SPATIAL AND TEMPORAL EPIDEMIOLOGY OF BASAL STEM ROT IN OIL PALM *(ELAEIS GUINEENSIS)* IN TAWAU REGION, SABAH.

WONG WAN CHEW

THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE

SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITI MALAYSIA SABAH
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DECLARATION

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MATRIC NO. : **PS05-001-011**

TITLE : **SPATIAL AND TEMPORAL EPIDEMIOLOGY OF BASAL STEM ROT IN OIL PALM (*ELAEIS GUINEENSIS*) IN TAWAU REGION, SABAH.**

DEGREE : **MASTER OF SCIENCE (ENVIRONMENTAL SCIENCE)**

VIVA DATE : **27 JUNE 2008**

DECLARED BY

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2. CO-SUPERVISOR

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ABSTRACT

Spatial And Temporal Epidemiology Of Basal Stem Rot In Oil Palm (*Elaeis guineensis*) In Tawau Region, Sabah.

Intense oil palm monoculture has resulted pathogenic diseases, pests and physiological disorders, especially basal stem rot. The BSR disease was believed caused by *Ganoderma boninense* (fungal pathogen). The actual mechanisms of infection was ambiguous, even thought controls and treatments of BSR disease only aimed to prolonging productivity life of oil palm. The objectives of present study were to determine the relationship between the incidences of external visible disease symptoms (recorded by visual census) and subclinical symptoms (detected by GSM test) with soil properties. The study site located in Tawau region in state of Sabah. It was situated in a flat landscape with three different of soil type namely Inanam series, Lumisir and Paliu with 9x9x9 m in planting density. Sampling design was divided into four main parts included mapping disease incidence, visual census assessment on oil palms, Ganoderma infection detection employed with Ganoderma selective medium technique (GSM), and soil sampling. In this present study, GSM test has been demonstrated that 8.5 % of total palms were infected, however they still appeared healthy. In addition, semi-variogram analysis revealed infected palms had a short distance of spatial dependency to their surrounding palms (1 to 2 palms) and small-scale spread of an agent might be occurred. The possible agents might be air-borne spores through human, insect and animals or spread via root-to-root contact. At topsoil layer, subclinical symptoms were positive correlated with soil pH, coarse sand and fine sand whereas negative correlated with organic C, clay, slit, Al, available P, total P, total N, Ca, Mg, K and CEC.

ABSTRAK

Epidemiologi Penyakit Reput Pangkal Batang Pada Kelapa Sawit (Elaeis guineensis) Secara Ruang Dan Masa Di Daerah Tawau, Sabah.

Monokultur kelapa sawit menyebabkan penyakit pathologi, perosak and kekeliruan fisiologi terutamanya penyakit reput pangkal batang. Ia dijangka berpunca daripada Ganoderma boninense (pathogen kulat). Mekanisme jangkitan adalah kurang jelas, walaupun kawalan dan rawatan sekarang bertujuan untuk memanjangkan produktiviti dan jangka hayat kelapa sawit. Objektif kajian adalah mengenalpasti hubungan antara simptom penyakit visual (melalui banci visual) and simptom subklinikal (dikesan melalui ujian GSM) dengan sifat-sifat fizikal dan kimia tanah. Kawasan kajian tersebut terletak di daerah Tawau, negeri Sabah. Ia terletak di landskap yang rata dengan tiga jenis tanah yang berlainan iaitu Inanam, Lumisir dan Paliu serta 9x9x9 m jarak tanam. Reka bentuk persampelan terbahagi kepada empat bahagian iaitu pemetaan penyakit, banci visual pada pokok sawit, pengesanan jangkitan Ganoderma melalui medium Ganoderma terpilih dan persampelan tanah. Sebanyak 8.5% daripada jumlah pokok sawit didapati bahawa dijangkiti walaupun mereka masih kelihatan sihat. Selain itu, daripada analisis semi-variogram dicadangkan bahawa pokok sawit yang terjangkit mempunyai jarak pendek secara ruang dengan pokok berhampiran dengan mereka (1-2 pokok). Agen penyebaran berskala kecil yang mungkin adalah penyebaran spora melalui manusia, serangga dan haiwan atau melalui sentuhan antara akar. Di lapisan 0-40 cm, subklinikal simptom berkolerasi positif dengan pH tanah, tanah kasar dan tanah halus manakala berkolerasi negatif dengan organik karbon, tanah liat, kelodak, Al, P tersedia, jumlah P, jumlah N, Ca, Mg, K dan kapasiti pertukaran kation.

APPENDIX A

Random Soil Sampling of 40 Points for Soil Analysis.

Row No.	No. Tree
6	10
7	7
7	10
14	5
15	4
18	3
18	17
22	5
24	4
24	14
27	3
30	2
30	4
31	8
31	15
32	6
32	9
33	8
34	14
37	4
37	17
38	12
40	13
41	9
41	12
42	5
42	7
42	9
43	15
44	8
46	18
47	16
48	7
49	10
52	7
52	9
52	11
52	16
54	13
57	19

APPENDIX B

Composite Soil Sampling of 17 Points for Soil Analysis.

Row no.	No. Tree
4	3
10	5
13	16
16	6
19	14
22	7
26	12
29	9
33	10
36	10
38	8
43	6
43	12
49	4
49	15
54	2
55	17

APPENDIX C

Soil Analysis Procedures

1. Soil pH

The soil pH measurement is made in 0.01 M calcium chloride solution (Schofield and Taylor, 1955) and a Cyber Scan 500 pH meter was used to measure pH in a 2:5 mixture of soil to distilled water. The produce measured of pH was modified by Soon (2002).

Meter calibration for pH

a) Switch on to pH mode.
b) Rinse the electrode and temperature probe (calibrated) with distilled water or de-ionised water.
c) Immerse the electrode and temperature probe into the standard solution pH 7 and press CAL key to calibrate the meter. Select display to get the desired pH for calibration. Wait for the measured pH value to stabilize. The 'Ready' will be display when the ready has stabilized.
d) Press the CON key to confirm the calibration.
e) Calibration for pH 4, proceed c and d above using standard pH 4.

Soil pH procedures

a) Weigh 10 g dry soil into a container and add 25 ml distilled water. Stir and leave overnight.
b) Check meter calibration as above.
c) Stir the soil suspension, insert electrode and temperature probe into sample. Wait until the 'Ready' indicator is displayed and press the 'Hold' key and record pH.
d) Wash the electrode and temperature probe with water between measurements.
e) Check the pH 4 reading using the standard buffer solution after every 10 measurements. Re-calibrate the meter if necessary.

Remark: Electrode/ Temperature sensor holder shall be used for the soil pH measurement to give a more stable reading.

2. Particle Size

Soil texture describes the proportion of three sizes of soil particles- sand (large), silt (medium), and clay (small). The size of soil particles affects such soil traits as water holding capacity and aeration (Plaster, 2003). The determination of particle size of soil was used pipette method (Soil Conservation Service, 1984) and modified by Soon (2002), and defined as clay (less than 0.002 mm), silt (0.02-0.002 mm), fine sand (0.2-0.02 mm) and coarse sand (2.0-0.2 mm). The twelve textural classes and the soil triangle is redrawn are shown in the soil triangle in Figure 3.4 and 3.5 (modified from Plaster, 2003).

Reagents

- Hydrogen peroxide (30%)
- Sodium hexametaphosphate (dissolve 25 g pf sodium hexametaphosphate in 1 litre distilled water and make up to volume).

Procedure

a) Weight out 20 g soil and place in 500 ml beaker. Add about 50 ml water and 20 ml hydrogen peroxide. Allow reacting in the room temperature and stir with a glass rod if necessary.
b) Heat gently on a hot plate until no further reaction. Continue heating until no oxidisable organic matter remains.
c) Boil vigorously to destroy excess hydrogen peroxide, taking care to wash all fragments of soil from the side of the beaker with wash bottle.
d) Allow the sample to cool and add 10 ml sodium hexametaphosphate. Transfer and stir the sample for 10 minutes.
e) Transfer and wash into 500 ml measuring cylinder, making up to mark and note the temperature. Transfer the cylinder to the constant temperature bath and allow standing immersed in the water up to the 500 ml graduated mark until they have reached the temperature of the bath. After they have attained this temperature, the content is then shaken thoroughly and starting the watch.
   Refer to Table 1 of sedimentation time for particle of 2 µm and 20 µm diameters settling through water for a depth of 10 cm.
f) Look up for the time of sedimentation for sand corresponding to the observed temperature. Withdraw 10 ml of the suspension from a depth of 10 ml below the surface. This can be done by lowering the pipette so that the nozzle just touches the surface of the suspension. Note the scale reading on the stand and lower the pipette further through a depth of 10 cm (indicated by the scale on the stand). This adjusting is usually begun 30 seconds before the required time is up. Suck the suspension and drain the contents to the weighed porcelain and evaporate the suspension to dryness in the oven at 105°C, cool and weigh. The dry solids consist of silt and clay.
g) Decant off the supernatant liquid from the cylinder, transfer and wash the sediment into the beaker. Add water, stir well and allow standing for the period required for the sedimentation of the sand. After this duration, slowly decant off most of the liquid. Transfer the sand into the weighed dish and dry at 105°C and weigh. Sieve this dry sand through a 210 micro sieve and then reweigh the coarse sand that does not pass through.

Calculations

Weight of silt + clay (first pipette) = m_1 g
Weight of clay (second pipette) = m_2 g
Weight of sand (coarse and fine) = m_3 g
Weight of coarse sand = m_4 g
Weight of fine sand = $m_3 - m_4$ g

% silt = $(m_1 - m_2$ g X 500 ml X 100%)/ 10 ml X 20 g
% clay = $(m_2$ g X 500 ml X 100%)/10 ml X 20 g
% fine sand = $(m_3 - m_4$ X 100 %)/ 20 g
% coarse sand= $(m_4$ X 100%)/ 20 g

Table 1: Sedimentation time for particles size 2 µm and 20 µm diameter settling through water for a depth of 10 cm.

Temperature (°C)	Settling time with indicated particle diameter			
	2 µm		20 µm	
	hours	minutes	hours	minutes
20	8	0	4	48
21	7	49	4	41
22	7	38	4	35
23	7	27	4	28
24	7	17	4	22
25	7	7	4	16
26	6	51	4	10
27	6	48	4	4
28	6	39	4	0
29	6	31	3	55
30	6	22	3	49
31	6	14	3	44

Source: modified from Soon (2000)

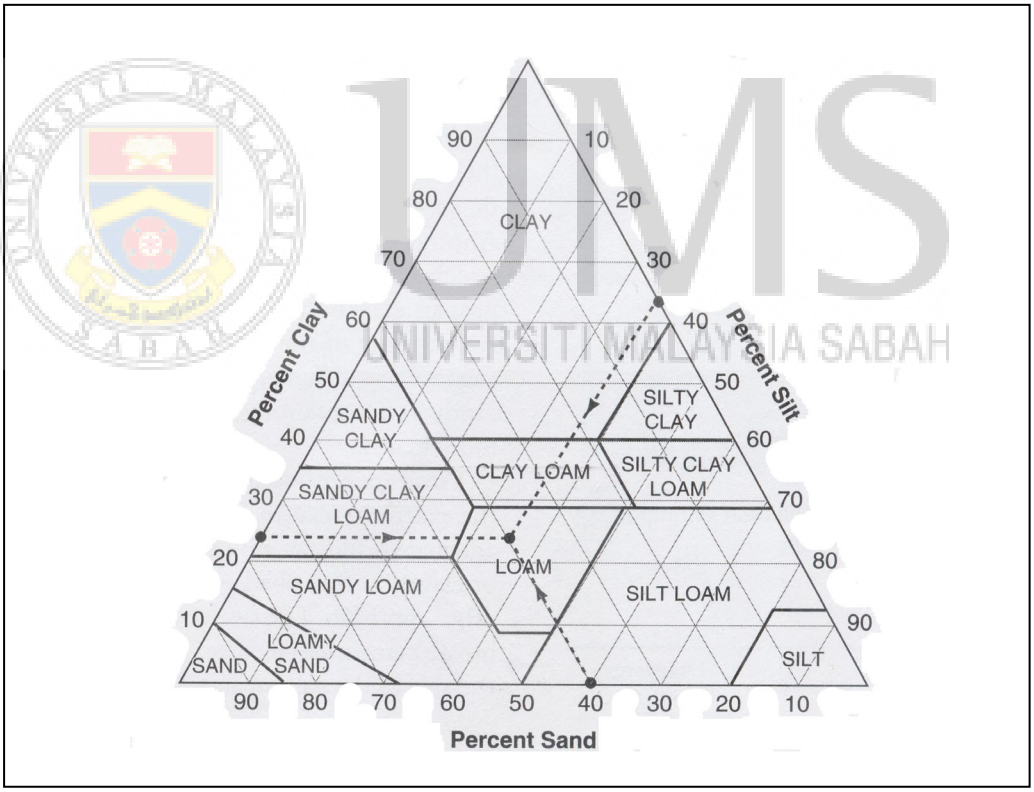

Figure 1: The soil triangle each side of the triangle is a soil separate and the numbers are the percentage of soil particles of that type. (Plaster, 2003)

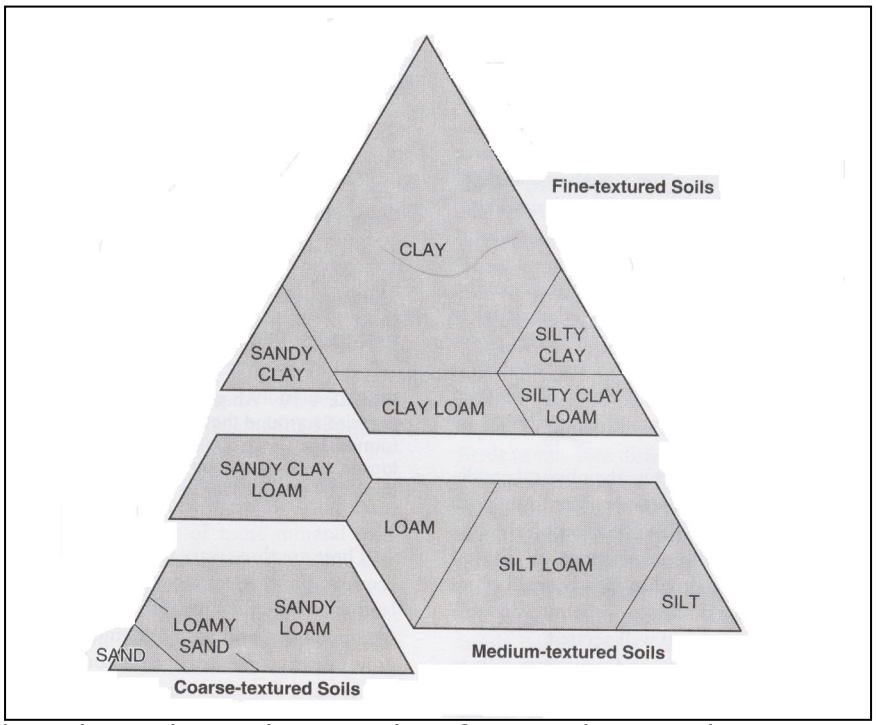

Figure 2: The soil triangle is redrawn to show fine-, medium-, and coarse-textured soils (modified from Plaster, 2003). Source: Plaster (2003)

3. Organic Carbon

Organic carbon determinations are often used as the basic for organic matter estimates through multiplying the organic carbon value by a factor. The amount of organic carbon is measured by titrimetric dichromate redox method which is wet-oxidation (Walkley and Black, 1934) and modified by Soon (2002).

Reagents

- 1 M potassium dichromate (dissolves exactly 49.04 g of dry potassium dichromate in water and make up to 1 litre).
- Concentrated sulphuric acid
- Orthophosphoric acid
- Diphenylamine Indicator
- 0.5 N ferrous solution

Procedure

a) Finely grind a sample of soil which has already passed 2 mm sieve. Take exactly 1 g (or an exact lesser amount if highly organic) into a 250 ml flask.
b) With a pipette add exactly 10 ml (V_1) of standard dichromate.
c) Shake so that the soil is fully wetted, and then rapidly add 20 ml concentration of sulphuric acid (the rate of acid addition must always be the same, otherwise the temperature attained will be vary).
d) Mix contents by gently rotation for 30 seconds, and then leave for one hour.
e) Add about 100 ml of distilled water, 5 ml orthophosphoric acid and 15 drops of indicator.
f) Titrate the sample (V_2) with the ferrous solution until the colour changes sharply from a turbid blue to a brilliant green.

Calculation

1ml 1 M $K_2Cr_2O_7$ equals to 3 mg Carbon

% Carbon = $(V_1 – V_2F)$ X 100% X 0.003/ weight of soil (where F= 10/ V_3)

% Organic matter = 1.724 X % C

4. Total Nitrogen

Total nitrogen is determined by Macro-Kjeldahl method (McKeague, 1978) and which is the most widely used and involves conversion of organic and inorganic N to NH_4^+ (McGill and Figueiredo, 1993).

Reagents

- Concentrated sulphuric acid
- Sodium sulphate anhydrous
- Hydrogen peroxide
- Kjeldahl catalyst tablet
- 3% boric acid (dissolve 30 g boric acid and make up to 1 litre distilled water)
- 0.01 M HCI (dissolves 10 ml of the stock 1 M standard HCI to 1 litre)
- 30% sodium hydroxide (dissolves 300 g sodium hydroxide and make up to 1 litre distilled water)
- Screened methyl red indicator (dissolves 0.1 g methyl red and 0.05 g methylene blue in 100 ml ethyl alcohol)

Procedure

a) Weigh out exactly 2.5 g soil into 250 ml digestion tube.

b) Add one catalyst tablet and approximately 4 g sodium sulphate.

c) Carefully add approximately 7 ml hydrogen peroxide and then 15 ml concentration of acid sulphuric.

d) Place the tubes in a cold digestion block and heat up slowly until a temperature of approximately 400°C is achieved.

e) After 2 hours remove the tubes from the block and leave to cool.

f) Transfer the tubes to the distillation unit. Add in 20 ml of distilled water and 90 ml of the 30% NaOH solution. Distill for 2-3 minutes, collecting the distillate in 10 ml of the 30% boric acid solution containing a few drops of the indicator solution.

g) Titrate the distillate with standard 0.01 M HCI until just red.

h) Carry out also blank through the above procedure.

Calculation

If the titre, after subtracting the average blank value is T ml, then

$$\% \text{ N in soil} = \frac{\text{Amount of 0.01 M HCI used X 0.00014 X 100\%}}{\text{Weight of soil}}$$

5. Potassium, Calcium and Magnesium

Potassium is measured in the leachate by Jenway PFP 7 Flame Photometer (modified by Soon, 2002) with neutral normal ammonium acetate extraction (Schollenberger and Simon, 1954). This method used a neutral salt solution to replace the cations present on the soil exchange complex; therefore the cation concentrations are referred to as "exchangeable" for noncalcareous soils (Jones, 2001). Calcium and magnesium are determined by Perkin Elmer 3300 Atomic Absorption Spectrophotometer with neutral normal ammonium acetate extraction (Schollenberger and Simon, 1954) modified by Soon (2002).

Reagents

- 1 M ammonium acetate pH 7 (dissolves 385 g ammonium acetate in waer and make up to 5 litres. Adjust solution to pH 7 by addition of a few drops of acetic acid)

Procedure

a) Prepare a leaching column.
b) 10 g soil is leached with 100 ml 1 M ammonium acetate for about 5 or 6 hours.
c) Collect the leachate in a 100 ml volumetric flask.
d) Make up the solution with 1 M ammonium acetate for K, Ca and Mg determination.
e) Pipette 1 ml of the leachate and dilute to 10 ml with 1 M ammonium acetate solution (DF=10) and determine K using Flame Photometer.
f) Pipette 5 ml of the leachate into a 50 ml volumetric flask, add 8 ml of the 1.2 % strontium chloride solution and make up to mark with a 1 M ammonium acetate solution and determine Ca in solution using Atomic Absorption Spectrophotometer.
g) Pipette 1 ml of the leachate into 50 ml volumetric flask. Add 8 ml of the 1.2 % strontium chloride solution and make up to mark with a 1 M ammonium acetate solution and determine Mg in solution using Atomic Absorption Spectrophotometer.

Calculation

$$\text{K in soil (m.e/100 g)} = \frac{10 \times \text{ppm (sample)} \times \text{DF}}{39.1 \times \text{weight of sample}}$$

$$\text{Ca in soil (m.e/100 g)} = \frac{20 \times \text{ppm (sample)} \times \text{DF}}{40.08 \times \text{weight of sample}}$$

$$\text{Mg in soil (m.e/100 g)} = \frac{20 \times \text{ppm (sample)} \times \text{DF}}{24.31 \times \text{weight of sample}}$$

6. Cation Exchangeable Capacity

The cation exchangeable capacity (CEC) of a soil is a measure of the quantity of readily exchangeable cations neutralising negative charge in the soil. It usually expressed in milliequivalents (me) per 100 g of soil (Jones, 2001). The method of CEC determination by ammonium acetate method at pH 7 is developed by Lavkulich (1981) is suitable for standard analysis of a wide range of soil types. CEC was determined from the concentration of ammonium ions in the potassium sulphate leaching solution by distillation method (modified by Soon, 2002).

Reagents

- Wash-alcohol 50% ethanol ammonium-free
- Absolute ethanol: 95 % ammonium-free
- 0.1 M potassium sulphate (dissolves 8.713 g K_2SO_4 in 1 litre of distilled water)
- 3 % boric acid solution
- 0.01 M HCI
- Magnesium oxide powder
- Screened methyl red indicator

Procedure

a) Wash the remaining soil in the soil column (after determination of exchangeable bases) with 100 ml 50 % wash-alcohol and about 50 ml of absolute ethanol.

b) Discard the ethanol. Leach the soil with 100 ml of 0.1 M K_2SO_4.
c) Collect the leachate in 100 ml volumetric flask and make up to volume.
d) Pipette 10 ml of this solution and distill the sample with a scoop of MgO for the determination of soil nitrogen.
e) The volume of 0.01 M HCl used to change the colour gives directly the CEC in me/ 100 g of soil.

Calculation

$$\text{CEC (me/ 100 g soil)} = \frac{10X}{W}$$

Where X is the number of ml of acid used
W is the weight of soil in g

7. Total Phosphorus

The ascorbic acid method of Murphy and Riley (1962) was modified by Soon (2002) is suitlable for the determination of orthophosphate in all digests. This method used the blue color developed by the molybdophosphate complex reduced by ascorbic acid in the presence of antimony (Sb) to estimate the concentration of P in solution (O'Halloran, 1993).

Reagents

- Digestion mixture (add to known volume of 60 % perchloric acid an equal volume of concentrated sulphuric acid. Cool the mixture to room temperature)
- Solution for colour formation (Murphy and Riley, 1962)
  - Reagent A- Dissolve 12 g ammonium molybdate in water and add 148 ml concentration of sulphuric acid. Dissolve 0.2908 g potassium antimony in water and add to the above solution and make up to 2 litre.
  - Reagents B- Dissolve 1.32 g ascorbic acid to every 250 ml reagent A used.

Procedure

a) Weigh 2 g soil into a digestion tube.
b) Add 6 ml digestion mixture.
c) Place the tubes in a digestion block and heat up the samples to 200°C until the reaction is completed (white-cloudy solution is formed).
d) Cool, transfer and filter into a 100 ml (V) volumetric flask and make up to volume with water and shake for 30 minutes.
e) Pipette 2 ml of the digest into a 50 ml volumetric flask.
f) Add 8 ml reagent B and make up to volume with distilled water (DF= 25).
g) Shake the solution and leave for 15 minutes to allow the blue colour to develop before measuring its intensity at 882 nm.

Calibration

a) Prepare 1000 ppm phosphorous standard solution by dissolving 4.3935 g KH_2PO_4 in water and making up to 1 litre.
b) Pipette 0, 1, 2, 3, 4 and 5 ml of 10 ppm P standard solution into 50 ml volumetric flask to give the linear calibration line ranging from 0 to 1 ppm P. Add 8 ml of reagent B and make up to volume. Shake and measure absorbance at 882 nm after standing 15 minutes.

Calculation

ppm phosphorus in soil = $\frac{\text{1 ppm X absorbance (sample) X V X DF}}{\text{Absorbance (1 ppm) X weight of sample}}$

Where V = volume of diluted sample

DF= dilution factor

8. Plant-available Phosphorus

Methods for determination of available P in an agronomic context is measured a pool of soil P that is related to that portion of soil P which is plant available (Tiessen and Moir, 1993). The amount of extracted phosphorus was determined with Bray P2 method (Bray and Kurtz, 1945) modified by Soon (2002). Bray P2 method adapted in a range of acid soil in which rock phosphate has been the primary P fertilizer source and/or the major portion of P exists in the soil as various forms of calcium phosphate (Jones, 2001).

Reagents

- 2 M ammonium fluoride (dissolves 37 g NH_4F and make up to 500 ml)
- 0.5 M HCI (dilute 20.2 ml concentration of HCI to 500 ml with water)
- Soil extracting solution (Bray and Kurtz No.2) (transfer 30 ml 2 M NH_4F and 400 ml 0.5 M HCI to a 2 litre flask and make up to volume)
- Solution for colour formation (Murphy and Riley)
  - Reagent A- Dissolve 12 g ammonium molybdate in water and add 148 ml concentration of sulphuric acid. Dissolve 0.2908 g potassium antimony in water and add to the above solution and make up to 2 litre.
  - Reagents B- Dissolve 1.32 g ascorbic acid to every 250 ml reagent A used.

Dissolve 12 g ammonium molybdate in water and add 148 ml concentration of sulphuric acid. Dissolve 0.2908

Procedure

a) Weigh 2 g soil into a 125 ml conical flask.
b) Add 20 ml (V) extracting solution and shake for exactly 30 minutes
c) Keep the flask in a tilted position for another minute to allow soil to settle and then filter using paper No. 1.
d) Pipette 2 ml of the filtrate into a 50 ml volumetric flask.
e) Add 8 ml reagent B and make up to volume with distilled water (DF= 25).
f) Shake the solution and leave for 15 minutes before measuring its absorbance at 882 nm.

Calibration

a. Prepare 1000 ppm phosphorous standard solution by dissolving 4.3935 g A.R. KH_2PO_4 in water and making up to 1 litre.
b. Pipette 0, 1, 2, 3, 4 and 5 ml of 10 ppm P standard solution into 50 ml volumetric flask to give the linear calibration line ranging from 0 to 1 ppm P. Add 8 ml of reagent B and make up to volume. Shake and measure absorbance at 882 nm after standing 15 minutes.

Calculation

Ppm extractable phosphorus = $\frac{\text{1 ppm X absorbance (sample) X V X DF}}{\text{Absorbance (1 ppm) X weight of sample}}$

Where V = volume of extractant used
DF= dilution factor

9. Exchangeable Aluminum

Potassium chloride method developed by Barnhisel and Bertsch (1982) is used to prevent any change in pH which might precipitate Al in case of Al whereas total (Al + H) is measured in the extractant by direct titration with an alkali (sodium hydroxide). The Al is then complexed by adding sodium floride and released alkali is then back titrated with an acid (modified by Soon, 2002).

Reagents

- 1 M potassium chloride (dissolve 74.55 g of KCI in water and make up to 1 litre)
- 0.01 M standard HCI (dilute 10 ml of the stock 1 M standard HCI to 1 litre)
- 0.01 M standard NaOH (dilute approximately 0.4 g NaOH in water and make up to 1 litre)
- 2.5 % sodium fluoride solution (dissolve approximately 25 g NaF in waer and make up to 1 litre)
- 0.1 % phenolphthalein solution (dissolve 0.1 g of the indicator in 100 ml of ethyl alcohol)

Standardization of NaOH

Titrate NaOH solution against 25 ml of the 0.01 M HCI, using phenolphthalein as indicator taking the reading when a pink colour is just obtained. Repeat three times and calculate the mean titre = x mol

Procedure

a) Weigh out 10 g soil into 125 ml conical flask (included two blanks with every batch of soils). Add exactly 50 ml 1 M KCI.
b) Shake for 30 minutes at 200 rpm and then filter using No. 1 paper.
c) Pipette 25 ml of filtrate into 250 ml conical flask and titrate with the standardized NaOH using phenolphthalein as indicator until a pink colour is just obtained. Record the titre = T_1 ml (after blank correction)
d) Add approximately 5 ml NaF solution.
e) Titrate with the standard 0.01 M HCI, shaking all the time until colourless. When the colour has disappeared, add more phenolphthalein and then more acid if colour returns. Continue until no colour returns after 1 minute. Record the titre = T_2 ml (after blank correction).

Calculation

The first titration measure (Al + H) (me/ 100 g) = $5\ T_1/\ x$
The second titration measure Al alone (me/ 100 g) = $T_2/5$

Spearman's Rho Correlation Coefficient for Soil Properties in Topsoil Layer (0-40 cm).

Soil	pH	TN	OC	K	Ca	Mg	CEC	TP	AP	Al	Clay	Silt	FS	CS
pH	1	-0.55**	-0.507**	-0.556**	-0.433**	n.s.	-0.493**	n.s.	n.s.	-0.715**	-0.64**	-0.473**	n.s.	0.702**
TN			0.771**	0.547**	0.645**	0.365**	0.436**	0.399**	0.356**	0.613**	0.551**	0.564**	-0.304*	-0.629**
OC			1	0.519**	0.794**	0.493**	0.462**	0.409**	0.443**	0.511**	0.571**	0.44**	-0.332*	-0.57**
K				1	0.469**	0.464**	0.634**	n.s.	0.373**	0.632**	0.767**	0.545**	-0.295*	-0.75**
Ca					1	0.661**	0.423**	0.357**	0.338*	0.431**	0.498**	0.412**	n.s.	-0.514**
Mg						1	n.s.	0.365**	0.400**	0.317*	0.383**	0.324*	n.s.	-0.399**
CEC							1	n.s.	0.285*	0.475**	0.59**	n.s.	-0.494**	-0.463**
TP								1	0.733**	n.s.	n.s.	n.s.	n.s.	n.s.
AP									1	n.s.	0.265*	n.s.	-0.268*	n.s.
Al										1	0.665**	0.548**	n.s.	-0.726**
Clay											1	0.346**	n.s.	-0.882**
Silt												1	n.s.	-0.637**
FS													1	n.s.
C														1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

n.s. Not significant at the 0.01 or 0.05 level.

Spearman's rho Correlation Coefficient for Soil Properties in Subsoil Layer (40-80 cm).

Soil	pH	TN	OC	K	Ca	Mg	CEC	TP	AP	Al	Clay	Silt	FS	CS
pH	1	n.s.	-0.379**	-0.723**	-0.361**	n.s.	-0.572**	-0.265*	n.s.	-0.833**	-0.727**	-0.265*	0.589**	0.692**
TN		1	0.488**	0.391**	0.495**	0.306*	n.s.	n.s.	n.s.	n.s.	0.342**	n.s.	n.s.	-0.36**
OC			1	0.531**	0.615**	0.393**	0.269*	n.s.	0.280*	0.308*	0.461**	n.s.	-0.454**	-0.378**
K				1	0.541**	0.448**	0.654**	n.s.	n.s.	0.752**	0.793**	n.s.	-0.609**	-0.74**
Ca					1	0.569**	0.332*	n.s.	n.s.	n.s.	0.473**	n.s.	-0.346**	-0.468**
Mg						1	0.297*	n.s.	n.s.	n.s.	0.291*	n.s.	-0.271*	-0.278*
CEC							1	n.s.	n.s.	0.474**	0.564**	n.s.	-0.694**	-0.481**
TP								1	0.661**	n.s.	n.s.	n.s.	n.s.	n.s.
AP									1	n.s.	n.s.	n.s.	n.s.	n.s.
Al										1	0.73**	n.s.	-0.522**	-0.694**
Clay											1	n.s.	-0.515**	-0.92**
Silt												1	n.s.	-0.327*
FS													1	0.381**
C														1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

n.s. Not significant at the 0.01 or 0.05 level.

APPENDIX F

Raw Data of 14 Soil Parameters in Topsoil Layer and Subsoil Layer.

No. data	Depth (cm)	pH	AP (ppm)	Al (me%)	Clay (%)	Slit (%)	FS (%)	CS (%)
1	0-40	6.3	2.72	0.12	1.92	4.87	10.5	82.71
2	0-40	4.9	1.48	0.24	2.12	13.74	15.6	68.6
3	0-40	6.8	6.61	0.06	10.93	3.97	14.5	70.6
4	0-40	6.8	3.29	0.1	11.02	3.72	11.78	73.48
5	0-40	5.2	3.12	0.08	11.47	12.79	15.32	60.42
6	0-40	5.7	2.26	0.16	1.92	6.7	8.7	82.68
7	0-40	7.2	4.24	0.12	8.51	7.4	13.57	70.52
8	0-40	6.4	53.67	0.16	3.11	8.54	9.16	79.19
9	0-40	6.6	2.77	0.16	4.17	11.73	13.78	70.32
10	0-40	6.1	4.62	0.18	11.09	7.16	15.84	65.91
11	0-40	6	11.83	0.14	11.04	7.93	13.48	67.54
12	0-40	4	3.71	0.48	22.36	14.06	7.96	55.62
13	0-40	6.6	1.46	0.12	2.42	1.96	14.9	80.72
14	0-40	5	2	0.12	5.85	15.41	14.3	64.44
15	0-40	5.1	2.1	0.1	10.39	6.96	12.17	70.48
16	0-40	4.2	1.46	0.48	23.4	15.39	15.96	45.25
17	0-40	5.7	2.36	0.12	12.15	6.04	15.01	66.8
18	0-40	6.4	49.77	0.18	11.22	1.5	13.5	73.78
19	0-40	4.2	2.44	0.12	12.11	4.09	16.38	67.42
20	0-40	4.5	3.46	0.1	6.61	6.82	13.92	72.64
21	0-40	5.8	1.79	0.1	10.99	6.88	17.06	65.07
22	0-40	4.9	2.91	0.12	4.5	10.59	11.98	72.93
23	0-40	3.7	13.56	0.72	22.82	14.37	10.1	52.7
24	0-40	3.8	2.23	0.68	28.99	11.49	18.63	40.89
25	0-40	5.5	3.92	0.12	4.11	5.89	13.04	76.96
26	0-40	3.6	1.87	0.76	18.66	13.18	13.69	54.47
27	0-40	4.8	17.05	0.2	12.03	12.36	6.64	68.97
28	0-40	3.5	23.6	0.72	14.15	19.58	15.7	50.57
29	0-40	3.8	6	0.74	35.64	10.73	15.54	38.09
30	0-40	4.6	15.28	0.2	16.58	13.35	8.1	61.97
31	0-40	5	18.59	0.1	13.68	15.83	13.95	56.55
32	0-40	5.2	14.06	0.12	14.37	2.6	16.46	66.57
33	0-40	5.2	37.84	0.24	19.41	14.17	11.78	54.64
34	0-40	3.8	18.46	0.72	19.16	16.11	13.26	51.47
35	0-40	4.5	48.53	0.22	10.22	9.87	14.76	65.15
36	0-40	4.3	4.65	0.24	23.27	12.99	9.1	54.64
37	0-40	6	55.7	0.16	12.18	10.89	11.39	65.54
38	0-40	3.5	19.16	0.9	43.61	11.92	7.01	37.46
39	0-40	5.9	5.36	0.16	10.85	9.89	10.16	69.1
40	0-40	3.8	1.51	0.32	24.27	6.05	8.6	61.08
41	0-40	4	9.26	0.24	34.6	12.21	7.16	46.03
42	0-40	4.7	2.45	0.44	14.7	13.91	9.55	61.84
43	0-40	4.4	31.76	0.54	20.06	13.63	15.12	51.19
44	0-40	3.7	26.94	0.2	23.28	9.08	6.24	61.4

No. data	Depth (cm)	pH	AP (ppm)	Al (me%)	Clay (%)	Slit (%)	FS (%)	CS (%)
45	0-40	4.2	4.7	0.3	6.9	15.24	8.41	69.42
46	0-40	5	19.93	0.31	13.38	14.7	16.79	55.13
47	0-40	3.6	4.08	1.86	45.72	10.05	8.7	35.53
48	0-40	4.2	5.09	0.24	14.47	15.15	6.11	64.27
49	0-40	4.4	10.05	0.32	19.16	9.43	6.87	64.54
50	0-40	5.5	78.01	0.14	13.25	17.11	14.11	55.54
51	0-40	3.6	96.74	0.62	19.47	15.33	10.55	54.65
52	0-40	3.7	19.88	0.48	8.34	18.19	11.71	61.76
53	0-40	4.5	2.34	0.2	12.74	9.6	13.56	64.1
54	0-40	4.5	1.42	0.36	16.79	17.2	14.13	51.88
55	0-40	5.1	36.06	0.24	16.97	6.64	13.46	62.93
56	0-40	3.5	93.35	0.18	37.73	13.1	8.69	40.48
57	0-40	6.3	44.98	0.36	30	16.14	8.78	45.08
58	40-80	4	1.3	0.44	45.51	9.47	6.26	38.76
59	40-80	4.1	5.23	0.24	53.32	9.95	10.22	26.51
60	40-80	3.8	1.32	1.1	52.5	7.67	7.74	32.09
61	40-80	3.6	1.19	2.6	67.02	5.6	5.63	21.75
62	40-80	3.8	0.96	1.29	41.48	9.46	13.28	35.77
63	40-80	3.4	4.89	2.04	75.96	5.74	3.35	14.95
64	40-80	3.8	1.82	1.34	39.07	8.82	7.2	44.91
65	40-80	3.8	1.41	0.36	28.26	14.57	7.15	50.02
66	40-80	3.5	4.1	0.94	31.14	11.44	7.58	49.84
67	40-80	3.7	1.06	1.1	18.83	27.01	5.6	48.56
68	40-80	3.5	3.06	0.74	30.65	10.69	11.53	47.13
69	40-80	3.6	21.5	0.26	50.57	12.03	5.94	31.46
70	40-80	4	1.83	0.96	35.54	10.98	7.01	46.47
71	40-80	3.5	11.22	1.04	21.16	24.24	6.89	47.71
72	40-80	3.5	4.33	0.76	28	15.83	9.2	46.97
73	40-80	3.5	0.8	2.06	45.66	18.63	8.65	27.06
74	40-80	3.2	9.1	1.44	30.54	14.7	9.69	45.07
75	40-80	4	16.57	0.32	29.6	17.7	12.97	39.73
76	40-80	4.3	1.14	0.18	10.11	18.6	10.03	61.25
77	40-80	5	0.77	0.12	3.24	12.59	10.73	73.44
78	40-80	3.8	3.27	1.08	23.41	14.48	21.38	40.73
79	40-80	7.6	1.22	0.1	4.41	8.62	13.68	73.29
80	40-80	4	3.84	2.72	52.86	14.07	10.86	22.21
81	40-80	5.1	1.48	0.06	3.77	8.16	10.89	77.18
82	40-80	6.8	1.13	0.12	4.87	13.48	16.75	64.9
83	40-80	7.8	0.96	0.12	2.65	6.54	13.68	77.13
84	40-80	6.5	1.06	0.12	5.17	14.2	17	63.64
85	40-80	3.5	3.01	1.3	21.75	17.36	13.26	47.63
86	40-80	5.6	1.47	0.08	6.79	10.93	15.6	66.68
87	40-80	4.8	0.9	0.36	14.05	16.8	5.52	63.63
88	40-80	3.8	2.79	2.14	5.46	6.87	12.48	75.19
89	40-80	6.6	1.76	0.16	25.4	20.21	13.72	40.67

No. data	Depth (cm)	pH	AP (ppm)	Al (me%)	Clay (%)	Slit (%)	FS (%)	CS (%)
90	40-80	4.3	0.86	0.16	9.94	7.91	18.41	63.74
91	40-80	7.3	2.45	0.7	12.15	6.34	13.69	67.82
92	40-80	6.9	0.99	0.1	11.78	3.59	15.48	69.15
93	40-80	5.4	1.45	0.1	12.8	10.64	15.56	61
94	40-80	4.5	10.23	0.44	12.92	6.13	10.91	70.04
95	40-80	7	1.37	0.06	11.1	6.6	11.3	71
96	40-80	7.2	1.25	0.12	11.68	14.04	17.7	56.58
97	40-80	5.8	3.14	0.14	11.34	7.5	13.22	67.94
98	40-80	6.1	1.17	0.16	13.88	6.12	16.89	63.11
99	40-80	5.7	1.31	0.12	12.7	0.69	18.9	67.71
100	40-80	6.4	10.93	0.08	14.85	3.28	17.03	64.83
101	40-80	3.8	3.98	1.9	42.6	10.39	8.87	38.14
102	40-80	4.9	4.05	0.22	12.48	15.29	10.81	61.42
103	40-80	7.4	34.33	0.12	10.6	17.85	15.8	55.69
104	40-80	4.7	4.09	0.12	10.51	7.93	12.6	68.96
105	40-80	5.1	2.19	0.14	12.28	14.86	13.9	58.96
106	40-80	4.8	1.25	0.26	18.91	12.45	12.74	55.9
107	40-80	4.6	1.37	0.42	13.88	19.37	12.45	54.3
108	40-80	5.3	6.97	0.14	12.05	11.8	13.97	62.18
109	40-80	4.6	0.84	0.14	12.71	20.56	13.98	52.74
110	40-80	3.5	0.97	2.14	36.8	14.23	12.75	36.22
111	40-80	4	0.96	0.5	19.14	18.14	13.05	49.67
112	40-80	4.6	3.94	0.38	11.62	10.26	8.82	69.3
113	40-80	3.6	17.65	1.16	24.14	14.77	15.16	45.93
114	40-80	4	3.19	0.54	20.53	17.24	15.55	46.68