# Vanuatu Soil Sampling and Analysis

Final Report

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**Soil Information for Yield Forecast based on DSSAT Model in Vanuatu**

**(Vanuatu Soil Sampling and Analysis)**

# 1 Introduction

Increasing demands for agricultural products and increased pressures on land, water, and other natural resources particularly under the rapidly changing climate needs information for rapid agricultural decision-making at all levels. It is very true for the Pacific Island Countries which are very vulnerable to climate change. Soil health in the Pacific Island Countries is detreating very rapidly due to prevailing tropical climate and climate change (Nisha et al, 2014, Nisha and Prasad, 2020, Suruban et al., 2022). The traditional agronomic research methods for the generation of data are no longer sufficient to meet the increasing demands for information. Traditional agronomic experiments are conducted at particular points in time and space, thus results are site- and season-specific, time consuming and expensive (Jones, et al. 2003). To address this issue, the decision support system for agrotechnology transfer (DSSAT) was developed by an international network of scientists under the banner of International Benchmark Sites Network for Agrotechnology Transfer Project (IBSNAT) (Tsuji, 1998, Uehara 1989, Hoogenboom et al, 2021). The DSSAT system facilitates the application of crop models in a systems approach to agronomic research. The crop simulation models simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics.

Vanuatu, an archipelago, is a South Pacific Ocean nation made up of roughly 13 principal islands and 60 secondary islands that stretch 1,300 kilometers. Vanuatu was previously known as New Hebrides when it was administered jointly by France and the U.K., until its independence in 1980. Vanuatu is characterized by an average rainfall of 1,600 to 3,000 mm with an average temperature of 23 to 26 ℃. The soils for the most part, are extremely fertile, with about 40 % (average) of the surfaces suitable for cultivation (65-58 % in Efate, 22-52 % un Erromango and 10-30 % in Anatom – Futuna (Desprez, 2011).

# 2 Objectives

The objective of this work is to generate physical and chemical characteristics of soil sampled from ongoing field experiments covering two islands of Vanuatu. The soil properties will be input into the DSSAT system to apply crop models under Vanuatu pedo-climatic condition.

# 3 Methodology

## 3.1 Study Sites

The soil samples were collected from two ongoing experimental plots in Vanuatu at the Department of Agriculture and Rural Development, DARD (Port Vila) (17°42'16.9"S 168°19'07.4"E) and the Vanuatu Agricultural Research and Technical Center, VARTC (Espiritu Santo) (15°27'05.3"S 167°11'21.2"E) (Fig 1). Major crops cultivated in the sampling sites include taro, cassava, sweet potato and different vegetables based on the previous crop cultivation history.

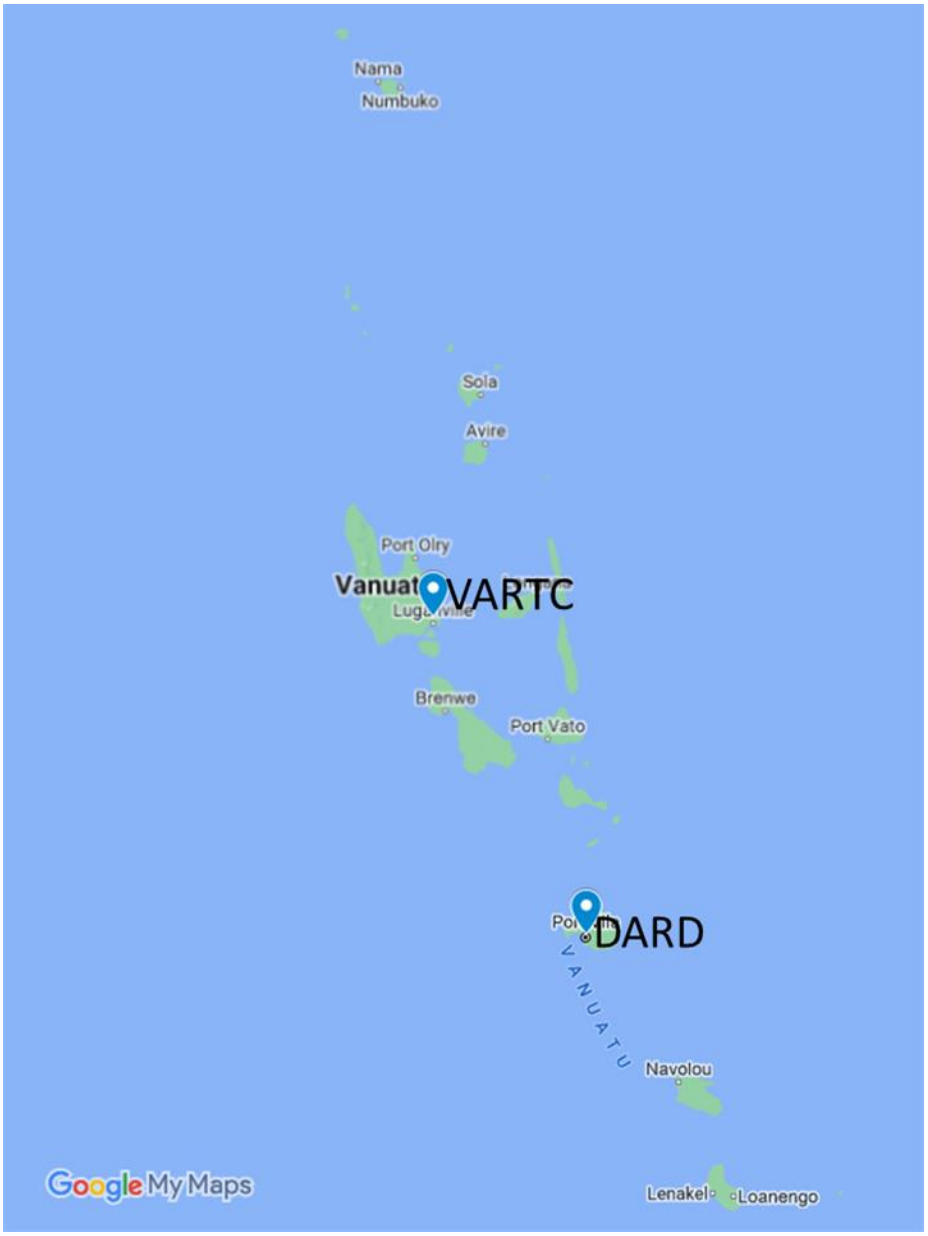


*Figure 1 Vanuatu map showing soil sampling sites*

## 3.2 Soil Sampling and preparation

Soil samples were collected following the soil sampling protocols as outline by Kader (2021) for the Pacific soil laboratories. At each site, undisturbed soil samples were collected up to the root-zone using 30 cm (5 cm diameter) PVC pipes and other required instruments. A soil sampling depth of 0-30cm was selected to cover the rooting depth of the field crops cultivated in Vanuatu as well as accommodate the weight of soil (10 kg) allowed by the Samoa Biosecurity from each sampling sites. Soil sampling was done by the local Vanuatu DARD and VARTC staffs. Virtual training on soil sampling and shipment protocols was provided to the DARD and VARTC staffs before sampling the soils (Fig 2).

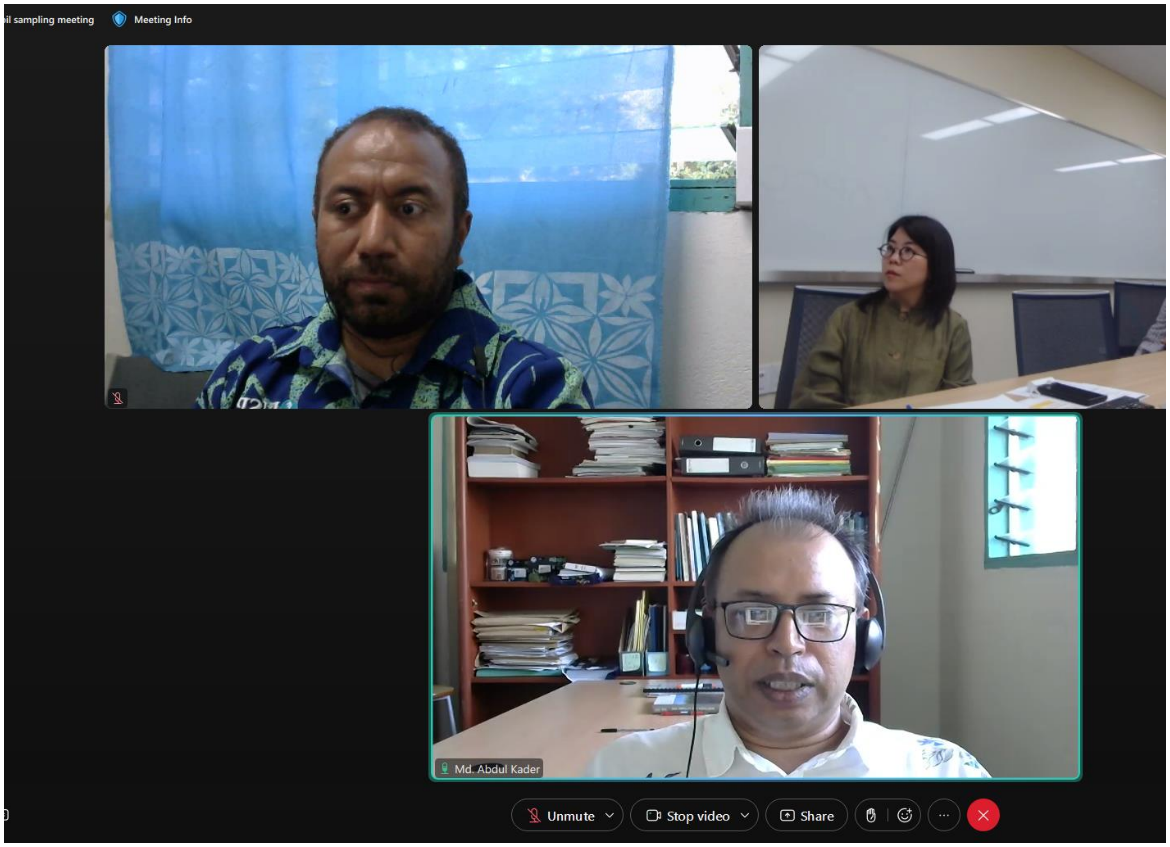


*Figure 2 Virtual training of DARD and VARTC staffs on soil sampling and shipment protocols on October 6, 2023*

Two biosecurity permits were obtained from the Ministry of Agriculture, Samoa Biosecurity Authority (Quarantine Department) were collected- one for each experimental sites before the soil sampling. In total eight soil samples including four disturbed and four undisturbed core samples were collected from each experimental site instead of 10 samples to accommodate the maximum allowable weight limit (10 kg) by the Samoa Biosecurity from each sampling sites. Collected soil core samples were shipped by airfreight to the University of the South Pacific (USP) Soil Laboratory in Apia after receiving biosecurity permits from Samoa followed by Samoa biosecurity and custom clearance. Each soil cores were cut into 5 pieces (0-5 cm, 5-10 cm, 10-20 cm, 20-25 cm and 25-30 cm) (Fig. 3), particularly to obtain a 5 cm undisturbed core samples from each soil horizons for the determination of bulk density and different hydraulic properties of soil e.g. saturation, field capacity, wilting point and saturated hydraulic conductivity. Soils were carefully removed, air-dried until constant weight, grounded and sieved with 2 mm sieve from the rest of the pieces of cores, except one 5 cm core from each horizon for in-depth physical and chemical analysis.


*Figure 3 Preparation and leveling of core samples before cutting into 5 pieces (0-5, 5-10, 10-20, 20-25 and 25-30 cm)*

Morphological soil properties e.g soil horizons were identified by visual observation of soil color, bulk density, soil texture and soil structure. Soil color were determined by Munsell soil color charts 2009 edition. Agronomics parameters e.g, root growth factor was estimated based on the soil density in core samples. Soil saturated hydraulic conductivity of each horizon was measured by following constant head method. Site parameters e.g Albedo fraction, evaporation limit, drainage rate, runoff curve no., mineralization factor were estimated based on secondary data and/ or literature data and physical observation of core samples. Photosynthesis factor was not determined due to the unavailability of crop specific photosynthesis data of Vanuatu. The remaining soil parameters were determined in the laboratory following standard protocols (Table 1).

*Table 1 Soil analysis to be investigated in this work with relevant determination methods*

| | Variable | Definition | Determination methods |
|---|---|---|---|
| 1 | SCOM | Color, moist, Munsell hue | Determination from soil samples (PVC) using Munsell colour chart |
| 2 | SALB | Albedo, fraction | Estimation based on literature |
| 3 | SLU1 | Evaporation limit, mm $day^{-1}$ | Estimation based on literature |
| 4 | SLDA | Drainage rate, fraction $day^{-1}$ | Estimation based on literature |
| 5 | SLRO | Runoff curve no. (Soil Conservation Service) | Determination based on soil and cropping system |
| 6 | SLNF | Mineralization factor, 0 to 1 scale | Estimation based on literature |
| 7 | SLPF | Photosynthesis factor, 0 to 1 scale | Estimation based on literature |
| 8 | SMHB | pH in buffer determination method, | Code provided based on lab method used |
| 9 | SMPX | Phosphorus determination | Code provided based on lab method used |
| 10 | SMKE | Potassium determination method | Code provided based on lab method used |
| 11 | SLMH | Master horizon | Identification from soil samples (PVC) based on soil morphological characteristics |
| 12 | SLLL | Lower limit, or wilting point, $cm^3$ $cm^{-3}$ | Lab determined using pressure plate apparatus or other techniques |
| 13 | SDUL | Drained upper limit, or field capacity, $cm^3$ $cm^{-3}$ | Lab determined using pressure plate apparatus or other techniques |
| 14 | SSAT | Upper limit, saturated, $cm^3$ $cm^{-3}$ | Lab determined using pressure plate apparatus or other techniques |
| 15 | SRGF | Root growth factor, soil only, 0.0 to 1.0 | Estimation based on soil morphological characteristics |
| 16 | SSKS | Saturated hydraulic conductivity, cm $h^{-1}$ | Lab determination by constant water head method |
| 17 | SBDM | Bulk density, g $cm^{-3}$ | Lab determination by core sampler method |
| 18 | SLOC | Organic carbon, % | Lab determination by $K_2Cr_2O_7$ wet oxidation method |
| 19 | SLCL | Clay (<0.002 mm), % | Lab determination by Pipette sampling method |
| 20 | SLSI | Silt (0.05 to 0.002 mm) | Lab determination by Pipette sampling method |
| 21 | SLCF | Coarse fraction (>2 mm), % | Lab determination by sieving techniques |
| 22 | SLNI | Total nitrogen, % | Lab determination by Kjeldahl method |
| 23 | SLHW | pH in water | Lab determination by Glass electrode pH meter |
| 24 | SLHB | pH in buffer | Lab determination in KCl buffer by Glass electrode pH meter |
| 25 | SCEC | Cation exchange capacity, cmol $kg^{-1}$ | Lab determination by Index Cation Method |
| 26 | Texture | Soil textural class | Lab determination by USDA textural triangle |

### 3.3 Summary of Deliverables/ Milestones and Dates

The summary of activities and the deliverables and due dates are summarized in the Table below:

*Table 2 Summary of activities and the deliverables and due dates*

| No. | Activities/ Deliverable | Milestones | Timeline |
|---|---|---|---|
| 1 | Soil Sample Collection | ▪ Collection of biosecurity permit<br>▪ Development of Soil sampling protocol | Sep 18-<br>Oct 15, |
| 2 | Soil Analysis | ▪ Training of DARD and VARTC staff(s) on soil sampling<br>▪ Soil sampling, packing, and transporting soil samples to Apia port, Samoa<br>▪ Biosecurity and custom clearance<br>▪ Soil analysis at USP Soil Lab, Samoa | Oct 15-31<br>Oct 20-<br>Nov 5<br>Nov 6-8<br>Nov 9-25 |
| 3 | Reporting | ▪ Draft report on findings of this work | Nov 9-14 |
| 4 | Final report | ▪ Deliver final technical report and financial report to APCC | Nov 27, 2023 |

# 4 Soil Analysis Result

## 4.1 Site and non-parametric variables

Site specific variables were mostly estimated from the relevant literature as the expert team were not able to travel onsite. Albedo fraction was estimated 0.05 and 0.06 for DARD and VARTC sites, respectively considering the tropical sunny weather and the dark colour of the soils (Table 3). Evaporation limit was estimated 4.5 mm $day^{-1}$ based on the Pan Evaporation data determined for Samoa with slight adjustment. Drainage rate was estimated 0.002 and 0.003 fraction $day^{-1}$for DARD and VARTC sites, respectively considering the soil density, structure, organic matter content and hydraulic conductivity. Three codes were generated for the determination of soil pH in buffer, Phosphorus and Potassium as SMKE, 2. Olsen and 1. Ammonium Acetate, respectively from the DSSAT Model default code fitting against the lab determination methods used for the soil analysis in this project.

*Table 3 Site and non-parametric variables for both DARD and VARTC sites*

| No | Variable | Definition | DARD | VARTC |
|---|---|---|---|---|
| 2 | SALB | Albedo, fraction | 0.05 | 0.06 |
| 3 | SLU1 | Evaporation limit, mm $day^{-1}$ | 4.5 | 4.5 |
| 4 | SLDR | Drainage rate, fraction $day^{-1}$ | 0.002 | 0.003 |
| 5 | SLRO | Runoff curve no. (Soil Conservation Service) | 86 | 77 |
| 6 | SLNF | Mineralization factor, 0 to 1 scale | 0.04 | 0.03 |
| 7 | SLPF | Photosynthesis factor, 0 to 1 scale | nd* | nd |
| 8 | SMHB | pH in buffer determination method, code | SMKE | SMKE |
| 9 | SMPX | Phosphorus determination code | 2. Olsen | 2. Olsen |
| 10 | SMKE | Potassium determination method, code | 1.Ammonium Acetate | 1.Ammonium Acetate |

*nd=not determined

## 4.2 Laboratory determination of parametric soil variables

### 4.2.1 Morphological soil properties

Soil morphological properties including rooting depth are presented in Table 4 and 5 for DARD and VARTC soil samples, respectively. Soil A horizon was identified until 20 or 25 cm for most of the DARD disturbed soil samples while it was 0-20 cm for undisturbed soil samples. Below A horizon, B horizon was identified for all the soil samples, however boundary between A and B horizons was not identified sharply due to lack of onsite soil profile study. A very compacted soil was found below A horizon particularly for undisturbed soil samples. It was also indicated by the saturated hydraulic conductivity data. The hue of A horizons was mostly 7.5 YR (except undisturbed sample 2) while it was 10YR for B horizons (except undisturbed samples 3 and 4). Root growth factor of DARD A horizon was estimated between 0.8 and 0.9 while it was estimated between 0.6 and 0.7 for B horizon.

*Table 4 Soil horizon, colour and root growth factor of DARD soil samples*

| Sample | Depth (cm) | Horizon | Color code | Soil colour | Root growth factor |
|---|---|---|---|---|---|
| ***DARD Disturbed*** | | | | | |
| 1 | 0-25 cm | A | 7.5YR2.5/1 | Black | 0.9 |
| | 25-30 cm | B | 10YR 3/4 | Dark yellowish brown | 0.7 |
| 2 | 0-20 cm | A | 7.5YR2.5/1 | Black | 0.8 |
| | 20-30 cm | B | 10YR 3/4 | Dark yellowish brown | 0.6 |
| 3 | 0-20 cm | A | 7.5YR 3/2 | Dark brown | 0.8 |
| | 20-30 cm | B | 10YR 3/2 | Very dark greyish brown | 0.6 |
| 4 | 0-20 cm | A | 7.5YR 3/1 | Very dark grey | 0.8 |
| | 20-30 cm | B | 10YR 3/3 | Dark brown | 0.6 |
| ***DARD Undisturbed*** | | | | | |
| 1 | 0-20 cm | A | 7.5YR 3/2 | Dark brown | 0.8 |
| | 20-30 cm | B | 10YR 4/4 | Dark yellowish brown | 0.5 |
| 2 | 0-20 cm | A | 10YR 3/3 | Dark brown | 0.8 |
| | 20-30 cm | B | 10YR 3/6 | Dark yellowish brown | 0.5 |
| 3 | 0-20 cm | A | 7.5YR 3/2 | Dark brown | 0.8 |
| | 20-30 cm | B | 7.5YR 2.5/2 | Very dark brown | 0.5 |
| 4 | 0-20 cm | A | 7.5YR 5/3 | Brown | 0.8 |
| | 20-30 cm | B | 7.5 YR 3/2 | Dark brown | 0.5 |

On the other hand, VARTC soil samples were very well aggregated, loose and comparatively reddish in colour compared to the DARD soil samples. A horizon was identified until 25 cm depth for both disturbed and undisturbed soil cores except one core sample (undisturbed 4) (Table 5). The hue of A horizons was 5 YR while it was 2.5YR for B horizons. Root growth factor for A horizon was estimated very high (0.9) both for disturbed and undisturbed soil samples. However, it was ranged between 0.7 and 0.8 for both disturbed and undisturbed B horizon.

*Table 5 Soil horizon, colour and root growth factor of VARTC soil samples*

| Sample | Depth (cm) | Horizon | Color code | Soil colour | Root growth factor |
|---|---|---|---|---|---|
| ***VARTC Disturbed*** | | | | | |
| 1 | 0-25 cm | A | 5YR 3/3 | Dark reddish brown | 0.9 |
| | 25-30 cm | B | 2.5YR 2.5/2 | Very dusky red | 0.8 |
| 2 | 0-25 cm | A | 5YR 3/2 | Dark reddish brown | 0.9 |
| | 25-30 cm | B | 2.5YR 3/2 | Dusky red | 0.8 |
| 3 | 0-25 cm | A | 5YR 3/3 | Dark reddish brown | 0.9 |
| | 25-30 cm | B | 2.5YR 3/2 | Dusky red | 0.8 |
| 4 | 0-25 cm | A | 5YR 3/3 | Dark reddish brown | 0.9 |
| | 25-30 cm | B | 2.5 YR 3/2 | Dusky red | 0.8 |
| ***VARTC Undisturbed*** | | | | | |
| 1 | 0-25 cm | A | 5YR 3/2 | Dark reddish brown | 0.9 |
| | 25-30 cm | B | 2.5YR 3/2 | Dusky red | 0.7 |
| 2 | 0-25 cm | A | 5YR 3/3 | Dark reddish brown | 0.9 |
| | 25-30 cm | B | 2.5YR 3/2 | Dusky red | 0.7 |
| 3 | 0-25 cm | A | 5YR 3/2 | Dark reddish brown | 0.9 |
| | 25-30 cm | B | 2.5YR 2.5/2 | Very dusky red | 0.8 |
| 4 | 0-20 cm | A | 5YR 2.5/2 | Dark reddish brown | 0.9 |
| | 20-30 cm | B | 2.5 YR 2.5/2 | Very dusky red | 0.7 |

### 4.2.2 Soil chemical properties

Soil pH in KCl buffer of DARD soils A horizon varied from 4.6 to 5.2 while it was slightly higher for B horizons ranging from 4.7 to 5.8 (Table 6). Soil pH in water for A horizon varied from 6.0 to 6.8 while it was slightly higher for B horizons ranging from 6.0 to 6.9. A good amount of Olsen P was measured for A horizons ranging from 10.5 to 75.1 mg $kg^{-1}$ while it was always found lower (23.4-54.8 mg $kg^{-1}$) in B horizons except one soil sample (Disturb sample 1). Olsen P concentration was always found lower in B horizon than A horizons except Disturb sample 1. A significant stratification of Olsen P between the soil horizons was observed in case of undisturbed soil samples. Similarly, a strong stratification of soil organic carbon and total N was observed in undisturbed soil samples having high organic carbon (3.8-5.9%) and total N (0.39-0.41%) in A horizon. However, soil organic carbon and total N were more or less similar in A and B horizon of disturbed soil indicating homogenization. Exchangeable K was also stratified having higher exchangeable K in A horizon except both disturbed and undisturbed sample 1. Contrarily, very less stratification of CEC was observed between the soil horizons. It varies from 10.3 to 19.2 Cmol(+) $kg^{-1}$ soil for A horizons and 10.3 to 13.4 Cmol(+) $kg^{-1}$ soil for B horizons.

*Table 6 Chemical properties of DARD soil samples*

| Sample | Horizon | pH in buffer | pH in water | Olsen P (mg $kg^{-1}$ soil) | Organic Carbon (%) | K (Cmol(+) $kg^{-1}$ soil) | Nitrogen (%) | CEC (Cmol(+) $kg^{-1}$ soil) |
|---|---|---|---|---|---|---|---|---|
| ***DARD Disturbed*** | | | | | | | | |
| 1 | A | 4.8 | 6.5 | 10.5 | 3.6 | 0.75 | 0.33 | 11.7 |
| | B | 5.6 | 6.8 | 23.4 | 4.0 | 0.90 | 0.32 | 11.3 |
| 2 | A | 5.0 | 6.8 | 61.4 | 3.7 | 1.01 | 0.33 | 12.8 |
| | B | 5.8 | 6.9 | 54.8 | 3.3 | 0.50 | 0.36 | 13.4 |
| 3 | A | 4.6 | 6.0 | 50.4 | 3.5 | 0.85 | 0.33 | 10.3 |
| | B | 4.8 | 6.1 | 34.9 | 3.5 | 0.39 | 0.34 | 12.4 |
| 4 | A | 5.2 | 6.4 | 53.7 | 3.4 | 1.00 | 0.34 | 10.6 |
| | B | 5.2 | 6.4 | 44.6 | 4.1 | 0.84 | 0.31 | 12.3 |
| ***DARD Undisturbed*** | | | | | | | | |
| 1 | A | 5.0 | 6.5 | 49.3 | 5.4 | 0.63 | 0.39 | 10.8 |
| | B | 4.8 | 6.0 | 7.9 | 1.8 | 0.86 | 0.11 | 10.5 |
| 2 | A | 5.1 | 6.5 | 33.0 | 3.8 | 1.03 | 0.36 | 11.1 |
| | B | 4.7 | 6.4 | 28.5 | 1.0 | 0.82 | 0.11 | 11.2 |
| 3 | A | 5.0 | 6.4 | 75.1 | 4.9 | 1.07 | 0.41 | 19.2 |
| | B | 4.8 | 6.2 | 14.9 | 0.8 | 0.79 | 0.24 | 10.3 |
| 4 | A | 5.2 | 6.5 | 12.3 | 5.5 | 1.10 | 0.40 | 20.3 |
| | B | 5.4 | 6.6 | 8.5 | 1.8 | 1.07 | 0.23 | 13.7 |

Soil pH values in KCl buffer of VARTC disturbed soils A horizons were found slightly acidic than the undisturbed soils (Table 7). It varied from 4.4 to 5.2 while it was slightly lower for B horizons ranging from 4.4 to 4.8. Soil pH in water for A horizon varied from 5.6 to 6.1 while it was varied from 5.4 to 5.8 for B horizons. Olsen P concentration in both A and B horizon was found very low compared to the DARD soil samples. Organic carbon and total N concentrations showed stratification having higher values in A horizon than B horizon likewise DARD soil samples. However, Organic carbon and total N concentrations of VARTC samples were higher than DARD soil samples. A good amount of exchangeable K was measured in both A (0.24-1.08 Cmol (+) $kg^{-1}$) and B horizons (0.54-0.78 Cmol (+) $kg^{-1}$). CEC of VARTC soil samples found slightly higher than DARD soil samples with a clear stratification between A and B horizons. It ranged from 18.4 to 21.8 Cmol (+) $kg^{-1}$) for A horizons while it ranged from 13.7 to 18.4 Cmol (+) $kg^{-1}$) for B horizons.

*Table 7 Chemical properties of VARTC soil samples*

| Sample | Horizon | pH in buffer | pH in water | Olsen P (mg $kg^{-1}$ soil) | Organic Carbon (%) | K (Cmol(+) $kg^{-1}$ soil) | Nitrogen (%) | CEC (Cmol(+) $kg^{-1}$ soil) |
|---|---|---|---|---|---|---|---|---|
| ***VARTC Disturbed*** | | | | | | | | |
| 1 | A | 4.6 | 5.8 | 5.4 | 5.6 | 0.91 | 0.47 | 18.4 |
| | B | 4.6 | 5.6 | 2.3 | 3.5 | 0.68 | 0.29 | 13.7 |
| 2 | A | 4.4 | 5.6 | 7.6 | 5.3 | 0.96 | 0.48 | 20.4 |
| | B | 4.6 | 5.8 | 9.2 | 4.2 | 0.71 | 0.32 | 18.4 |
| 3 | A | 4.8 | 5.8 | 9.3 | 6.2 | 0.82 | 0.45 | 20.1 |
| | B | 4.4 | 5.4 | 4.5 | 4.3 | 0.60 | 0.33 | 17.5 |
| 4 | A | 4.8 | 5.7 | 3.9 | 4.5 | 0.88 | 0.49 | 21.1 |
| | B | 4.6 | 5.6 | 3.3 | 3.8 | 0.62 | 0.30 | 17.4 |
| ***VARTC Undisturbed*** | | | | | | | | |
| 1 | A | 5.1 | 6.1 | 8.3 | 5.8 | 1.08 | 0.50 | 21.3 |
| | B | nd* | nd | nd | nd | nd | nd | nd |
| 2 | A | 5.2 | 5.6 | 4.1 | 6.0 | 0.24 | 0.49 | 21.8 |
| | B | 4.8 | 5.8 | 2.4 | 3.3 | 0.78 | 0.32 | 15.2 |
| 3 | A | 5.0 | 5.6 | 2.6 | 6.7 | 0.62 | 0.47 | 20.3 |
| | B | 4.8 | 5.8 | 3.7 | 2.7 | 0.62 | 0.32 | 15.4 |
| 4 | A | 5.2 | 5.7 | 6.4 | 5.9 | 0.34 | 0.46 | 20.8 |
| | B | 4.6 | 5.7 | 5.8 | 2.8 | 0.54 | 0.33 | 15.2 |

*nd=not determined

### 4.2.3 Soil physical properties

Saturated hydraulic conductivity of A horizons for disturbed soil samples varied from 68.4 to 484.2 cm $hr^{-1}$ while it was ranged from 1.7 to 3.8 cm $hr^{-1}$ for the B horizon. Hydraulic conductivity of undisturbed DARD soil samples varied from 23.6 to 141.2 cm $hr^{-1}$ for A horizon while it was below detection limit for B horizon due to very compact clay soil (Table 8). Soil in A horizons were found very loose having low bulk density (0.84-1.07 g $cm^3$) while B horizons were found very compacted particularly for undisturbed soil samples. Moisture content of A horizons at saturation, field capacity and wilting point were ranged from 0.55 to 0.70, 0.38 to 0.55 and 0.18 to 0.23 $cm^3$ $cm^{-3}$, respectively. However, all those soil water constants were measured comparatively low for B horizons.

A very small percentage of coarse fraction varied from 1.1 to 2.3 was measured both A and B horizons of both disturbed and undisturbed soil samples of DARD. A high clay content varied from 28.5 to 58.5% was observed in A horizon as well as B horizons (16.2-58.4%). Similarly, silt content was also measured very high varied from 24.2 to 51.9% in A horizon and 24.2 to 61.8% in B horizon. Soil texture of disturbed and undisturbed A horizons were determined Clay loam and Silty clay loam/Clay loam, respectively and B horizons, Silt loam and Sandy loam/ Silty clay loam/Clay loam, respectively.

A very high hydraulic conductivity ranging between 484.2 and 1636.1 cm $hr^{-1}$ was measured for A horizon of VARTC disturbed soil samples while it was measured between 493.2 and 1375.8 cm $hr^{-1}$ for undisturbed soil samples (Table 9). Hydraulic conductivity was also much higher in VARTC B horizon compared to the soils of DARD B horizon. The hydraulic conductivity of B horizon was measured for only one disturbed sample (438.8 cm $hr^{-1}$) due to preserving B horizon soil samples for the measurement of other soil parameters. It was ranged from 11.9 to 334.8 cm $hr^{-1}$ for undisturbed soil samples.

A very small percentage of coarse fraction varied from 1.1 to1.9% was measured both for the A and B horizons of disturbed and undisturbed soil samples of VARTC. VARTC soil samples were comparatively looser than the DARD soils. Soil in A horizons were found very loose having low bulk density (0.79-1.03 g $cm^3$) while B horizons were found mostly compacted particularly for undisturbed soil samples. Moisture content of A horizons at saturation, field capacity and wilting point were ranged from 0.66 to 0.73, 0.46 to 0.58 and 0.19 to 0.25 $cm^3$ $cm^{-3}$, respectively while those soil water constants varied from 0.38 to 0.68, 0.27 to 0.43 and 0.07 to 0.24 $cm^3$ $cm^{-3}$, respectively for B horizons. A high clay content was also observed for VARTC soil samples A (34.7-39.2%) as well as B horizons (34.7-59.7%). Similarly, silt content was also measured very high varied from 28.0 to 54.6% in A horizon and 28.0 to 41.8% in B horizon. Soil texture of disturbed and undisturbed A horizons were determined Sandy clay loam and Sandy loam, respectively and B horizons, Sandy clay loam and Sandy loam, respectively.

*Table 8 Physical properties of DARD soil samples*

| Sample | Horizon | Saturated hydraulic conductivity (cm $hr^{-1}$) | Bulk density (g $cm^3$) | Upper limit, saturated ($cm^3$ $cm^{-3}$) | Field capacity, ($cm^3$ $cm^{-3}$) | Wilting point, ($cm^3$ $cm^{-3}$) | Coarse fraction (>2mm) (%) | Clay (%) | Silt (%) | Soil texture |
|---|---|---|---|---|---|---|---|---|---|---|
| ***DARD Disturbed*** | | | | | | | | | | |
| 1 | A | 484.2 | | | | | 1.0 | n.d. | n.d. | n.d. |
| | B | n.d. | 0.93 | 0.65 | 0.41 | 0.18 | 1.5 | 44.3 | 46.9 | Clay |
| 2 | A | 68.4 | 0.92 | 0.64 | 0.44 | 0.19 | 1.2 | n.d. | n.d. | n.d. |
| | B | 3.8 | 1.22 | 0.58 | 0.35 | 0.12 | 1.3 | 58.4 | 24.2 | Clay |
| 3 | A | 151.4 | 1.05 | 0.69 | 0.52 | 0.21 | 2.1 | 58.5 | 11.8 | Clay loam |
| | B | 1.7 | 1.45 | 0.35 | 0.27 | 0.09 | 1.2 | 26.2 | 53.9 | Silt loam |
| 4 | A | 130.0 | 0.88 | 0.68 | 0.46 | 0.18 | 1.5 | 30.6 | 46.4 | Clay loam |
| | B | 2.0 | 1.47 | 0.36 | 0.29 | 0.09 | 1.5 | 25.2 | 54.0 | Silt loam |
| ***DARD Undisturbed*** | | | | | | | | | | |
| 1 | A | 23.6 | 1.07 | 0.55 | 0.38 | 0.20 | 1.0 | 34.0 | 51.9 | Silty clay loam |
| | B | trace | 1.29 | 0.57 | 0.32 | 0.11 | n.d. | n.d. | n.d. | n.d. |
| 2 | A | 141.2 | 0.91 | 0.69 | 0.42 | 0.19 | 2.3 | 38.8 | 46.5 | Silty clay loam |
| | B | trace | 1.42 | 0.39 | 0.31 | 0.11 | 1.6 | 16.2 | 20.2 | Sandy loam |
| 3 | A | n.d. | n.d. | n.d. | n.d. | n.d. | 1.4 | 34.2 | 51.7 | Silty clay loam |
| | B | trace | 1.46 | 0.46 | 0.36 | 0.09 | 1.6 | 35.6 | 29.8 | Clay loam |
| 4 | A | 41.0 | 0.84 | 0.70 | 0.54 | 0.23 | 1.5 | 28.5 | 42.0 | Clay loam |
| | B | trace | 1.45 | 0.42 | 0.32 | 0.10 | 1.2 | 33.9 | 61.8 | Silty clay loam |

*nd=not determined

*Table 9 Physical properties of VARTC soil samples*

| Sample | Horizon | Saturated hydraulic conductivity (cm hr$^{-1}$) | Bulk density (g cm$^3$) | Upper limit, saturated (cm$^3$ cm$^{-3}$) | Field capacity, (cm$^3$ cm$^{-3}$) | Wilting point, (cm$^3$ cm$^{-3}$) | Coarse fraction (>2mm) (%) | Clay (%) | Silt (%) | Soil texture |
|---|---|---|---|---|---|---|---|---|---|---|
| ***VARTC Disturbed*** | | | | | | | | | | |
| 1 | A | 851.7 | 0.98 | 0.69 | 0.40 | 0.22 | n.d. | n.d. | n.d. | n.d. |
| | B | 438.8 | 0.96 | 0.68 | 0.43 | 0.24 | n.d. | n.d. | n.d. | n.d. |
| 2 | A | 484.2 | 1.03 | 0.66 | 0.41 | 0.21 | 1.2 | 52.0 | 32.1 | Sandy clay loam |
| | B | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| 3 | A | 689.2 | 0.87 | 0.70 | 0.46 | 0.23 | 1.4 | 39.2 | 54.6 | Sandy clay loam |
| | B | n.d. | n.d. | n.d. | n.d. | n.d. | 1.6 | 51.8 | 41.8 | Sandy clay loam |
| 4 | A | 1636.1 | 0.94 | 0.71 | 0.58 | 0.22 | 1.9 | n.d. | n.d. | n.d. |
| | B | n.d. | 1.53 | 0.52 | 0.35 | 0.14 | 1.7 | 59.7 | 23.9 | Sandy clay loam |
| ***VARTC Undisturbed*** | | | | | | | | | | |
| 1 | A | n.d. | n.d. | n.d. | n.d. | n.d. | 1.2 | 34.7 | 28.0 | Sandy loam |
| | B | 192.2 | 1.50 | 0.38 | 0.27 | 0.08 | 1.2 | 34.7 | 28.0 | Sandy loam |
| 2 | A | 799.3 | 1.03 | 0.69 | 0.49 | 0.19 | 1.8 | 25.9 | 46.8 | Silty loam |
| | B | n.d. | n.d. | n.d. | n.d. | n.d. | 1.6 | 34.5 | 62.8 | Silt clay loam |
| 3 | A | 493.2 | 0.79 | 0.71 | 0.50 | 0.25 | 1.5 | 40.6 | 52.9 | Silty clay |
| | B | 334.8 | 0.96 | 0.55 | 0.19 | 0.07 | 1.6 | 42.1 | 28.3 | Clay |
| 4 | A | 1375.8 | 0.89 | 0.73 | 0.56 | 0.25 | 1.3 | 28.1 | 51.2 | Silt clay loam |
| | B | 11.9 | 1.51 | 0.56 | 0.36 | 0.11 | 1.1 | 39.0 | 37.7 | Clay loam |

*nd=not determined

## 5 Conclusion

Two experimental soil datasets generated through this short research can be utilized for crop modelling study under Vanuatu pedo-climatic conditions. We recommend using an average of four replications for better representing the soil characteristics of the experimental sites as the replicated soil datasets do not represent composite samples rather represent sub-samples. The disturbed (average) and undisturbed (average) soil datasets could be useful for developing scenario or predicting crop yields both under normal/modern cultivation system (where farmers practice tillage) and traditional shifting cultivation system (undisturbed) (where farmers do not practice tillage). The shifting cultivation system has been practicing a lot in all the Pacific Island Countries including Vanuatu. We also recommend generating a larger soil dataset by sampling and analyzing multiple locations covering a wide range of soils, cropping systems and agroecology to predict crop yield more accurately.

The research faced some limitations. Soil samples arrived very late to the USP Soil laboratory (9 November afternoon, 2023) due to unavoidable circumstances (a category 3 cyclone in Fiji, administrative issues, to name a few) which made the task very difficult to complete within the stipulated timeframe maintaining high quality of analysis. Another shortcoming of this research was limited amount of soil samples that were allowed by Samoan Biosecurity Authority. This slowed down the lab analysis as the same soil samples were used for analyzing multiple soil parameters chronologically one after another without discarding the soil samples. This also limited the scope of repeated analysis to generate high quality soil data. However, in future, all those issues could be minimized based on the lesson learned in this research work.

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