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Cloud-Based Smart Farming for Crop Production Suitability Using Wireless Sensor Technology

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Abstract:
In the Philippines, agriculture plays a dominant role in its economic development. Generating more than 6% of its total export, 25% total area is constraint-free while about 75% areas with various problem soils such as steep slopes, poor drainage, coarse texture soils, heavy cracking clays, severe fertility limitations, acid sulfate soils, feat soils, mine tailing and polluted lands. This paper aims to develop a low-cost, portable cloud-based dashboard connected to a gateway via Internet of Things (IoT) for monitoring real-time measurements providing local farmers, concerned government agencies and units in the Philippines, a modernframework for smart farming which analyzes crop production suitability in terms of edaphic and climatic factors per locality. The integration of Wireless Sensor Network (WSN) technology is required to measure moisture content, humidity, temperature and pH level of the soil and point its actual geographic locations utilizing Global Position System (GPS) in three-dimension (3D) and three-hundred-sixty degrees (3600) street view sattelite map.

Keywords: *Cloud-Based, Smart Farming, Crop Production Suitability, Wireless Sensor Network*

I. INTRODUCTION

Philippines is prone to natural calamities due to its natural tropical location. It is situated in the so called “Pacific Ring of Fire”where 66% of tropical cyclones enter or originate an average of 20 events annually [1].

As consequences to this, flooding has become the most prevalent disaster since year 2000. Being an archipelagic,it become prone to soil erosion with its topographic variations in its various islands, mountains and hilly lands and had experienced decrease in land cover [2].

As shown in Table I, the total land area of the Philippines according to the data provided by the Philippine Statistics Authority (PSA)in 2015 is 30 million hectares (ha) of which 7.19 million ha are classified as agricultural area. Agriculture played a dominant role in the economic development of the Philippines. It generated about more than 6% of its total export, 25% of the total area is constraint-freewhile about 75% consist of areas with various kinds of problem soils [3]. Table 2 described the different categories of problem soils in the Philippines [4].

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Table I. Philippine Land Resources

Total Land Area	30 million hectares
Classified Forest Lands	15.05 million hectares (50%)
Unclassified Forest Lands	0.76 million hectares (3%)
Alienable and Disposable Lands	14.19 million hectares (47%)
Agricultural Area	7.19 million hectares (24%)
Irrigated Area	1.856 million hectares (59.32%)

Table II. Categories of Philippines Soils

Problem Soils	Extent in hectares (ha)	% of the Total Area
Steep Slopes	8,900.00	29.7
Poor Drainage	91, 000.00	0.3
Coarse Texture Soils	360,000.00	1.6
Heavy Cracking Clays	766,000.00	2.5
Severe Fertility Limitations	12,000.00	39.2
Acid Sulfate Soils	27,000.00	0.1
Peat Soils	16,000.00	0.1
Mine Tailing/Polluted Lands	22,000.00	0.1

Climatic and Edaphic are both environmental factors that affect the surroundings. These are socalled external forces that affect the life of all organisms that resides in an ecosystem.Environmental conditions have marked effects on the climates of different areas. Theseconditions cause changes in temperature, humidity, air pressure, evaporation and precipitationwhich are all climatic factors that are interconnected with one another. Likewise, edaphic factorsindirectly affect us by regulating the chemical and biological processes of the organisms that lives in it [6].

Soil suitability classification is needed in order to determine what type of soil is an appropriate match to a certain type of crops. It refers to the use ofa piece of land based ontheir physical, chemical properties and environmentalfactors as well. It may come up with a thorough evaluation of soil properties and qualities such as depth, texture, slope, drainage, erosion, flooding and fertility[7].

The Food and Agriculture Organization (FAO) framework [8] for land evaluation as shown in Table 3classifiedlandsaccording toorder, class and interpretation.Order was subdivided into “Suitable” denoted with letter prefix “S” and “Not Suitable” denoted with “N”. Classwasfurther subdivided into three (3) more classes denoted with “S1”interpreted as“Highly Suitable”,“S2” for“Moderately Suitable”and “S3” for “Marginally Suitable”. Two (2) other ordersfor “Not Suitable”denoted with “N1” and “N2”for “Permanently Not Suitable” [9].

Table III. FAO Structure of Suitability Classification

Order	Class	Interpretation
S - Suitable	S1	Highly Suitable
	S2	Moderately Suitable
	S3	Marginally Suitable
N – Not Suitable	N1	Marginally Not Suitable
	N2	Permanently Not Suitable

II. RELATED WORKS

A. Soil-Crop Suitability Analysis

According to theguidebook developed by the Philippine Rice Research Institute (PhilRice), soil-crop suitability analysis implied what crops would benefit the most from the given soil type [10].

Wang et al., stated in their study that in order to achieve optimum utilization of available land resources for sustainable agricultural production, crop-land suitability analysis is consider a prerequisite [11].

FAO further cited that, crop production[12] involved the interpretation of data related to soil, vegetation, topography, climate.

B. Smart-Farming

According to Culibrinaet al., they have emphasized potentials of Smart Farming (SF)[13]which contributed food sustainability for 21st century using wireless sensor network in farming.

Kaewmard et al., reiterated in their study that feeding[14]the world in the 21st century is the biggest challenge as smart farming used agriculture automation system instead of traditional agricultural methods.

C. Internet-of-Things in Agriculture

Muangprathuba et al.,pointed out that the Internet-of-Things (IoTs) [15] had begun to play a major role in the agro-industrial and environmental fields.

Mekala et al., mentioned that, IoT was a revolutionary technology that represented the future of computing and communications where most of the people all over the world depend on agriculture using modern technologies to control the cost, maintenance and monitor performance [16].

D. Remote Wireless Sensing

In the optimization of IoT in agriculture, Capello et al., stated that optimization [17] of agriculture and installation of Wireless Sensor Network (WSN) in the field have improved effectiveness and efficiency of the farmers.

Wireless sensor network, according to Foughalia et al.,composed of a set of on-board processing units, called "motes", communicating remotely via wireless links and collects a set of environmental parameters surrounding the motes, such as temperature, humidity, and pressure and transmit collected data to the gateway which provides a connection to the wired world [18].

E. Cloud Computing

As technology had evolved, a new emerged service like Cloud-IoT[19] enabled a freely accessible web-service permitting a plug and play of the remotely deployed sensors.

F. Geospatial Mapping

In producing theagro-climatic map of Bukidnon province, located in southern Philippines, Adornado et al., pointed out that climatic factors[20] affecting the plant growth such as evaporation, temperature, relative humidity and rainfall maps were combined.

Another study reported by Bobade et al., in Seoni district of Madhya Pradesh, India,the incorporation of GIS technology[21]on land evaluation for agricultural planning based on soil survey data were incorporated through GIS technology.

III. METHODOLOGY

Researchers aimed to develop a low-cost, portable cloud-based dashboard utilizing Internet of Things (IoT) as the gateway framework to monitor edaphic and climatic factors of soil components through the use of wireless sensor network technology to provide local farmers and other stakeholders data analytics that would assist them to determine which type of crops are suitable and not suitable for cultivation in their respective regions through the application of suitability ratings and while some soil properties and conditions are similar in some regions the ratings can be applied as well. A satellite map will be generated using a GPS in order to track the geolocation of the study area which was randomly selected in the Central Luzon province, Philippines.

A. Hardware and Software Components

The different hardware, software components, block diagram and system design architecture of the functional prototype were discussed further below.

ArduinoATmega 2560 served as the main circuit board providing connection, wired

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through jumper wires and communicating serially via TX (Transmit) and RX (Receive) pins to different sensors powered by a two-port USB type portable 2000mah power bank. Wireless Sensors such as DHT22 monitored the temperature and humidity of soil, two-legged sensor with a controller PCB for soil moisture content, DFRobot pH sensor to observe the acidity and alkalinity level, Neo 6m Ublox for the GPS pointing to the latitude and longtitude coordinates of the google map and satellite image, NodeMCU connected all the hardware components to the IoT gateway via SSID (Service Set Identifier) fromthe prepaid cellular phone wifi hotspot to the cloud hosting provider – DigitalOcean (www.digitalocean.com). A Nextion 2.5 inches Thin-Film-Transistor (TFT) touchscreen outputted the navigation menu of the interface. The menu asked for inputs of the predefined type of crops such as rice and corn, the type of soils such as Silt, Silty, Silty loam, Loam, Loamy, Clay, Sandy and the specific location of the study area listed in dropdown box. The real-time sensor readings and measurements were displayed in the dashboard both in table and in line chart formats.

The Arduino Sketch, the Integrated Development Environment (IDE) which is written in C++ was the one responsible for gathering data from sensors and sending it toNodeMCU. While the codes to configure the connection from the IoT device to the gateway is in PHP programming language. The development stage ran in Microsoft Windows 7 Operating System (OS).

Figures 1 and 2 showed the block diagram and the architecture system design of the prototype.

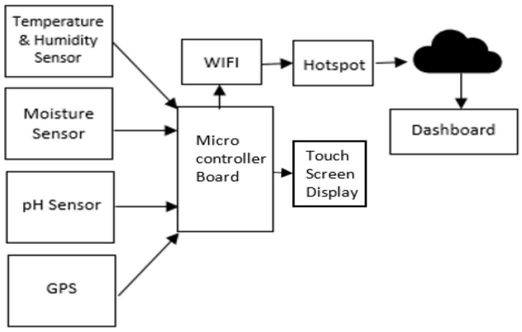

Fig. 1. The Block Diagram

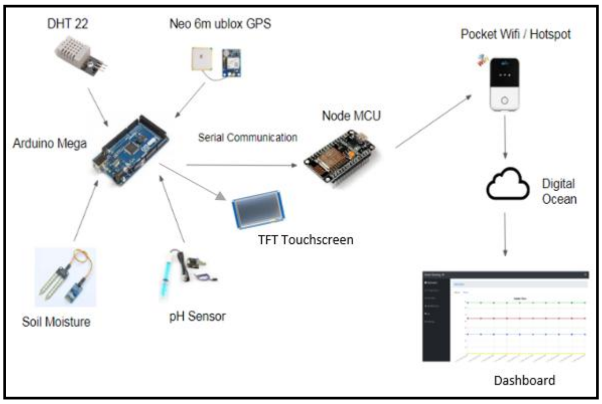

Fig. 2. Architecture System Design

B. Soil Moisture Content Measurement

According to Campbell, soil moisture content [22] can be measured through its volumetric and gravimetric water content. Volumetric Water Content (VWC) is the volume water divided by the total volume of sample and expressed in the form:

$$\boldsymbol{\theta} = \frac{\mathbf{VW}}{\mathbf{VT}}$$

Where:

θ = Volumetric water Content (VWC)

$\mathbf{V_W}$- Volume of Water

$\mathbf{V_T}$ – Total Sample Volume

Whilst, Gravemetric Water Content (GWC) is the mass of water divided by the mas of dry solids and is expressed in the form:

$$\mathbf{w} = \frac{\mathbf{mw}}{\mathbf{md}}$$

Where:

m - mass

w- water

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d- dry solids

B.1. Soil Bulk Density (Pb)

It is the Mass of Dry solid divided by the Total Volume of the sample and express in the form of:

$$\mathbf{Pb} = \frac{\mathbf{Md}}{\mathbf{VT}}$$

B.2 Two-legged Analog Moisture Sensor Voltage Value

Table IV. Analog Voltage Value

Components	Value
Dry Soil	<350
Moist Soil	350 - 745
Watery Soil	746 - 950

C. potential of Hydrogen (pH) Sensor

Itisa value that measures the acidity or alkalinity of the solution and a number between 0 to 14. Under the standard conditions, pH=7, means the solution is neutral, pH<7, means the solution is acidic; pH>7, means the solution is alkaline.

C.1. Linear Function in Determining Correct pH values

Slope Intercept Form: $\boldsymbol{y = mx + b}$

where:

m = *Slope*
x = *Analog Reading*
b = *y Intercept*

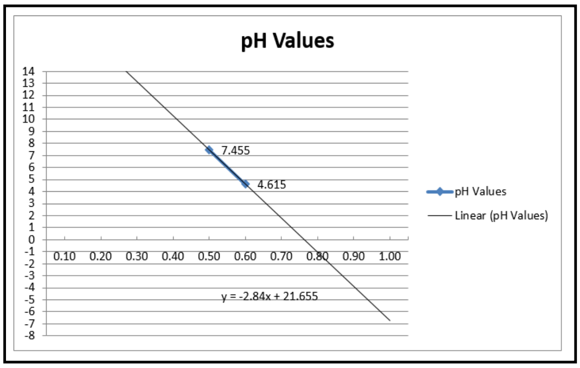

Fig. 3. Sample Determination of Exact pH Value
Using Linear Function

D. The Study Area

The selection of study area for the pilot testing and experiment had used the probability sampling technique known as Simple Random Method.

According to Brown [23], random sampling has the greatest freedom but may represent the sample in terms of time and energy for a given sampling error.

The selected pilotarea was in the Central Luzon region, Philippines, particularly in Nueva Ecija. From this province, a municipality wasselected randomly.

E. GPS Validation

The geolocation coordinates generated from the piloted study area were validated from the National Color-Coded Agricultural Guide Map (NCCAG) by the Department of Agriculture (DA), the primary government agency in the Philippines mandated by law, responsible for the promotion of agricultural development by providing the policy framework, public investments, and support services needed for domestic and export-oriented business enterprises.

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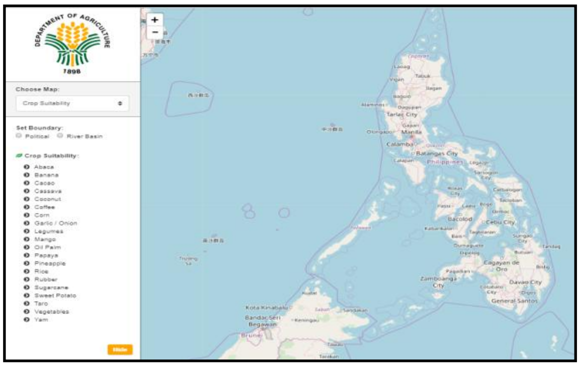

Fig. 4. The NCCAG Map found at www.farmersguidemap.gov.ph/

F. Determination of Soil Type

Determination of soil type through the soils texture feel flow chart [24].

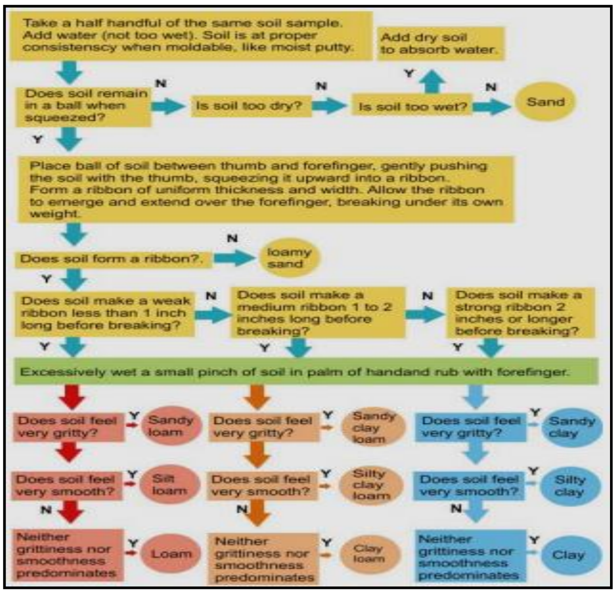

Fig. 5. Soil Texture Feel Flow Chart

G. Testing and Collection of Data

Data from the study area were collected remotely through wireless sensors via IoT using pocket WIFI hotspot to the cloud server and all readings and measurements were displayed in the dashboard in the form of table and chart.

H. Validation of Results

The basis for the validation of results were FAO's structure of suitability classificationsfound in Table 3 and PhilRice's crop suitability analysis of soils for different crops conducted in Nueva Ecija in 2008.

IV. RESULTS AND DISCUSSION

Nueva Ecija was selected as the area of the study. Located in the Central Luzon region and consists of twenty-seven(27)municipalities and five (5) key cities. The municipality of Zaragosa was randomly selected from the rest of the municipalities for pilot testing purposes.

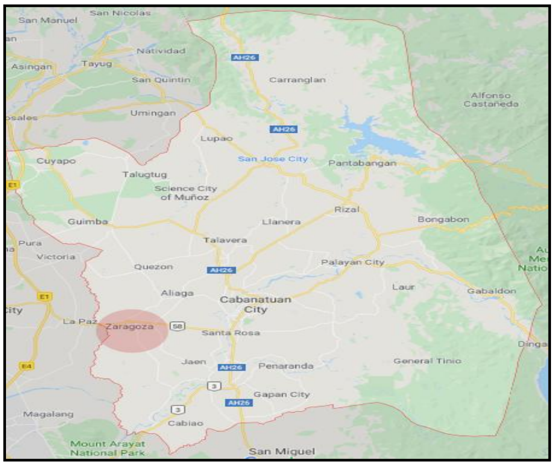

Fig. 6. Map of Nueva Ecija

Thesoil testingwasconducted in one of the rice fields in Zaragosaon October 13, 2019 as shown in Fig. 6. The collection of data commenced by assembling the soil moisture sensor, humidity and temperature sensor, pH sensor and GPS attached to the main circuit board of Arduino. The connection from the power cord and to power bank had turned the main circuit-board's on. It signaled the initialization process of the attached sensors.

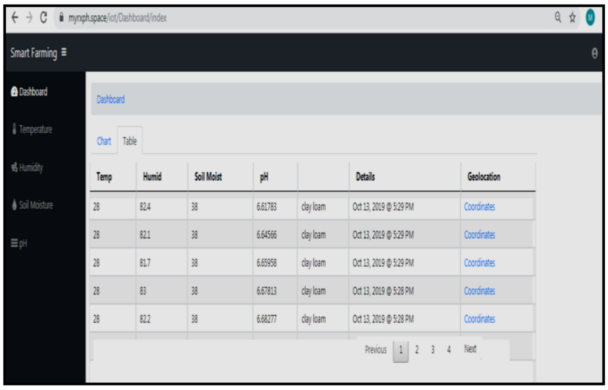

Fig. 7 (a)

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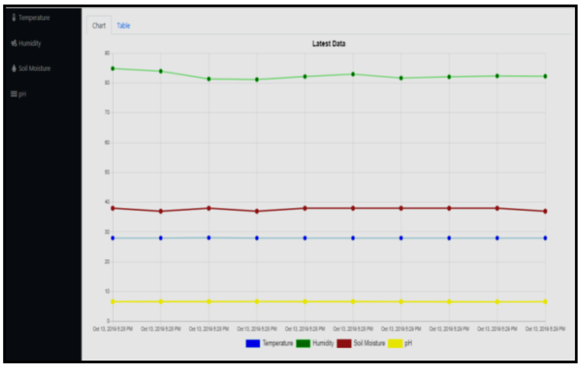

Fig. 7 (b)

Fig. 7 (a) showed the data collected by sensors in table form such as temperature, humidity, soil moisture, soil type, the date and time of the testing and the coordinates of the geolocation.

While Fig.7 (b) illustrated in line chart format the data collected indicated by colors such as blue for temperature, green for humidity, red for soil moisture and yellow for pH level.Further, Table 5 below confirmed the collected data with the following values:

Table V. Edaphic and Climatic Values

Temperature (Degree Celcius)	Humidity	Soil Moisture (%)	pH Level	Soil Type	Date/Time	Geolocation
28	82.4	38	6.61753	Clay Loam	Oct 13, 2019 @ 5:28PM	Coordinates
28	82.1	38	6.54566	Clay Loam	Oct 13, 2019 @ 5:28PM	Coordinates
28	81.7	38	6.65958	Clay Loam	Oct 13, 2019 @ 5:28PM	Coordinates
28	83.0	38	6.67813	Clay Loam	Oct 13, 2019 @ 5:28PM	Coordinates
28	81.2	38	6.68277	Clay Loam	Oct 13, 2019 @ 5:28PM	Coordinates

Table 5revealed that in terms of edaphic and climatic factors the soil texture of the sample soil was clay loam, moisture content read an average of 38%, temperatures at an average of 28 degrees Celcius, pH levelsof the soil were at an average of 6.6 or pH<7, equivalent to “Acidic”. The geolocation coordinates at15°26'24.7"N latitude and 120°46'52.9"Elongitude pointed to the map and satellite images as shown in Fig.8 (a) andFig. 8 (b).

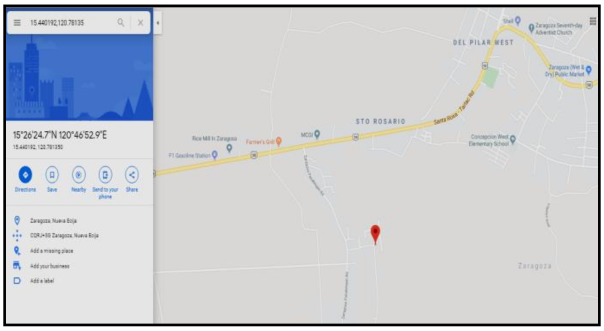

Fig. 8 (a). The Google map pointing towards Zaragosa, Nueva Ecija

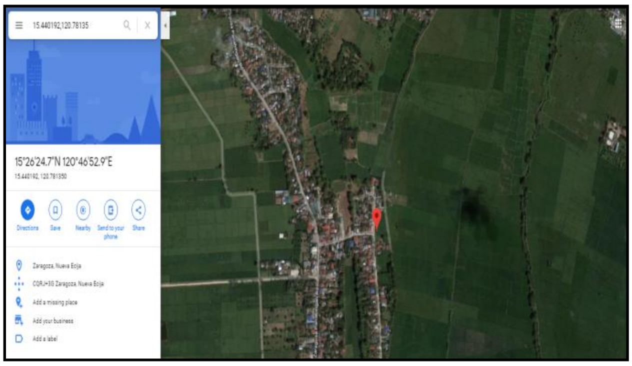

Fig. 8 (b). The satellite map pointing towards Zaragosa, Nueva Ecija

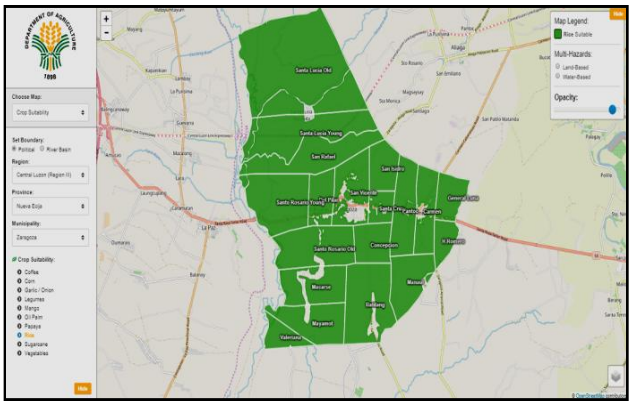

Fig. 8 (c). The National Color-Coded Agricultural Map of Nueva Ecija in Terms of Political Boundary (http://www.farmersguidemap.gov.ph/)

Fig. 8 (c) illustrated the crop suitability of rice in Zaragosa, Nueva Ecija in terms of political boundary among other crops such as coffee, rice, garlic/onion, legumes, mango, oil palm, sugarcane and vegetables.

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Table VI (a)

Soil Series	Slope	Rice Irrigated Lowland	Rice Rainfed Upland	Rice Rainfed Lowland	Maize	Sorghum	Onion
Annam	undulating to rolling	S2sf	S2cf	S2cts	S1	S1	S3tf
Bantog	level to nearly level	S1	S2cw	S2c	S1	S1	S1
Maligaya	level to undulating	S2f	S2cf	S2cf	S2f	S2f	Nf
Prensa	gently sloping	S2sf	S2cf	S2csf	S2f	S1	S3f
Quingua	level to nearly level	S2f	S2cf	S2cf	S2f	S1	S2f
San Fabian	rolling to hilly	S3f	S3f	S3w	S3f	S3f	S3f
San Manuel	level to nearly level	S3sf	S2cf	S3sf	S1	S1	S1
Sibul	undulating, rolling to steep	S2sf	N2t	N2t	S2f	N1t	Ntf
Umingan	level to undulating	S2sf	S3f	S2sf	S2sf	S2sf	S2sf
Zaragosa	level to nearly level	S3f	S3f	S3f	S3f	S2sf	S3f

Suitability ratings:
S1 - Highly suitable
S2 - Moderately suitable
S3 - Marginally suitable
N1 - Currently not suitable
N2 - Permanently not suitable

Limitations due to:
t - topography; slope
w - drainage; flooding
s - texture; coarse fragments; soil depth
f - soil fertility
c - climate

Table VI (b)

Soil Series	Slope	Tobacco	Sweet Potato	Sugar-cane	Peanut	Water Melon	Mango
Annam	undulating to rolling	S3ts	S2f	S3t	S3t	S3t	S3t
Bantog	level to nearly level	S3ws	S1	S1	S1	S2ws	S1
Maligaya	level to undulating	S3wsf	S2f	S2f	S3f	S3wf	S2f
Prensa	gently sloping	S2f	S3f	S3f	S2f	S2f	S2f
Quingua	level to nearly level	S2f	S2f	S2f	S2f	S2f	S2f
San Fabian	rolling to hilly	S3f	S3f	S3f	S2tsf	S3sf	S3s
San Manuel	level to nearly level	S1	S1	S1	S1	S1	S1
Sibul	undulating, rolling, to steep	Nt	S3f	Nt	Nt	Nt	Nt
Umingan	level to undulating	S2sf	S2f	S2sf	S2sf	S2sf	S2sf
Zaragosa	level to nearly level	S3f	S3f	S3f	S3f	S3f	S3f

Suitability ratings:
S1 - Highly suitable
S2 - Moderately suitable
S3 - Marginally suitable
N1 - Currently not suitable
N2 - Permanently not suitable

Limitations due to:
t - topography; slope
w - drainage; flooding
s - texture; coarse fragments; soil depth
f - soil fertility
c - climate

The crop suitability analysis in Table 5 (a) and Table 6 (b) provided by PhilRice [25], revealed that the condition of slope in Zaragosawas "level to nearly level", the type of crops were"Rice found in Irrigated Lowland", "Rainfed Upland", "Rainfed Lowland", "Maize", "Sorghum", "Onion", "Tobaco", "Sweet Potato", "Sugar-Cane", "Peanut", "Water Melon" and "Mango". Below the matrices were legends of "Suitability Ratings"such as "S1", "S2", "S3", "N1", "N2" with corresponding "limitations due to" indicated by the following letter suffixesas *"t"* for topography, *"w"* for wetness due to flooding or drainage, *"s"* forphysical properties, *"f"* forfertility of the soil and *"c"* forclimate.

The suitability analysis further disclosed that **"Rice"** and other crops were interpreted as **"Marginally Suitable"** for the type of soil in Zaragosa as indicated by crop suitability rating of**"S3f"** with limitation due to **"f"**or fertility of the soil.

V. Conclusion

This study helps promote smartfarming in the country, making farming more convenient and efficient with the integration of the portable wireless sensor technology connected to Cloud IoT framework. This revolution is a big help for the local farmers to empower them with the use of 21st technology. As wellas with the governmentbodyin the agriculture sector, this will serve as reference in making policy direction and planning.

With this innovation, farmers can make a better decision which type of crops are suitable to plant in their respective soil areas and what are its limitations making it not suitable. Areas with the same soil properties can apply the same crop production suitability. The 3D satellite image transmitted by the GPS had accurately directed to the actual randomly selected ricefield in Zaragosa, Nueva Ecija, Philippines in 360 degrees view.

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