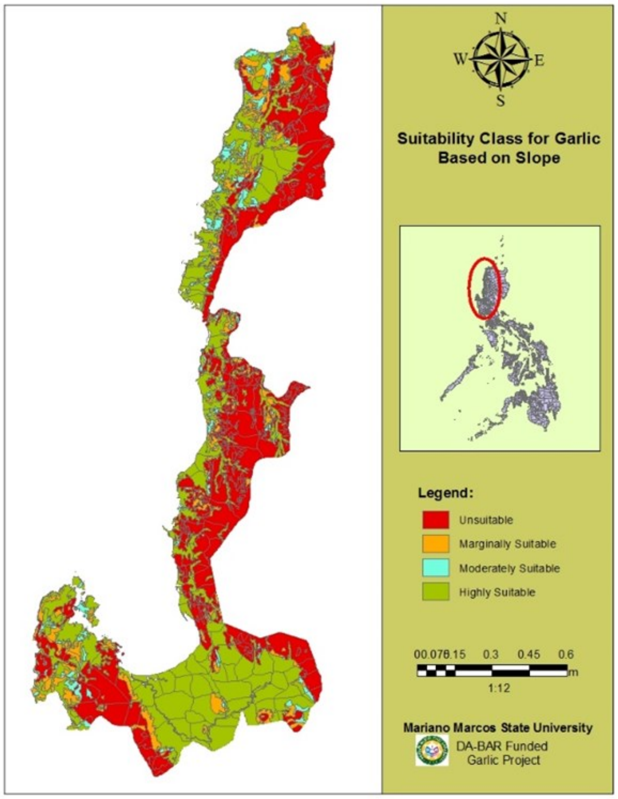

Figure 9. Suitability class for Garlic based on slope

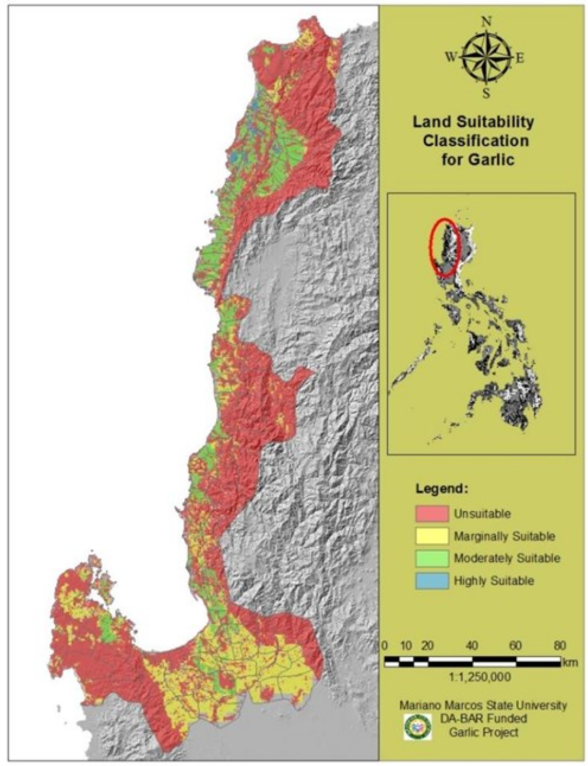

Figure 10. Suitability map for garlic production in Region 1

Table 4. Area covered per suitability classification of garlic in Region 1

Suitability Class	Province				Total
	Ilocos Norte	Ilocos Sur	La Union	Pangasinan	
Unsuitable, ha.	15,205	102,655	44,936	105,671	268,467
Marginally suitable, ha.	190,823	96,665	58,844	361,934	708,266
Moderately suitable, ha.	107,076	49,222	37,383	40,299	233,980
Highly suitable, ha	15,192	58	437		15,687
TOTAL	328,296	248,600	141,600	507,900	

yield of garlic are greatly affected. Scenario analysis indicates that the climatic suitability for garlic in the current scenario and the future (2030 and 2050) will drastically change from the current to 2050. For instance, in the present scenario, the highly suitable areas in Ilocos Norte are about 27,300ha. However, if there is an increase in temperature, a highly suitable area for garlic will shrink to 3,000 ha in 2030 and 0 in 2050 (Table 5). In the regional context, the current scenario shows that a total of 34,800 ha are highly suitable for garlic, 187,300 ha, 325,000ha, and 679,300ha for moderately suitable, marginally suitable, and unsuitable, respectively (Table 5a). A decrease of about 88.79% and 48.77% of the highly suitable and moderately suitable areas will be

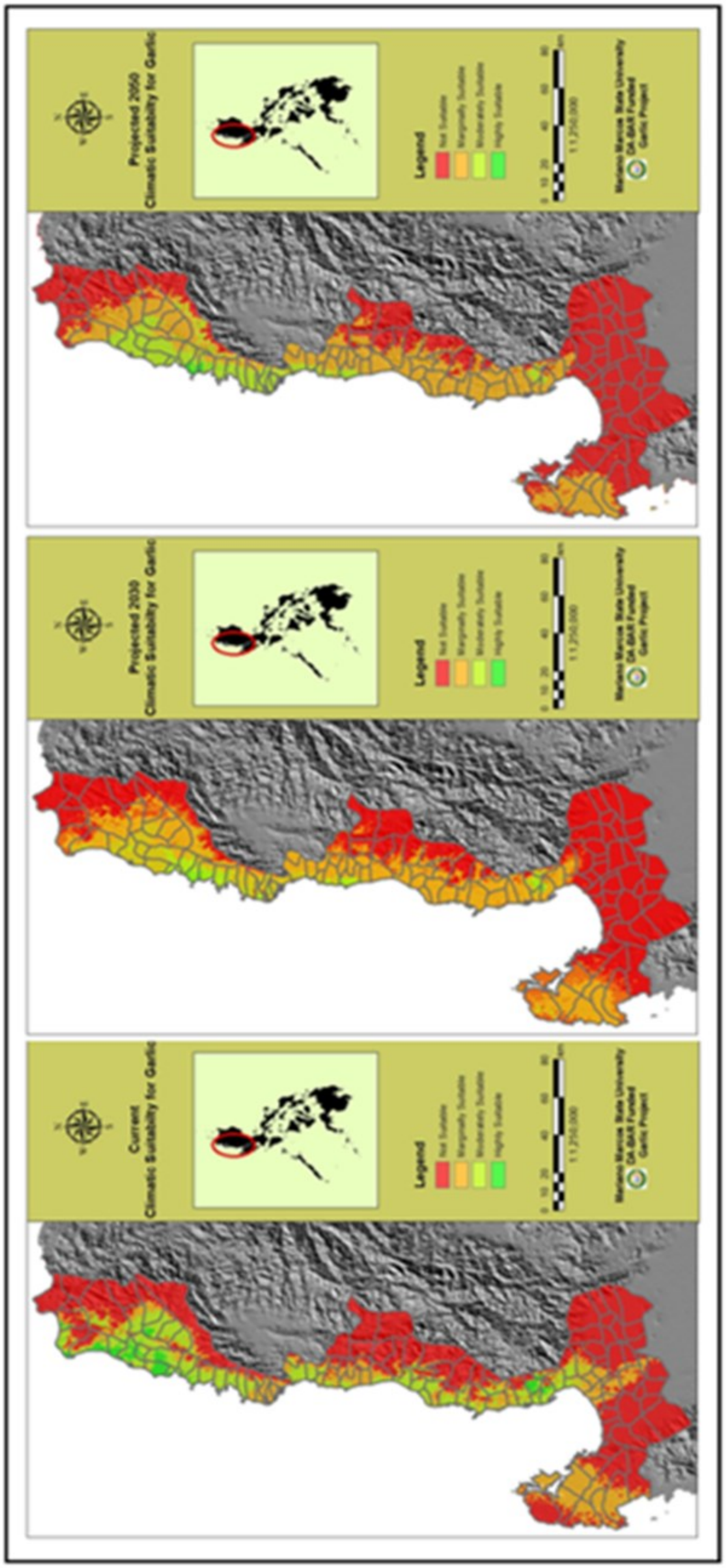

Fig 10. Scenario analysis of suitable areas for garlic at the current year, 2030 and 2050 based on RCP 8.5.

Table 5. Scenario analysis on the climatic suitability of garlic in Region 1 using Maxent Model and RCP 8.5 for 2030 and 2050

Classification	Province											
	Ilocos Norte			Ilocos Sur			La Union			Pangasinan		
	Current	2030	2050	Current	2030	2050	Current	2030	2050	Current	2030	2050
Unsuitable	170,200	176,500	191,100	93,300	143,900	152,900	53,00	26,500	28,800	362,800	384,300	434,700
Marginally Suitable	46,700	82,500	117,600	104,600	56,400	74,400	35,900	104,900	107,100	137,800	121,500	73,200
Moderately Suitable	84,100	66,300	19,600	49,600	48,200	21,300	46,300	9,400	5,700	7,300	2,100	-
Highly Suitable	27,300	3,000	-	1,100	100	-	6,400	800	-	-	-	-
TOTAL AREA	328,300	328,300	328,300	248,600	248,600	248,600	141,600	141,600	141,600	507,900	507,900	507,900

Table 5a. Summary of the scenario analysis on the climatic sustainability of garlic in Region 1 from current to 2050

Classification	**Current**	**2030**	**2050**
Unsuitable	679,300	731, 200	807,500
Marginally Suitable	325,00	365,300	372,300
Moderately Suitable	187,300	125,900	46,600
Highly Suitable	34,800	3,900	-
TOTAL AREA	1,226,400	1,226,400	1,226,400

observed 2030. In contrast, a 12.40% and 7.64% increase in marginally suitable and the unsuitable regions will be observed, respectively. The same trend is observed in the 2050 scenario, but no highly suitable area will be observed in this period.

Conclusions and Recommendations

The results showed that soils in Ilocos Norte are more suitable for garlic production in terms of physical and chemical properties. Soil properties are the most limiting factor that affects garlic suitability due to the low organic matter content and texture.

Of the 957,933ha suitable for garlic production, only 15,687ha are highly suitable, 233,980ha are moderately suitable, and 708,266ha are marginally suitable. Of the 15,687ha highly suitable for garlic in Region 1, Ilocos Norte shares about 97% and 45.76% for moderately suitable.

Based on climatic suitability, in the current scenario, highly suitable areas in Ilocos Norte are about 34,800ha. An increase in temperature will greatly affect the climatic suitability for garlic, which will shrink to 3,000 ha in 2030 and 0 in 2050.

In the regional context, in the current scenario, about 34,800ha are highly suitable for garlic, 187,300ha, 325,000ha, and 679,300ha for moderately suitable, marginally suitable, and unsuitable, respectively. A decrease of about 89% and 33% in the highly suitable and moderately suitable areas in 2030, while an increase of 12.4% and 7.6% in marginally suitable and unsuitable areas will be observed.

The continuous intensive farming practices in the Ilocos Region may further aggravate the degrading quality of the soils. The judicious application of synthetic fertilizer to these soils may still be responsive to plant growth and development, but it further degrades the soil quality and may promote groundwater contamination. Thus, the application of organic fertilizer, green manuring, and crop residue incorporation should be promoted to abate the degrading quality condition of the soils in Region I. These practices may help increase soil organic matter content, thereby improving the soil quality and sustaining productivity.

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