Development of a Mechatronics System for Measuring Soil pH and approximating NPK Value

Saheed Akande and Mgbeze Emmanuel Chukwuweike
Department of Mechanical and Mechatronics Engineering
Afe Babalola University
Ado-Ekiti, Nigeria
sakande1@abuad.edu.ng, mgbezeemma@yahoo.com

Saka Saheed Olaoluwa
National Biotechnology Development Agency
Ilesha, Osun State, Nigeria
ssaheed9@gmail.com

Abstract

In this work, a system for approximating soil NPK (Nitrogen- Phosphorus-Potassium) level, from the measured pH value of the soil was developed. The moisture level of the soil was also determined. The proposed system's design involves the use of soil moisture sensor, pH sensor, and peristaltic liquid pump with silicone tubing (12V DC power) employed as the actuator. The system is mobile and can be easily transported from one place to another. Extensive literature review revealed that most researchers determine the NPK level of soil from the reference chart of pH level 0-7 which considers only the acidic level. This is due to the fact that the required nutrients for most crops are present in the soil of pH level of 4.5-7.0. However, crops like asparagus, beans, and garlic can yield optimally in alkaline soil of pH level of 6.5-8.0.This justifies the need to extend our findings to alkaline pH level. The develop system approximate the NPK level of both acidic and alkaline soil, from the measured corresponding pH value. The actuator is explored for necessary action of irrigation and fertigation if required after determine the moisture level and the NPK level.

Keywords
Approximating Soil NPK, Soil pH value, reference chart of pH level, Acidic Level and Alkaline pH level.

1. Introduction
The quantity and quality of farm produce is a reflection of soil condition (Christensen, 2001). Crops degrade when there is insufficient rate of supply of necessary nutrients. Fertilizer is usually applied to improve soil properties for proper plant growth. The type and quantity of fertilizer to be applied depends on the contents of the available nutrients in the soil. (Ghosh and Devi, 2019) stated that soil moisture, pH value and NPK value are generally known as the most important soil conditions considered in farming.

Soil pH is a characteristic that describes the relative acidity or alkalinity of the soil.pH values ranges from 0-14. Soils are considered acidic below a pH of 5, and very acidic below a pH of 4 (Slessarev, et al., 2016). Crops like apple, carrot, corn among others require acidic soil with pH in the range of 4.5-7.0. Conversely, soils are considered alkaline above a pH of 7.5 and very alkaline above a pH of 8. Plants, shrubs and vegetables like Asparagus, leek, elder- box, and garlic, among others require alkaline soil with pH in the range of 6.5-8.0. Soil pH values are measured in a standard laboratory, by mixing 10g of soil with 20 ml of 0.01 M $CaCl_2$ solution. The pH is measured using an appropriate electrode connected to a pH meter (Burt and Soil Survey Staff, 2014).Recently, spectrophotometric methods have been developed to measure soil pH involving addition of an indicator dye to the soil extract. These compared well to glass electrode measurements but offer substantial advantages such as lack of drift, liquid junction and suspension effects (Bargrizan, et al., 2017).

The availability of some plant nutrients is greatly affected by soil pH. The "ideal" soil pH is close to neutral within a range 6.5-7.5. Research have shown that most plant nutrients are optimally available to plants within this range, thus very compatible to plant root growth. Nitrogen (N), Phosphorus (P), Potassium (K), and Sulfur (S) are major plant nutrients for plant growth. Nitrogen (N) helps plants to produce strong, healthy, green leaves. Plants will show they are Nitrogen deficient with yellowing leaves. Phosphorus (P) stimulates strong root growth and hardness of plants will show they are phosphorous deficient with dark purple colored leaves. Potassium (K) is for plant's overall health and vigor. Potassium deficient plants are more susceptible to various kinds of diseases and parasitic infestations, as their defenses are weakened owing to their inability to produce sufficient nutrition (Ishani, 2019).

Soil moisture is the water that is held in the spaces between soil particles**.** An ideal soil is one with45% Mineral, 5% Organic matter, 25%water, and 25% air (Warren and George, 2013).The ideal soil moisture level is a function of the soil type as well as the intended crop. In this regards, to obtain an ideal soil for optimal yield requires the knowledge of pH value, the available nutrient especially NPK as well as the soil moisture. Determining these parameters is a problem of interest in this work.

Objectives

The objectives of this study are outlined as follows;

i. To develop a system that approximate soil NPK level from the measured pH level,
ii. To measure the soil moisture level,
iii. To automatically fertigate the soil if there is a need based on the result obtained in (i) and (ii),
iv. To send the user a visual feedback via an LCD display.

2. Literature Review

Extensive literature review reveal that several researchers have studied extensively on different crop yield, soil pH and the NPK level. For an instance, Samia et al. (2012) explored the effect of urea, NPK and compost on growth and yield of soybean in Semi-Arid Region of Sudan. Yulin et al. (2017) researched on comparison of soil analytical methods for estimating wheat potassium fertilizer requirements in response to contrasting plant potassium demand in the glasshouse. However, there are limited work that approximate the soil nutrient level based on pH, though there is a widely accepted fact that pH influences soil nutrient. Nevertheless, some researchers like, Salve et al. (2015) developed a remote sensing device for checking rural situations for different components such as NPK, temperature and stickiness along with other variables that can be of centrality. With this, one can apply fertilizer to the necessary places on the farmland and maintain a strategic distance from over fertilization of the crops.

Also, Deepaet al.(2018) in his research proved that measurement of N (nitrogen), P (phosphorus), K (potassium) contents of soil is necessary to decide how much extra content of these nutrients are to be added in the soil to increase fertility. This improves the quality of the soil which in turn yields a good quality crop. Fiber optic based color sensor was developed to determine N. P and K values in the soil sample. Here, colorimetric measurement of aqueous solution of soil was carried out. The color is based on the principle of absorption of color by the solution. It helps in determining the N, P, K amount as high, medium, low or none. The sensor probe along with proper signal conditioning circuits is built to detect the deficient component of the soil. It is useful in dispensing only required amount of fertilizers in the soil.

Furthermore, Khakal et al. (2016) showed that NPK values can be predicted from the pH using the PHEC sensor and pH Electrode (EC100GTSO05B) whose range is between 0-7. The system have sensors which are capable of detecting the degree of temperature, element contents in soil (N, P, and K), humidity, soil moisture and soil pH. The system also has a mechanism to alert farmers regarding the temperature changes in the greenhouse so that early precaution steps can be taken. This system is useful to recognize and detect motion automatically around a robot's environment in order to equip a mobile robot for a surveillance task for farm. It helps to manage and measure agricultural micro-parameters. It can be useful in chemical industries to predict the content of some chemical mixing during production of fertilizer. Sachin et al. (2015) also implemented the measurement of NPK, temperature, moisture, humidity using Wireless Sensor Network (WSN). Integration of sensors were used for monitoring environmental factors as well as the soil parameters. The outputs are connected to the WSN via multiplexer. The user defined intervals the signals are measured, transferred and logged to the server on the network. The server can be connected to the network via a standard Wireless-G router.

Sindhuja et al. (2017) implemented soil nutrient identification system using Arduino and explore electrochemical sensor system for continuous nutrient determination. The flow-through electrochemical sensor with two electrode system works based on Flow Injection Analysis (FIA) technique for detecting the nutrients. The electrochemical sensor is connected to the analog input port of Arduino controller based and the LCD module is connected to the Arduino port. The electrochemical sensor is dipped into the soil sample. When current flows through the electrode, oxygen diffuses into the cell and is absorbed by both electrodes. The Arduino receives the analog input signal from the electrochemical sensor where the sensor senses the nutrients present in the given soil sample and the signal is sent to the Arduino. However, to the best of researchers knowledge, there is limited work that determine or approximate the level of NPK (as the major components of fertilizer) based on the measured pH. This is the basis of this work.

3. Methods

A reprogrammable system consisting of hardware and software components are explored in this work. The system consists of a soil moisture sensor, pH level sensor, water pump connected to a relay and a LCD display connected to the Arduino input and output pins and also 5v solar panels connected in series which are able to charge the 12v power supply of the system. The software includes programmed codes on an Arduino UNO board. The system sends the data containing the present data of the soil properties to an LCD display for user feedback. The digital and analog components will be incorporated into a hardware frame made of wood and pipes. The top of the frame has solar panels built on it to recharge the battery in the system and an LCD display on the surface shows the output reading values of the various sensors. Figure 1 illustrates the circuit connections of the system.

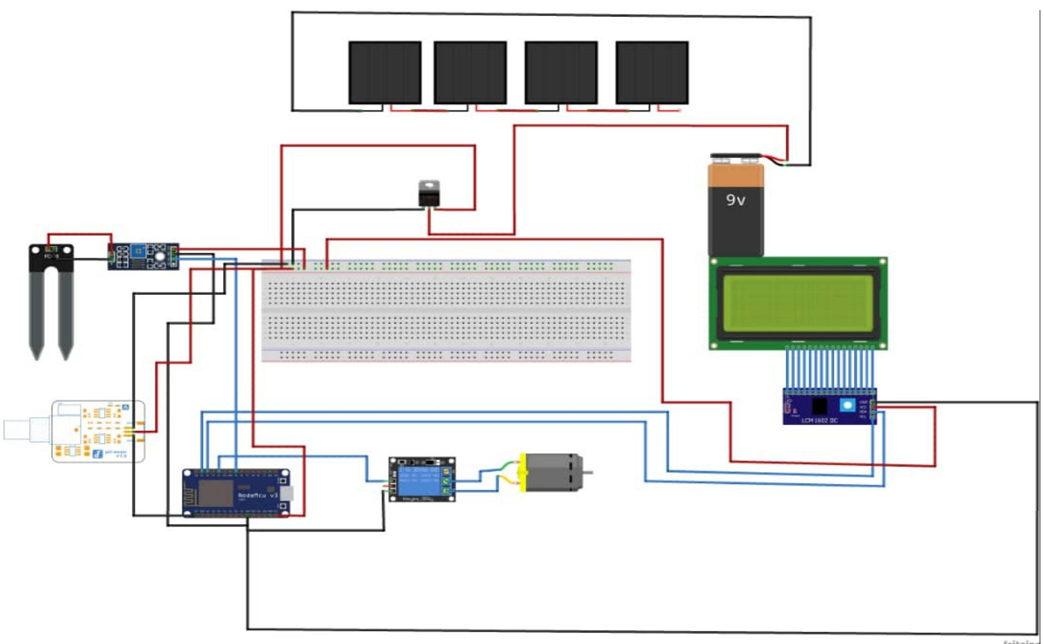

Figure 1: The circuit diagram for the developed system

4. Data Collection

Ten (10) different soil samples were collected at different locations. The pH values of the soil samples were measured by the developed system. The pH was measured by mixing a portion of the soil sample with distilled water in the ratio 1:1 and stirred for a minute. The pH probe was dipped into the solution and the pH values were recorded when the reading gets stable after approximately 30 to 60 seconds. The results obtained were validated by explore a standard laboratory test to determine the pH of the sample. The results from the equipment developed and laboratory show no differences.

The microcontroller was programmed to read the soil moisture and turn on the irrigation system (water pump) when the soil moisture falls below 40% and wait for another hour before irrigating again if the moisture drops below required or programmed level. Soil samples with varying moisture content were collected and tested and the results were recorded. A code was written (See APPENDIX A below) to approximate the NPK using the established chart that illustrates how soil pH influences nutrient availability (see Figure 2 below).

5. Results and Discussion

5.1 Numerical Results

Table 1 shows the results of the pH of the soil samples

Table 1: Results based on the pH value of the soil from the developed system

Soil sample	pH
Sample A	6.30
Sample B	7.60
Sample C	5.80
Sample D	5.50
Sample E	6.10
Sample F	6.00
Sample G	5.50
Sample H	4.90
Sample I	7.10
Sample J	7.40

Table 2: Results based on the soil Moisture content and the actuator action

SOIL SAMPLE	Moisture Content (%)	Water Pump Status (On/Off)
Sample A	64	OFF
Sample B	56	OFF
Sample C	31	ON
Sample D	48	OFF
Sample E	38	ON

Table 3: Results based on the NPK predictions from the soil pH value

Soil sample	N	P	K
Sample A	5	4	5
Sample B	5	5	5
Sample C	4	2	4
Sample D	4	2	4
Sample E	5	3	5
Sample F	5	3	5
Sample G	4	2	4
Sample H	2	1	2
Sample I	5	5	5
Sample J	5	5	5

5.2 Graphical Results
Graphical result from Table 2 above is shown in Figure 3 below.

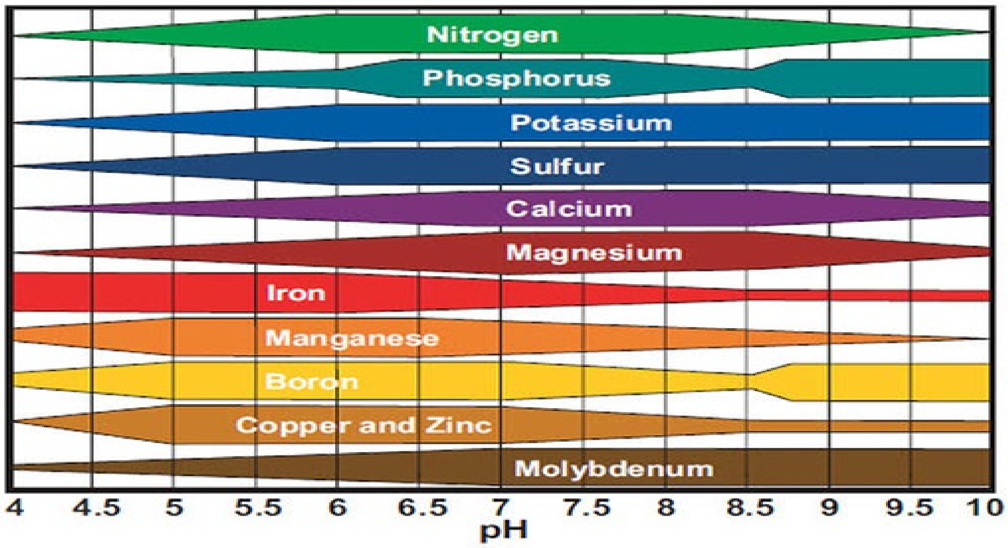

Figure2: Chart illustrating how soil pH influences nutrient availability

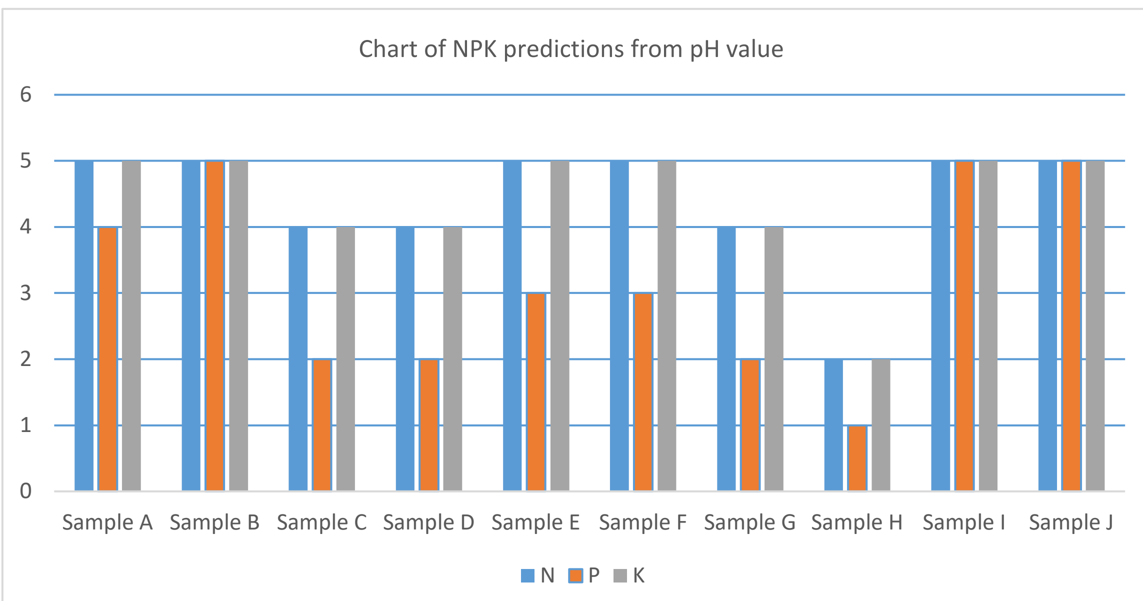

Figure3: Graphical result of NPK predictions gotten from the pH value

5.3 Validation
To validate the accuracy of the system developed in this work, various liquids with known pH were tested with the system developed and the results gotten were compared to the standard pH values of the liquids as shown in Table 4 below.

Table 4: Accuracy

Liquid substance	Known pH	pH gotten from system developed
Soapy water	11.5-12.0	11.10
Milk	6.3-6.6	6.50
Pure water	7.0	6.60
Tomato juice	3.5-4.5	5.10
Orange/ Grape Juice	2.5-3.5	3.20

6. Conclusion

One of the most important factors for effective farming are soil moisture, pH, NPK and irrigating the farmland based on the required soil moisture content for the type of crops and plants available on the farm. A sensory based soil measuring system was used to get the soil moisture content, pH and predict the NPK from the pH value. Irrigation was implemented which can be applied to fertigation if required based on design specifications. Sufficient information was provided to assist the farmer to calculate the amount of fertilizer needed to improve the soil via a LCD. This developed system is easy to use and can be adopted by local farmers.

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Biographies

Engr. Dr. Akande Saheed is an Associate Professor in the Afe Babalola University, Ado-Ekiti, Department of Mechanical and Mechatronics Engineering. He earned B.Sc. in Metallurgical and Materials Engineering from Obafemi Awolowo University, Ile-Ife, Nigeria. M.Sc and Ph.D. in Industrial and Production Engineering, University of Ibadan. Nigeria. He has published numerous journal and conference papers. His research interests include scheduling, mechatronics design, simulation, and optimization. He is a Registered Engineer (COREN) and a Member Nigeria Society of Engineers (NSE), and the Nigerian Institute of Industrial Engineering (NIIE)**.**

Mgbeze Emmanuel is a Mechatronics Engineering graduate of Afe Babalola University, Ado-Ekiti, Department of Mechanical and Mechatronics Engineering. He is currently working at Kabin city Nigeria Limited as a supervisor. He also has interests in automation and control, simulation and Mechatronics design. He is a graduate member of the Nigerian Society of Engineers (NSE). He has carried out various real estate projects in Home Automation and security in Lagos state Nigeria using IOT devices.

Saka Saheed Olaoluwa is a Scientific Officer at National Biotechnology Development Agency Ilesha Branch Osun State. He is the Chief Executive Officer (CEO) of Apex Electronics Laboratory with registration number **3347985.** He is currently undergoing M.Sc program at Federal University Oye-Ekiti, Ekiti State, Nigeria in Physics Department. He earned his B.Tech in Pure and Applied Physics from Ladoke Akintola University of Technology Ogbomoso, Oyo State, Nigeria. He has been involved in several Mechatronics design including: Design and Development of reverse breaking system, Design and Development of a Smart Clinic, Design and Development of home automation using remote control, Design and Development of Aerated Fish Pond, Design and Development of a remote controlled Fire Fighting robot among others.
Presently, he is working on Design and Development of a 3-Components Digital Blast Seismograph as the M.Sc thesis in Progress. His research interest includes Embedded System Technology, Mechatronics, AI, Robot Design and manufacturing software design among others.

APPENDIX A

Source code

```
// Arduino Modul pro měření pH
// nastaveníčíselpropojovacíchpinů
intmoisturePin = A1;
intPumpPin = 4;
intthresholdValue = 740;
intpercentValue = 0;
#include <Wire.h>
#include <LCD.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x3F,2,1,0,4,5,6,7);
constintpinPo = A0;
void setup() {
  // komunikaceposériovélincerychlostí 9600 baud
lcd.begin(20, 4);
//lcd.begin();
```

```
lcd.setBacklightPin(3, POSITIVE);
lcd.setBacklight(HIGH);
lcd.print ("HI USER ");
lcd.setCursor(0, 1);
lcd.print ("RAE SMART FARM");
lcd.setCursor(0,2);
lcd.print ("READ MANUAL TO USE");
  delay (8000);
pinMode(moisturePin, INPUT);
pinMode(PumpPin,OUTPUT);
digitalWrite(PumpPin, HIGH);
Serial.begin(9600);
}
void loop() {
  // vytvořenípomocnýchproměnných
intsensorValue = analogRead(moisturePin);
Serial.println(sensorValue);
percentValue = map(sensorValue, 320, 1024, 100, 0);//meaning sensorvalue, minimum value, maximum value,
minimum percentage value, maximum percentage value
if(sensorValue>thresholdValue){
digitalWrite(PumpPin,LOW);
Serial.println("PumpPin is off");
Serial.println("percentValues ");
Serial.print(percentValue);
Serial.print("%");
lcd.clear();
lcd.setCursor(0, 3);
lcd.print("moist: ");
lcd.print(sensorValue);
lcd.setCursor(13, 3);
lcd.print(percentValue);
lcd.print("%");
lcd.setCursor(1,2);
lcd.print("Pump is on");
    }
  else {
digitalWrite(PumpPin, HIGH);
Serial.println("PumpPin is on");
Serial.print("percentValues ");
Serial.print(percentValue);
Serial.print("%");
lcd.clear();
lcd.setCursor(0, 3);
lcd.print("moist: ");
lcd.print(sensorValue);
lcd.setCursor(13, 3);
lcd.print(percentValue);
lcd.print("%");
lcd.setCursor(1,2);
lcd.print("Pump is off");
  }
intpole[10];
intzaloha;
  unsigned long intprumerVysl = 0;
  // načtenídesetivzorkůpo 10 ms do pole
  for (inti = 0; i< 10; i++) {
```

```
    pole[i] = analogRead(pinPo);
delay(10);
  }
  // seřazeníčlenů pole naměřenýchvýsledkůpodlevelikosti
  for (inti = 0; i< 9; i++) {
    for (int j = i + 1; j < 10; j++) {
      if (pole[i] > pole[j]) {
zaloha = pole[i];
        pole[i] = pole[j];
        pole[j] = zaloha;
      }
    }
  }
  // uložení 2. až 8. výsledku do
  // proměnné, z které se vypočteprůměr
  // (vynechánídvoučlenů pole nazačátku
  // a konci pro lepšípřesnost)
  for (inti = 2; i< 8; i++) {
prumerVysl += pole[i];
  }
  // výpočethodnoty pH z průměru
  // měření a přepočetnarozsah 0-14 pH
  float prumerPH = (float)prumerVysl * 5.0 / 1024 / 6;
  float resultingPH = -5.70 * prumerPH + 21.34;
  // vytištěnívýsledkůposériovélince
Serial.print("Measured pH: ");
Serial.println(resultingPH);
  // pauza 900 msprědnovýmměřením, celkemtedy 1s
lcd.setCursor(2, 0);
lcd.print("pH: ");
lcd.print(resultingPH);
lcd.setCursor(1, 1);
lcd.print("N=1 P=5 K=5");
   //delay(900);
lcd.setCursor(1, 1);
   if (resultingPH<=4.25)
    {
     //lcd.setCursor(1, 1);
lcd.print("N=1 P=1 K=1");
Serial.println("N=1 P=1 K=1");
    }
    else if(resultingPH<=4.5 &&resultingPH>= 4.25)
   {
    //lcd.setCursor(1, 1);
lcd.print("N=2 P=1 K=2");
Serial.println("N=2 P=1 K=2");
    }
  else if (resultingPH<=5.0 &&resultingPH>= 4.5)
   {
Serial.println("N=2 P=1 K=2");
lcd.setCursor(1, 1);
lcd.print("N=2 P=1 K=2");
   }
  else if (resultingPH<=5.5 &&resultingPH>= 5.0)
  {
Serial.println("N=3 P=1 K=3");
```

```
lcd.setCursor(1, 1);
lcd.print("N=3 P=1 K=3");
  }
  else if(resultingPH<=6.0  &&resultingPH>= 5.5)
  {
Serial.println("N=4 P=2 K=4");
lcd.setCursor(1, 1);
lcd.print("N=4 P=2 K=4");
  }
  else if(resultingPH<=6.25 &&resultingPH>= 6.0)
   {
Serial.println("N=5 P=3 K=5");
lcd.setCursor(1, 1);
lcd.print("N=5 P=3 K=5");
   }
 else if(resultingPH<=6.50 &&resultingPH>= 6.25)
  {
Serial.println("N=5 P=4 K=5");
lcd.setCursor(1, 1);
lcd.print("N=5 P=4 K=5");
  }
   else if(resultingPH<=7.75 &&resultingPH>= 6.5)
   {
Serial.println("N=5 P=5 K=5");
lcd.setCursor(1, 1);
lcd.print("N=5 P=5 K=5");
   }
  else if(resultingPH<=8.25 &&resultingPH>= 7.75)
   {
Serial.println("N=4 P=3 K=5");
lcd.setCursor(1, 1);
lcd.print("N=4 P=3 K=5");
   }
  else if(resultingPH<=8.5 &&resultingPH>= 8.25)
   {
Serial.println("N=3 P=3 K=5");
lcd.setCursor(1, 1);
lcd.print("N=3 P=3 K=5");
   }
   else if(resultingPH<=9.00 &&resultingPH>= 8.5)
   {
Serial.println("N=3 P=4 K=5");
lcd.setCursor(1, 1);
lcd.print("N=3 P=4 K=5");
   }
   else if( resultingPH<=9.75 &&resultingPH>= 9.0)
   {
Serial.println("N=2 P=5 K=5");
lcd.setCursor(1, 1);
lcd.print("N=2 P=5 K=5");
   }
    else if (resultingPH<=14.00 &&resultingPH>= 9.75)
   {
Serial.println("N=1 P=5 K=5");
lcd.setCursor(1, 1);
lcd.print("N=1 P=5 K=5");
```

```
  }
delay(900);
}
```