SOIL HEALTH ASSESSMENT OF TARO (C*olocasia esculenta*) FARMS IN SAMOA

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Abstract

Forty (40) composite topsoil samples (0-10 cm deep) were collected from farms exporting taro to New Zealand and Australia in the two main islands of Upolu and Savaii in Samoa in order to measure the farms' soil chemical, biochemical and biological health status and to evaluate any soil nutritional problems that may affect taro productivity. Chemical indicators measured include pH (1:5 soil:water ratio), organic C, total N, Olsen P, exchangeable cations (K, Ca and Mg) and micronutrients (Cu, Fe, Mn and Zn). Biochemical indicators measured include anaerobically mineralisable N (AMN), labile carbon (LC) and fluorescein diacetate (FDA) assay. Soil biological health was assessed by counting nematodes (free-living and plant-parasitic). The topsoils are moderately acidic (pH 5.53). The mean levels of organic C (11.3%) and total N (1.02%) are high since long-term cultivation by machinery has not occurred in Samoa. However, mean Olsen P level was low (10 mg/kg) and can potentially be a limiting nutrient for taro in the long term. Exchangeable Ca and Mg are both high. However, the topsoils have only medium levels of exchangeable K and given the high uptake of taro for this nutrient and high rainfall and leaching rates, this could be another nutrient element that may limit production in the future. Micronutrient levels (Cu, Fe, Mn and Zn) are generally very high so deficiencies are unlikely. Biochemically, the level of AMN (32.7 mg/kg), LC (1310 mg/kg) and FDA (153 mg/kg) were high indicating microbial activity is high and is significant for the fertility of Samoan soils. This could be the result of farmers practicing traditional mixed cropping and the absence of mechanical tillage. Free living nematodes outnumber plant parasitic nematodes with their ratio being almost 2.5:1 and this suggests that taro exportation is unlikely to pose a biosecurity problem overseas.

Introduction

Taro (*Colocasia esculenta*) is the most important staple and export crop of the south Pacific island country of Samoa. Exported taro corms generally land on the shores of American Samoa, Australia and New Zealand. In 2009, Samoa exported almost 200 tonnes of taro corms. The Samoan government is trying to enhance the agricultural competitiveness of the country and has been encouraging farmers to grow more taro for export by expanding the areas under production. Most Samoan soils are derived from relatively young basaltic parent materials (Wright 1963) with high organic matter content and are generally regarded as able to support current production levels without further nutrient additions. Also, imported commercial fertilisers are expensive. Thus, only a few farmers apply fertiliser to their taro crop. Considering crop nutrient removals can be substantial over the long term, it is therefore important to assess the health status of soils and where possible, also monitor it on a regular basis. Soil health is the capacity of soil to sustain and support growth of crops and animals while also maintaining and improving the environment (Lal, 2011). The capacity of soil to sustain and support plant growth is determined by the interaction of physical, biological and chemical properties as well as soil management practices employed in the farm. The objectives of this work are to: (1) assess the topsoil health status of taro exporting farms in Samoa using chemical, biological and biochemical indicators; and (2) diagnose any potential nutritional issues associated with growing taro for export in the long term.

Methods

From July to August 2013, a total of 40 composite topsoil samples (0-10 cm) were collected from selected taro exporting farms from the two main islands of Upolu (20 samples) and Savaii (20 samples) (Figure 1). Samples were collected along two 50-m transect lines forming a cross (X) pattern (Figure 2). The GPS coordinates (longitude and latitude) of the ends of the transect lines were recorded. There were a total of 25 topsoil samples collected every 2 m from each 50-m transect line. Samples from the two transect lines were then composited and mixed thoroughly. Samples were brought to the laboratory, dried, sieved to less than 2 mm and analysed for chemical, biochemical and biological properties. Chemical properties analysed include pH (1:5 soil:water ratio), organic carbon by the Walkley-Black method, total N by the Kjeldahl method, Olsen P, exchangeable K, Ca and Mg, the DTPA-extractable micronutrients Fe, Cu, Mn and Zn (Blakemore et al. 1987). Biochemical properties analysed include 7-day anaerobically mineralisable N (AMN) (Keeney 1982), labile or active C using the potassium permanganate oxidation procedure (Weil et al. 2003) and fluorescein diacetate (FDA) hydrolysis enzyme assay (Schnurer and Rosswall 1982). Biological soil health was assessed by extracting, photographing, counting, and classifying nematodes as to free-living (FL) or plant-parasitic (PP) using a light microscope (Coyne et al. 2007). Plant-parasitic nematodes were distinguished from free-living ones by the presence of a stylet in their mouth. There was no attempt to identify all the nematodes on each slide. Only some of the more important nematode genera from the slides were identified in this study. To provide an assessment of soil health status, values of the various soil health indicators were compared with critical or guideline values except for nematode counts and ratio for which no guideline values exist.

Results and Discussion

Chemical indicators

Table 1 shows the topsoil chemical and biochemical health indicators for both Upolu and Savaii islands and their averages. The topsoils are moderately acidic (pH 5.53) but pH may decline further under continuous cropping and high rainfall and leaching rates. At pH below 5.5, the solubility of aluminium increases and this may reach phytotoxic levels. Thus, correcting pH by liming or adding ash or biochar to reach pH above 5.5 may need to be considered in the near future. Despite Samoa being situated in the hot humid tropics, the levels of organic C and total N (11.3% and 1.02%, respectively) are high since long-term cultivation by machinery has not occurred in the country. Olsen P levels tend to be low (10 mg/kg) and can potentially be a limiting nutrient in the long term. Almost 82% of farms are below the guideline value (Table 2). Therefore, response to P fertilisation needs to be investigated in pot and field trials.

On average, only medium levels of exchangeable K are present in the topsoil (Table 1) and given the high uptake of taro for this nutrient (e.g. 250 to 375 kg K/ha at harvest as reported by Goenaga and Chardon (1995)), this could be another element that may limit production in the long run under continuous cropping with no fertilisation and under conditions of high rainfall that lead to high leaching rates. About 28% of the farms sampled have exchangeable K below the guideline value (Table 2). Nutrient leaching rates have not been explicitly measured in Samoa. However, is expected to be high given that the average annual rainfall in Samoa range from 2000-7000 mm, although most areas receive <4000 mm. The highlands of both Upolu and Savaii islands receive 5000-7000 mm (Lee 2012).

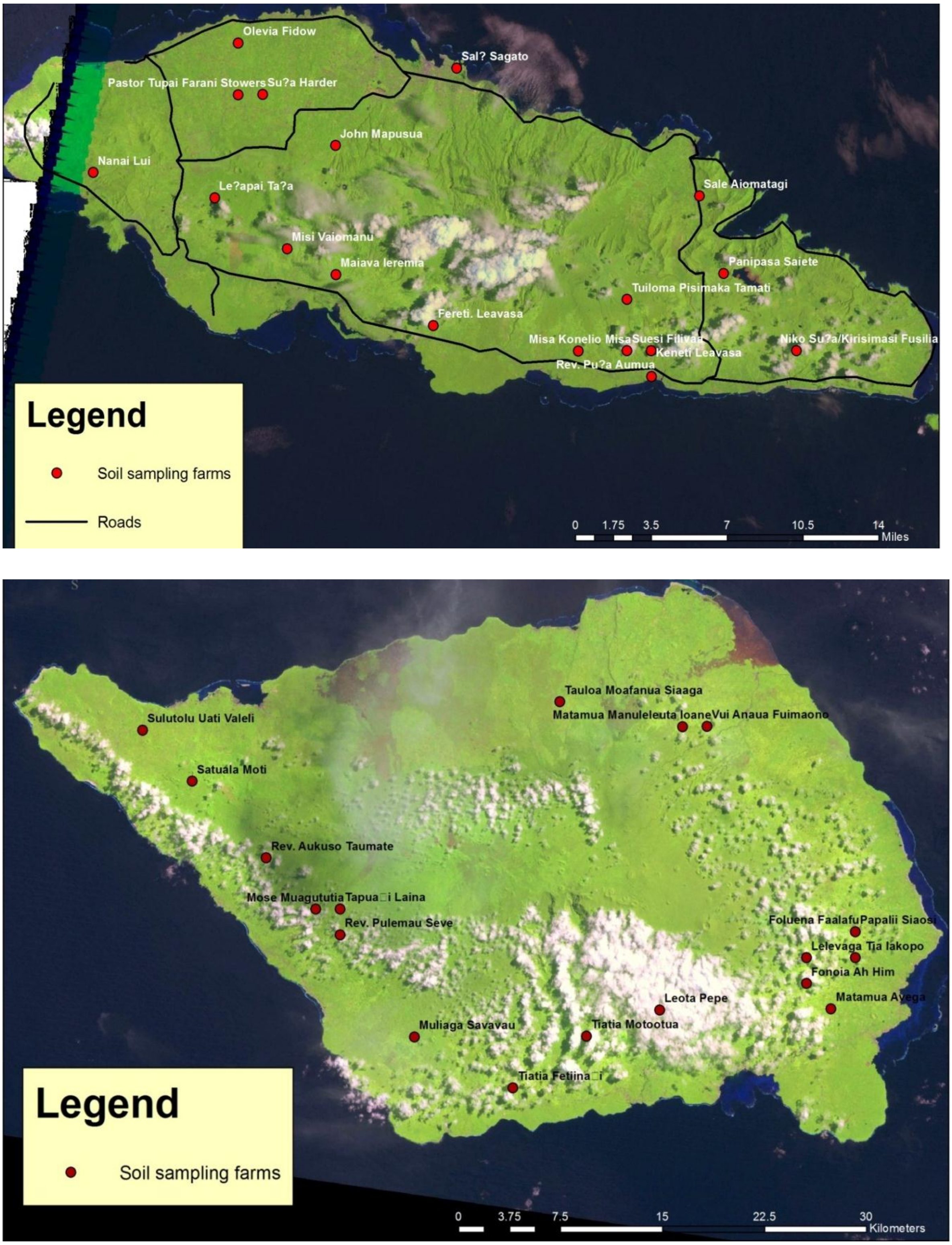

Figure 1. Maps showing the locations of taro farms sampled in Upolu (top) and Savaii (bottom) islands (Note: Labels represent names of farm owners).

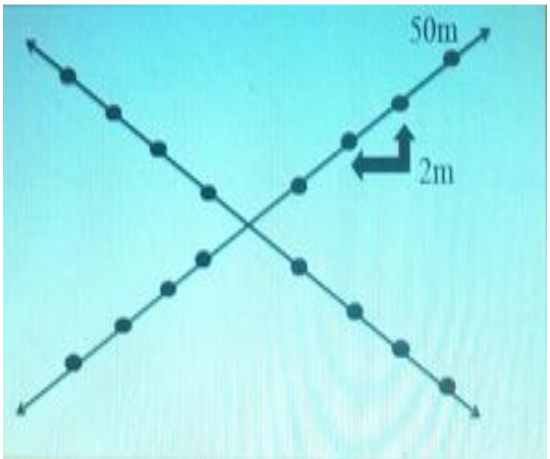

Figure 2. Transect sampling scheme used for each farm.

Table 1. Mean topsoil chemical and biochemical properties of taro-exporting farms in Samoa

Property	Upolu Island	Savaii Island	Average
pH (1:5)	5.44	5.62	5.53
Organic C (%)	9.1	13.6	11.3
Total N (%)	0.82	1.22	1.02
C/N Ratio	11	11	11
Olsen P (mg/kg)	12.2	8.0	10.1
Exchangeable K (cmol/kg)	0.5	0.7	0.6
Exchangeable Ca (cmol/kg)	9.7	15.0	12.4
Exchangeable Mg (cmol/kg)	5.6	8.7	7.2
DTPA extractable Cu (mg/kg)	5.8	3.1	4.5
DTPA extractable Fe (mg/kg)	105.4	88.9	97.2
DTPA extractable Mn (mg/kg)	50.2	20.7	35.4
DTPA extractable Zn (mg/kg)	7.9	6.7	7.3
AMN (mg/kg)	23.8	41.6	32.7
Labile C (mg/kg)	1,229	1,391	1,310
FDA (mg/kg)	149	157	153

Table 2. Soil health status of taro-exporting farms in Samoa

Property	Guideline Value	No. of Farms Below Guideline Value	Percentage of Farms Below Guideline Value
pH (1:5)	4.9	0	0
Organic C (%)	3.0	0	0
Total N (%)	0.2	0	0
Olsen P (mg/kg)	15	30	82.5
Exchangeable K (cmol/kg)	0.4	11	27.5
Exchangeable Ca (cmol/kg)	3.5	0	0
Exchangeable Mg (cmol/kg)	0.8	0	0
DTPA extractable Cu (mg/kg)	0.2	0	0
DTPA extractable Fe (mg/kg)	3	0	0
DTPA extractable Mn (mg/kg)	0.9	0	0
DTPA extractable Zn (mg/kg)	0.8	0	0
AMN (mg/kg)	10	0	0
Labile C (mg/kg)	650	0	0
FDA (mg/kg)	50	0	0

Exchangeable Ca and Mg levels are high and at satisfactory levels. Micronutrient levels (Cu, Fe, Mn and Zn) of soils are also generally very high so deficiencies are unlikely (Tables 1 and 2) although levels of other micronutrients like B and Mo should also be investigated in the future.

Biochemical indicators

AMN, labile C, and FDA and values were all high due to the high levels of organic C and total N. (Table 1) and generally indicate good nutrient cycling. This could be the result of farmers practicing traditional mixed cropping and the absence of widespread mechanical tillage by machinery. AMN has long been used as a soil nitrogen availability index (Keeney 1982). It is an indicator of the capacity of microorganisms to convert (mineralise) N tied up in complex organic residues into the plant available form of ammonium. The amount of ammonium-N produced during the 7-day incubation reflects the soil's capacity for N mineralisation (Gugino et al. 2009).

Active or labile C is a measure of the small fraction of the organic matter that can serve as an easily available food source for soil microorganisms, thus helping maintain a healthy soil food web (Weil et al. 2003; Gugino et al. 2009). Labile C is a good leading indicator of biochemical soil health and tends to respond to changes in soil management earlier than total organic matter content, because when a large population of soil microbes is fed with enough organic matter over an extended period of time, well-decomposed organic matter builds up. A healthy and diverse microbial community is essential to maintain disease resistance, nutrient cycling, aggregation, and many other important functions (Gugino et al. 2009).

The fluorescein diacetate (FDA) hydrolysis assay measures the enzyme activity of microbial populations and provides an estimate of overall soil microbial activity. This assay is considered non-specific because it is sensitive to the activity of several enzyme classes including lipases, esterases, and proteases. The activity of these enzymes results in the hydrolytic cleavage of FDA (colourless) into fluorescein (fluorescent yellow) (Schnurer and Rosswall 1982).

Labile C is significantly higher in Savaii compared to Upolu while FDA and AMN values were comparable in the two islands (Table 1).

Nematodes

Table 3 shows the population of free-living and plant-parasitic nematodes and their ratio. The population of both nematode types are high due to the high organic matter content of the soil that serves as food source for these microorganisms. The free-living nematodes are much higher than plant-parasitic nematodes with their ratio being almost 2.5:1. Free-living nematodes are non-parasitic and contribute to substantial mineralisation of nutrients such as nitrogen. Although no guideline values for nematode population ratio exists (Nematologists Takaniko Rabuete and Tony Pattison, pers. comm.), the higher this ratio, the healthier the soil is biologically because the non-parasitic ones greatly outnumber the parasitic ones. This suggests that taro exportation should not pose a biosecurity problem overseas for as long as the high organic matter content of the soil is maintained and good disinfection procedure is carried out at the packhouse prior to shipment.

Majority of plant-parasitic nematodes identified belong to the genus *Helicotylenchus* (Table 3) which is of no concern to taro production in the South Pacific (Carmichael et al. 2008). The destructive *Meloidogyne* nematodes were only encountered infrequently in the sampled soils so is also not a concern.

Table 3. Mean soil nematode populations, nematode ratios and some nematode genera identified in taro-exporting farms in Samoa.

Nematode population (No. per 100 g soil)	**Upolu Island**	**Savaii Island**	**Average**
Free-living (FL)	5,208	5,766	5,487
Plant-parasitic (PP)	2,317	2,219	2,268
Ratio (FL/PP)	2.24	2.59	2.42
Some FL genera identified	*Rhabditae* (bacteriavore); *Tylenchus* (fungivore); *Tripyla* (predatory)		
Some PP genera identified	*Helicotylenchus; Rotylenchus; Pratylenchus; Xiphenema; Meloidogyne* (root knot nematode)		

Conclusions

Chemically, the soils are generally healthy with respect to organic C, total N, exchangeable Ca and Mg, and micronutrient levels (Cu, Fe, Mn, Zn). Biochemically, anaerobically mineralisable N, labile C, FDA enzyme activity are all high. Biologically, free-living nematodes outnumber plant parasitic nematodes reflecting healthy soils.

Soil health issues identified include acidity, low Olsen P, and only moderate levels of exchangeable K that could decline rapidly due to crop removal and high leaching rates. Nutrient addition trials involving P and K and raising soil pH above 5.5 may be required in future to boost productivity and maintain soil health.

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