__Original Research Article__

Effects of pH on Climate smart sorghum and green gram management for increased productivity in Tharaka-Nithi and KituiCounties: A comparative observational and satellite-based pH approaches

Abstract

Soil pH is one of the most important soil properties influencing plant growth and productivity. The pH of the soil affects nutrient availability, microbial activity, and soil structure. As a result, accurate soil pH measurement is critical for effective soil management, plant growth, and sustainable agriculture practices. This study was conducted by analyzing the Landsat 8 satellite images, soil data of field surveys, laboratory analyses and statistical computations. The research combined and integrated the soil data from survey and laboratory with Landsat 8 satellite images to build two multiple regression equations model to enable the comparison of the two datasets i.e., field data and satellite data. The field and satellite data depicted the soil pH to range between 6.4 -7.8 for greengram while that of sorghum study area was 6.5 to 7.5. Field data showed a very strong relationship between field and satellite data with R^2 for green gram soil pH being 0.91 while that for sorghum was 0.99.The positive relationship between field and satellite data is an indication that soil pH can be estimated from satellite thereby increasing the frequency of soil pH monitoring and as well as having a cost-effectiveand rapid method for soil pH determination.

Key words: Soil pH, Landsat 8, Greengram, Sorghum, Satellite, Climate Smart

Introduction

The availability of certain nutrients and micronutrients, especially phosphorus and as well as biological activity, are influenced by soil pH (Ghazali et al. 2020). The soil pH or the salt composition is affected by the initial soil parent material, category of plant cultivated, the climatic condition especially the volume of rainfall, and the soil age. Soil pH is an important variable as a quality indicator as it controls different biological and chemical processes happening in soil(Natarajan et al. 2022). Soil pH measures the acidity or alkalinity which is critical in managing cropping process since it controls the nutrient availability for the crop. Thus the soil pH influences health of the crop and soil. Majority of the agricultural crops prefers a pH value between 5.4 and 7.4 range(Ghazali et al. 2020). In agriculture activities, the pH of the soil is critical. Because it influences a range of chemical and biological processes, soil pH is a control variable in soils. It is a determination of the acidity or alkalinity of a soil. Soil salinity, alkalinity, and acidity all have an impact on soil and crop production(Gogumalla et al. 2022) . It reduces agriculture yield through limiting access to nutrients.Gogumalla et al. (2022) indicates that soil pH is useful to analyse in agriculture since it is an indication of soil acidification and overfertilization concerns. It regulates the amount and quantity of soil minerals that plants require to thrive. Remote sensing plays an increasing role in near real-time soil, crop, and pest management(Mulla 2013). Further this type of data has been used in enabling a better understanding of the in-field variability of soil and plant properties and subsequently optimize cropmanagement to maximize crop performance and minimize environmental effects(Ge, Thomasson, and Sui 2011).

Improving soil fertility and moisture levels enhances soil ecosystem functions and food and pasture production in these regions. Encouraging farmers to join soil and water conservation groups, while providing economic incentives, could potentially accelerate the adoption of soil and water practices at the farm level through pulling resources together.Arid and semi-arid regions in Kenya are dominated by 10 soil types; Solanchaks, Solonetz, Cambisols, Arenosols, Leptosols, Vertisols, Fluvisols, Phoezems, Calcisols, and Gypsisols. Among the main soil fertility challenges in these soils are moisture stress, high erodibility, and low organic matter content, salinity, and sodium toxicity, the deficiencies of mainly N, P, Zn, and Fe, hence the vulnerability of over 14 million inhabitants to the shocks of low crop and pasture production.

Study area

According to Fig 1, the study area is Chiakariga and Katangi _Ikombe wards in the Kenyan counties of Machakos and Tharakanithi. Boltet al., (2019) and (Paper & Mugabe, 2016) have both shown that these areas are ideally suited for growing crops like sorghum and green gram. The region has experienced varying amounts of rainfall over time, with a start date that changes from year to year. Additionally, the temperature has been changing over time, which has had a significant effect on the soil moisture and evapotranspiration level. Areas considered as arid and semi-arid zones in Kenya are known to cover agro-climatic zones (ACZs) IV to VII, with mean annual rainfall ranges between 150 mm and 550 mm per year for arid zones, and 550 mm and 850 mm per year in semi-arid zones. High temperatures and high rates of evapotranspiration are evident throughout the year. ASALs occupy 88% of the land area in the country and are home to over 30% of the human population and at least 70% of the national livestock herd and over 65% of the wildlife Plate 1. Due to the vast areas prone to drought, Kenya's vulnerability to food insecurity is highest among the pastoralists and small-scale agriculturalists in the ASALs of the country; whereas vegetation in the ASALs ranges across the country depending on altitudes and degree of aridity.

The soil characteristics are, over 50% of these soils were found to be clay loams and sandy loamsand soil moisture holding capacity tends to increase with the clay content. The bulk density generally increased with the soil depth. The hydraulic conductivity followed a similar trend. A good number of soils in the mountains, hills and uplands are brown to red, pulverized clay loam to clay at the depth of 0 to 20 cm. Increased bulk density with the soil depth explained increased compaction, hence reduction in macrospores.The footbridges on the southern slopes have moderately deep to deep clay loam to clay soils with favourable physical and chemical properties.On the lower slopes are shallow to moderately deep calcareous soils with texture of stony, gravelly, sandy clay loam to sandy clay. At the middle upper slopes, the soils are clay loam. On the lowest slopes, the soils are brown, friable clay and in some areas they are stony and shallow.

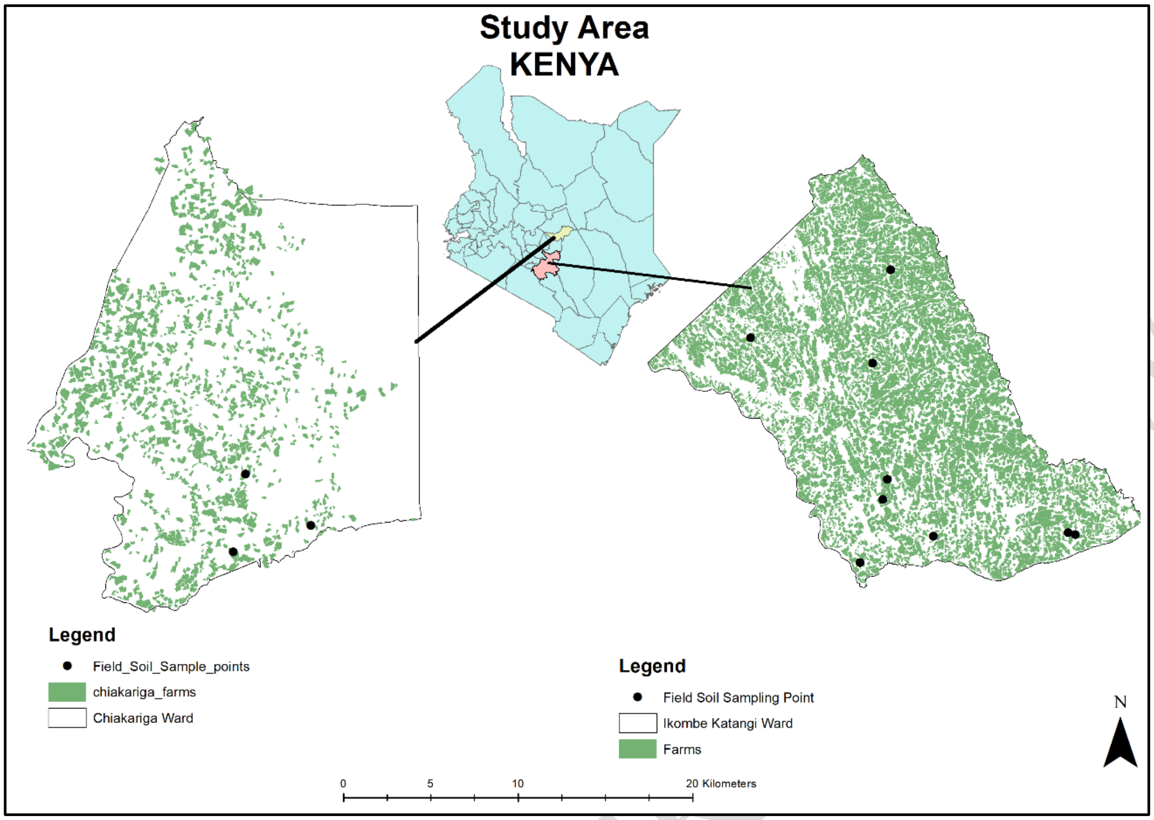

Figure 1: Study area for Chiakariga and IkombeKatangi ward

Materials and methods

Data sets for soil pH characteristics were extracted from the International Soil Reference and Information Centre (ISRIC) soil database. Field data collection through soil sampling of various farms in the study area. The data was taken to the lab for analysis of the soil pH using a pH meter. This is a Standard Operating Procedure for determining pH in soil that has been developed and validated. This standard method employs a soil:water ratio of 1:2.5.(Chacha.,2014; Schofield and Taylor 1955).The soil pH was measured in terms of hydrogen ion concentration (more precisely, activity) of the soil-water or soil-salt suspension system, with H2O molecules dissociating into H+ and OH- ions contributing only a small fraction to the solution pH. Under 'normal' conditions, only one out of every ten million molecules (10-7) is dissociated. pH is defined chemically as the decimal logarithm of the reciprocal of hydrogen ion activity, H+ (Schofield and Taylor, 1955). This definition was adopted because ion selective electrodes used to measure pH respond to activity.

$pH = -\log10\ [\alpha H+] = \log\ (1/[\alpha H+])$.

The values were documented based on GPS farm data as shown in Figure1- in this section.

Table 1: Observed and Estimated soil pH Data

CROP	OBSERVED SOIL PH	ESTIMATED SOIL PH
GREEN GRAMS	6.5	6.4
GREEN GRAMS	7.1	6.4
GREEN GRAMS	7.8	6.8
GREEN GRAMS	7.2	7.5
GREEN GRAMS	7.5	7.0
GREEN GRAMS	7.0	7.0
GREEN GRAMS	7.9	6.9
GREEN GRAMS	7.8	7.6
GREEN GRAMS	7.8	7.8
SORGHUM	7.8	6.8
SORGHUM	7.6	6.5
SORGHUM	7.9	7.0

Results

The data extracted from the satellite image and the field data are shown in table 1. The soil pH estimated data was validated using field data and the results are presented in Figure 2. a & b for Ikombe-Katangi study area and Chiakariga area respectively. The data used in the validation is shown in Table 1. The R2 for green gram for the soil pH was 0.9141 while that for sorghum was 0.9944 showing high correlation with the field data. The soil pH range from satellite data for green gram study area was estimated at 6.4 -7.8 while that of sorghum study area was 6.5 to 7.5 and is shown in Figure 3 a and b.

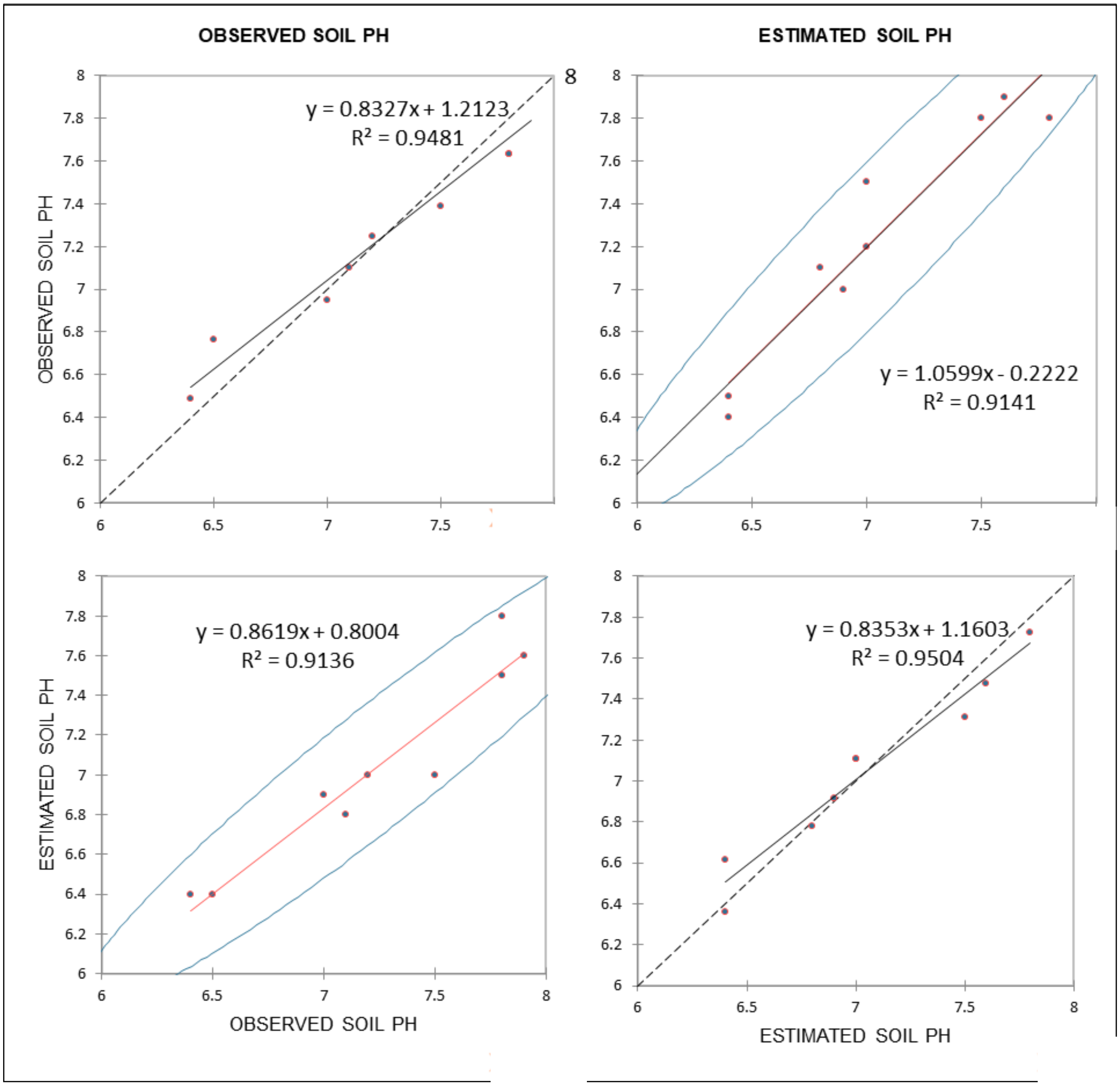

Figure 2.a: R2 results for remote sensing-based Soil pH correlations with sorghum field data

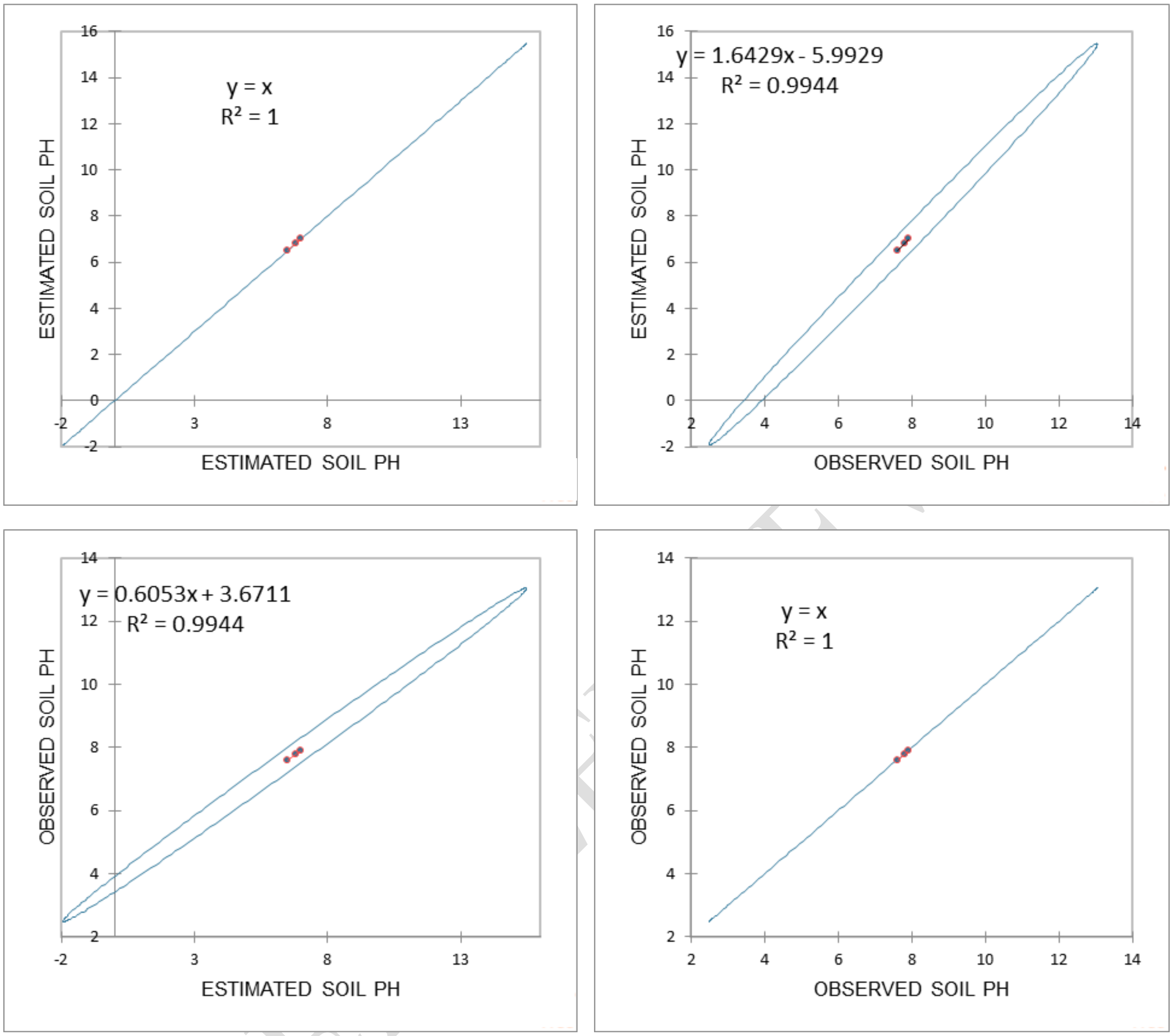

Figure 2.b: R^2 results for remote sensing-based Soil pH correlations with Green gram field data

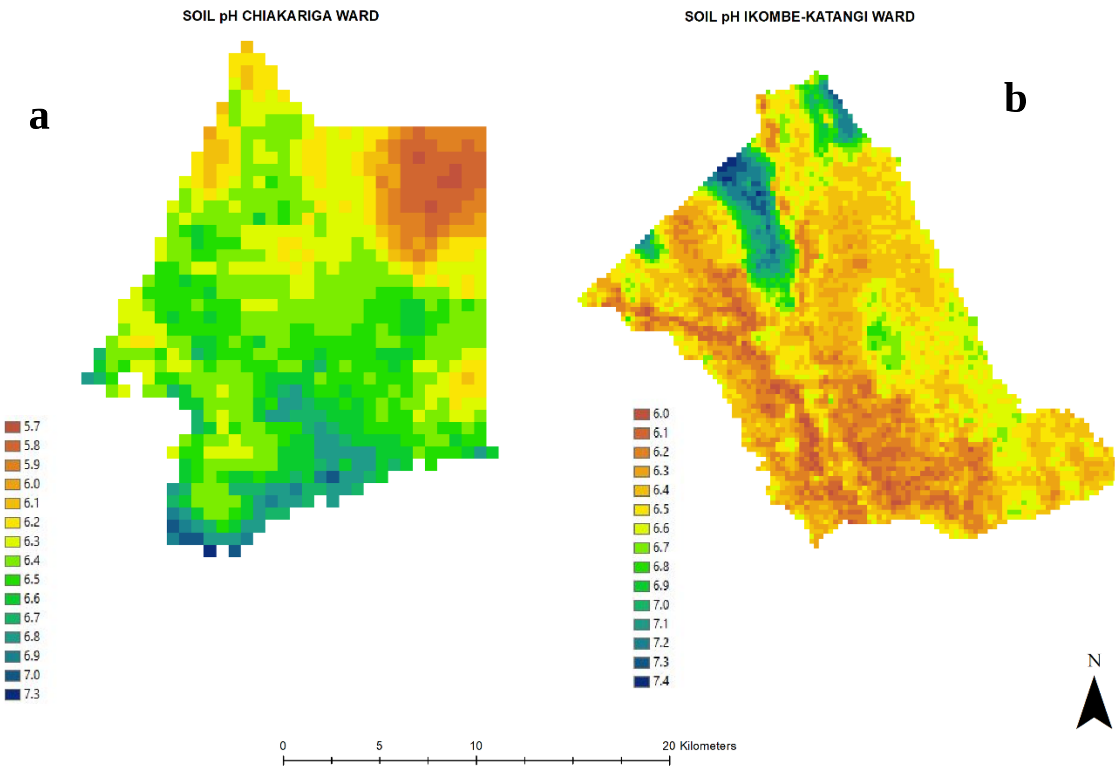

Figure 3. a and b: soil pH data from satellite data for Chiakariga and Ikombe-Katangi wards in Tharaka Nithi and Kitui counties respectively

Discussion

On the other hand, Karienye et al. (2019) points out that semi-arid and arid areas to be good for sorghum production. Ecological requirements of greengram according to (Mugo et al 2016) recommends that the soil be well drained loamy to sandy loamy soil, the pH should be 6.0 to 7.0 in well-drained soil (Mugo et al., 2016) in the research for identification of suitable land for greengram production in Kenya, optimum conditions were found to be well drained soils, soil pH of 6.2 to 7.0, Loam to sandy loam soil and slope of between 0-10%.

Soil pH is critical for understanding soil health, which influences crop yields, crop suitability, plant nutrient availability, and soil microorganism activity., (Gogumalla, et al.,2022).

According to the study by (Wimalasiri et al. 2020), Soil pH was found to be important in the MONICAH agro-ecosystem model for yield estimation. It was noted that soil pH and alongside other parameters affect crop growth. The values of soil pH were found to have high correlation with the field data as shown in Figure 2. a and b. Rainfall has emerged as very critical in the determination of crop yield, (Makowski et al., 2006).The soil pH was assessed for the Ikombe-Katangi and Chiakariga study area. The results showed that, the soil pH ranged from 6.0 to 6.7 for both study areas as shown in Figure 2. a and b. The uptake in sorghum is influenced by soil pH and the drainage of the soils, as documented in the sorghum manual for semi-arid area of Kenya by the Ministry of Agriculture, Livestock and Fisheries Kenya. Checking these parameters is crucial for the performance of crop in the field. In another study by (Sustainability 2020) parameters such as rainfall, soil pH, soil drainage, soil texture and temperature were used in the investigation of suitable areas for crop irrigation. Wenner (1983) in the investigation of suitable areas of cropping in Nepal, soil texture, soil PH, soil drainage and slope were used, among other factors. The study by Ghazali et al.,2020 in conclusion confirmed the ability to estimate the soil pH from Landsat satellite data using band blue, green, red shortwave infrared for paddy rice fields. The fertility of the soil is determined by quality of the physical properties of the soil such as soil pH, (Rowell 1994). Gogumalla,et al.,(2022) confirmed the ability to estimate the soil pH from open source data such as sentinel 1, 2 and Landsat data. In his study he confirmed that satellite data with high spatial, spectral and temporal resolutions can estimate soil pH with fairly good accuracy.

According to (Jones 2002) soil pH plays an important role in agricultural activity through the alterations of mineral concentration in the soil. These minerals such as Boron, manganese, copper, zinc and iron affects the plants growth. The concentration of Boron, Manganese, Cooper, Zinc and Iron in acidic soils is higher than in the alkaline condition, (Jones 2002).Soil pH is controlled by soil colloids whose influence comes from clay, organic matter and oxides, (Delgado 2016).

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