Spatial heterogeneity of soil under rice and oil palm production in India

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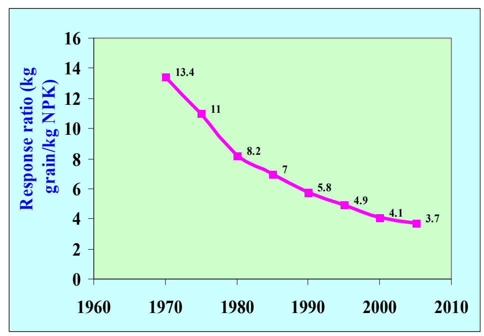
Outline of presentation

- Spatial variability of soil parameters under rice cultivation
- Spatial variability of soil parameters under oil palm cultivation
- Training in the area of sensor based application

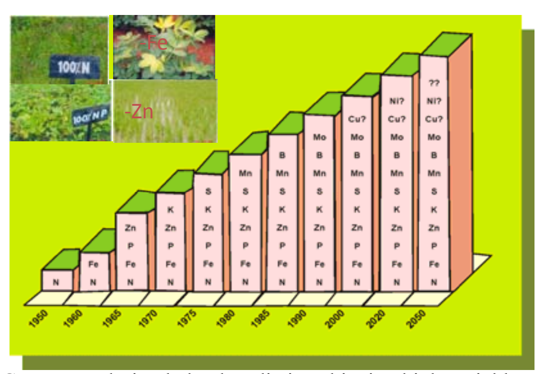
Spatial variability of soil parameters under rice cultivation

Declining NPK response ratio – a cause of concern in India



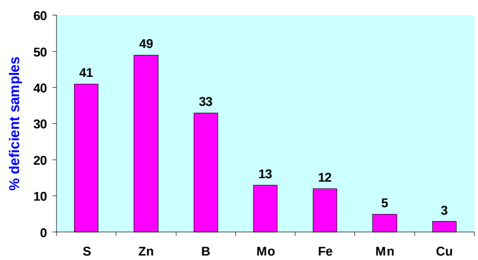
Falling productivity growth rate (% per annum) of major crops in India

Crop	Productivity		
	1980-81 to 1989-90	1990-91 to 1999-2000	2000-01 to 2002-03
Rice	3.19	1.27	-0.72
Wheat	3.10	2.11	0.73
Pulses	1.61	0.96	-1.84
All Food grains	2.74	1.52	-0.69
Oilseeds	2.43	1.25	-3.83
Non-food grain	2.31	1.04	-1.02



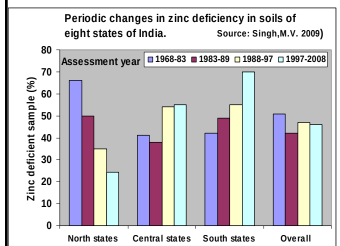
Green Revolution helped India in achieving higher yields but led to multi nutrient deficiencies in crops

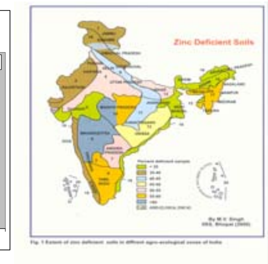
Deficiency of Micronutrients in soils of India



✓ S, Zn, B, Mo, Fe, Mn and Cu deficiency to the tune of 41, 49, 33, 13, 12, 5 and 3 % respectively

Zn deficiency in Indian soils

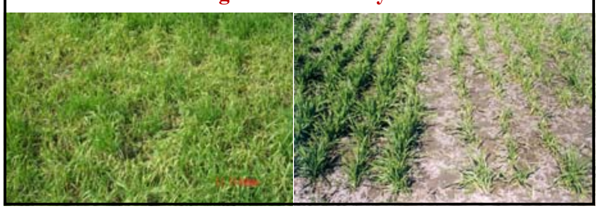




❖ Zinc deficiency in northern states like Punjab, Haryana and Uttar Pradesh showed a decreasing trend during past four decades but in other parts of countries it is increasing

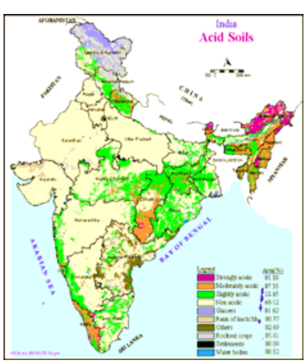
Zinc deficiency in rice

Manganese deficiency in wheat



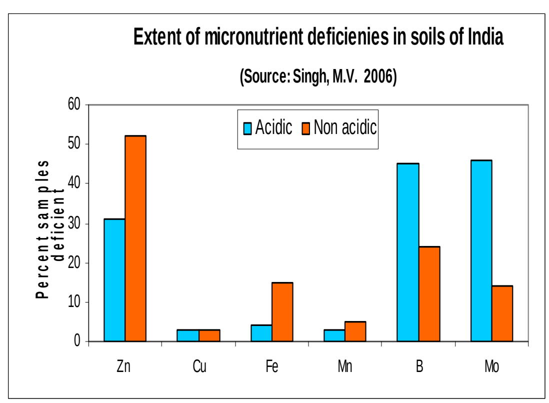
Iron chlorosis in paddy and sugarcane

Acid Soil in India



- ❖ Area under Acid soil is about 100 million ha
- ❖ 51 million ha under forests
- ❖ 49 million ha under cultivation
- ❖ Acid soils constitute about 30% of the total cultivable area in India

(Sharma and Singh, 2002)



- Although correcting soil reaction is important aspect of ameliorating acid soils, nutrient especially micronutrient management like Zn deficiency and Fe and Mn toxicity in acid soils is an area of concern for obtaining higher crop yield.
- Soil surveys and maps illustrating the geographic distribution of soil micronutrient availability would provide improved guidance for proper management of these nutrients in soils.
- Such resource inventory data are necessary for a better understanding the nature and extent of micronutrient deficiencies and toxicities in plants, livestock and human (White and Zasoski, 1999).

Phyto-availability of cationic micronutrients in soils

- ✓ Several extractants have been used to evaluate the phyto-availability of micronutrients in soils, which includes: (i) mineral acids, (ii) chelating agents, (iii) buffered salts, (iv) neutral salts, and (v) other extractants proposed for routine soil testing.
- ✓ On a global scale, diethylenetriaminepentaaceticacid (DTPA) is most widely used soil extractant for extraction of plant available cationic micronutrients (Zn, Cu, Mn and Fe) in different soil types .
- ✓ But other extractants like ethylenediaminetetraaceticacid (EDTA), hydrochloric acid, ammonium bicarbonate-DTPA (ABDTPA) , Mehlich 1 and Mehlich 3 etc. are also very popular.
- ✓ The DTPA soil test was originally developed to identify near-neutral and calcareous soils with insufficient available Zn to support maximum yield of crops.
- ✓ Appropriate soil tests for phyto-available metal are not yet available for all types of agricultural soils around the world.

(Lindsay and Norvell, 1978; Alloway, 2008)

Objectives

- ❖ To assess the status of extractable and total cationic micronutrient (Zn, Cu, Mn and Fe) content
- ❖ To analyze the relationships of total and extractable micronutrients among themselves and with some soil properties
- ❖ To characterize the spatial variability of micronutrient status in some cultivated acid soils of India

Materials and methods

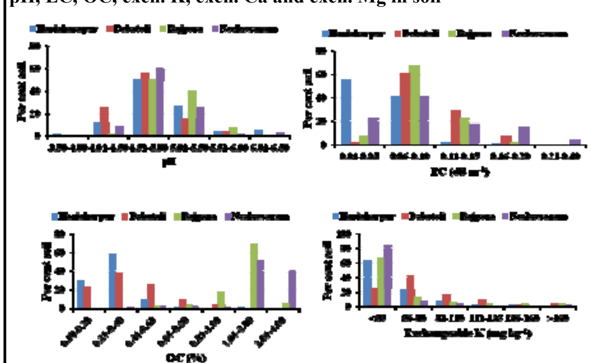
- ❖ Collection of 400 (100 from each series) geo-referenced surface (0-0.15 m depth) soil samples from four soil series

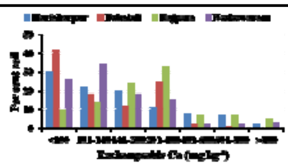
Name of the soil series	Location	Longitude and latitude	Above mean sea level (meter)	Average annual precipitation (mm)	Taxonomy	Texture	Land use
Hariharapur	Orissa	86^0 41''- 85^0 16'' East 21^0 43''- 20^0 20'' North	38 to90	1500	Alfisol	loam	Paddy-paddy/Paddy –vegetables
Debatoli	Jharkhand	85^0 8''- 85^0 20'' East 23^0 34''- 23^0 23'' North	612 to 691	1200	Alfisol	loam	Paddy-paddy/Paddy –vegetables
Rajpora	Himachal pradesh	76^0 9''- 76^0 4'' East 32^0 23''- 22^0 7'' North	1057 to 1420	1250	Alfisol	Loamy sandy	Paddy-wheat/tea
Neeleswaram	Kerala	75^0 8''- 75^0 53'' East 12^0 29''- 13^0 53'' North	-7 to 94	3000	Entisol	Sandy clay loam	Arecanut/ Paddy-paddy

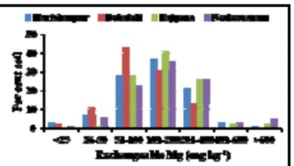
- Soil properties like pH and electrical conductivity (EC) (Jackson, 1973) Soil organic carbon (OC) content (Walkley and Black,1934), Neutral normal ammonium acetate extractable potassium (K) (Hanway and Heidel, 1952) and exchangeable calcium (Ca) and magnesium (Mg) (Jones, 1998) were estimated.
- The plant available fraction of micronutrients in soils was extracted by DTPA (Lindsay and Norvell, 1978), Mehlich 1 (Perkins, 1970), Mehlich 3, (Mehlich, 1984), 0.1 M HCl (Sorensen et al., 1971) and ammonium bicarbonate DTPA (ABDTPA) (Soltanpour and Schwab, 1977) extractants following the respective prescribed methods and analyzed by Atomic Absorption Spectrophotometer (AAS).
- Total elemental analysis was carried out with 0.5 g sample of each soil digested with a few drops of H_2SO_4 and 5 ml of HF + 0.5 ml of $HClO_4$ in a 50 ml capacity Teflon beaker (Jackson, 1973).

Results

pH, EC, OC, exch. K, exch. Ca and exch. Mg in soil







Parameter	CV (%)
pH	5.37 to 9.80
EC	32.4 to 74.3
OC	31.2 to 50.9
Exch. K	45.6 to 100
Exch. Ca	71.9 to 93.0
Exch. Mg	59.0 to 79.8

Extractable and total Zn in soil

	Hariharapur			Debatoli		
	Range	Mean	SD	Range	Mean	SD
DTPA-Zn(mg kg^{-1})	0.04-1.26	0.52	0.24	0.08-5.20	0.60	0.86
Mehlich 1-Zn(mg kg^{-1})	0.28-3.36	1.39	0.54	0.48-14.7	1.91	2.35
Mehlich-3-Zn(mg kg^{-1})	0.56-3.04	1.41	0.52	0.8-12.4	2.17	1.88
0.1 M HCl-Zn(mg kg^{-1})	0.40-3.76	1.75	0.59	0.28-14.9	1.45	2.28
ABDTPA-Zn(mg kg^{-1})	0.23-2.59	1.13	0.48	0.46-12.8	1.75	2.08
Total-Zn (mg kg^{-1})	8.80-67.5	34.2	11.3	16.0-86.5	34.5	15.2
	Rajpora			Neeleswaram		
	Range	Mean	SD	Range	Mean	SD
DTPA-Zn(mg kg^{-1})	0.28-9.12	1.72	1.29	0.14-10.8	1.49	1.46
Mehlich 1-Zn(mg kg^{-1})	0.48-8.08	2.62	1.58	0.48-11.6	2.58	1.85
Mehlich-3-Zn(mg kg^{-1})	0.88-8.08	3.15	1.38	0.16-6.24	1.84	1.19
0.1 M HCl-Zn(mg kg^{-1})	0.68-8.36	2.75	1.53	0.80-14.2	3.54	2.70
ABDTPA-Zn(mg kg^{-1})	0.59-6.65	2.14	1.38	0.34-7.33	1.69	1.11
Total-Zn(mg kg^{-1})	33.8-179	62.0	19.6	13.7-122	66.6	21.3

Simple correlation coefficients (r) for relationships of extractable and total Zn with soil properties in all the soils together (n = 400)

	pH	O. C.	EC	Exc. K	Exch. Ca	Exch. Mg	DTPA-Zn	Meh. 1-Zn	Meh. 3-Zn	0.1 M HCl -Zn	ABDTPA -Zn	Tot Zn
pH	1											
O. C.	0.12*	1										
EC	-0.08	0.14**	1									
Exc. K	0.22**	-0.12*	0.27**	1								
Exch. Ca	0.52**	0.11*	0.13**	0.54**	1							
Exch. Mg	0.47**	0.27**	0.24**	0.38**	0.72**	1						
DTPA-Zn	0.23**	0.47**	0.26**	0.21**	0.39**	0.34**	1					
Meh. 1-Zn	0.23**	0.35**	0.23**	0.20**	0.35**	0.29**	0.82**	1				
Meh. 3-Zn	0.19**	0.18**	0.29**	0.24**	0.36**	0.21**	0.77**	0.85**	1			
0.1 M HCl -Zn	0.24**	0.43**	0.28**	0.14**	0.35**	0.36**	0.85**	0.87**	0.74**	1		
ABDTPA-Zn	0.20**	0.24**	0.25**	0.30**	0.42**	0.32**	0.76**	0.88**	0.85**	0.78**	1	
Tot Zn	0.28**	0.66**	0.05	0.06	0.33**	0.38**	0.47**	0.42**	0.30**	0.43**	0.37**	1

Linear regression equations describing relationships of DTPA extractable Zn with Mehlich 1, Mehlich 3, 0.1 M HCl and ABDTPA extractable Zn

Regression equations	R^2 value
Mehlich 1- Zn = 1.233(DTPA-Zn) + 0.793	0.682
Mehlich 3- Zn = 0.950(DTPA-Zn) + 1.118	0.589
0.1 M HCl- Zn = 1.522(DTPA-Zn) + 0.753	0.731
ABDTPA- Zn = 0.908(DTPA-Zn) + 0.696	0.574

Behera et al. (2011) (Geoderma)

- Concentrations of total as well as extractable Zn varied widely among the acids soils and the amount of Zn extracted by different extractants also differed.
- Zinc deficiency was observed in 7 to 82 per cent soil and 2 to 57 per cent soils based on the DTPA extractable Zn and 0.1 M HCl extractable Zn, respectively.
- Correlation analysis revealed that the trend of extraction of zinc in acid soils by DTPA, Mehlich 1, Mehlich 3, 0.1 N HCl and ABDTPA extractants used for this investigation was similar indicating their usefulness for extractions of Zn in acid soils.

Extractable and total Cu, Mn and Fe in soil

- The concentrations of total as well as extractable Cu, Mn and Fe varied widely with different extractants and soil series.
- Cu extracted by DTPA, Mehlich 1, Mehlich 3, 0.1 N HCl and ammonium bicarbonate DTPA (ABDTPA) extractants was strongly correlated (r = 0.63 to 0.91) with each other.
- Likewise, the amount of Mn and Fe extracted by diethylene triamine penta aceticacid (DTPA), Mehlich 1, Mehlich 3, 0.1 M hydrochloric acid (HCl) and ammonium bicarbonate DTPA (ABDTPA) extractants was significantly correlated at the 0.01 level of significance.
- Based on DTPA extraction and critical values published in the literature, Mn and Fe deficiency were observed in 7 to 23 % and 1 to 3 % of the soil samples respectively.

Behera et al. (2012) (Agrochimica); Behera and Shukla (2014) (Pedosphere- in press)

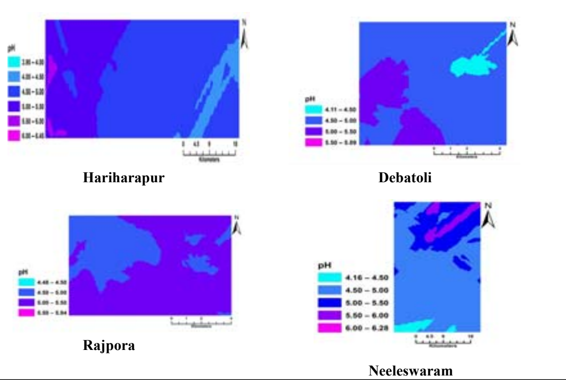
Spatial distribution of some soil properties and cationic micronutrients in acid soils

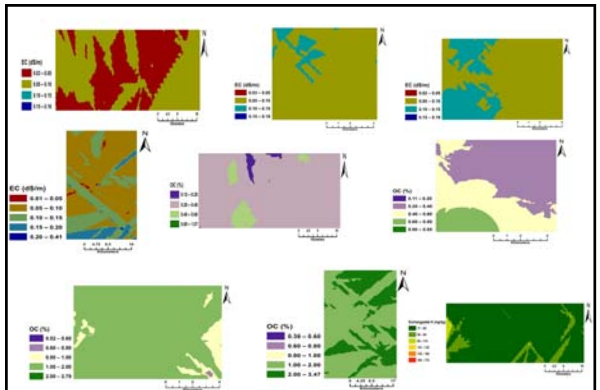
- ✓ Geostatistical software (ARC GIS) was used to analyze the spatial structure of the data and to define the semivariograms.
- ✓ From semivariograms, differences in nugget/sill ratio and range were examined forpH, EC, OC, exch. K, exch. Ca, exch. Mg and total and DTPA-Zn, Cu, Mn and Fe in soils of all the soil series.
- ✓ The semivariogram, the main component of kriging, is an effective tool for evaluating spatial variability.
- ✓ The variogram provides a clear description of the spatial structure of variables and provides some insight into possible processes affecting data distribution.

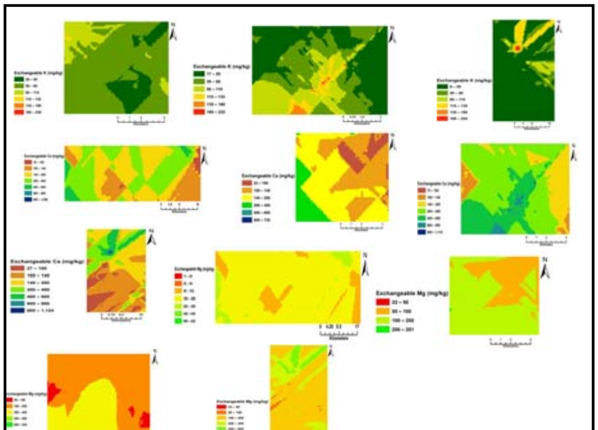
Variability of soil properties in acid soils of India

Property	Range for semivariogram models (m)	Spatial dependency	Coefficient of variation (%)	Magnitude of variability
pH	135-4509	Moderate	5-10	Low
EC	46-1337	Weak to strong	32-74	Moderate
OC	323-11936	Moderate to strong	31-50	Moderate
Exch. K	160-2794	Moderate to strong	45-100	Moderate
Exch. Ca	44-3359	Moderate to strong	72-93	Moderate
Exch. Mg	304-3586	Moderate to strong	59-91	Moderate
DTPA-Zn	2592-9078	Moderate to strong	46-143	Moderate to high
DTPA-Cu	3568-37854	Weak to strong	39-71	Moderate
DTPA-Mn	704-65837	Weak to strong	51-121	Moderate to high
DTPA-Fe	2692-5214	Moderate to strong	26-70	Moderate
Total Zn	992-65837	Moderate to strong	32-44	Moderate
Total Cu	3840-15250	Moderate to strong	33-71	Moderate
Total Mn	3513-24809	Weak to strong	30-81	Moderate
Total Fe	5845-65837	Weak to strong	26-47	Moderate

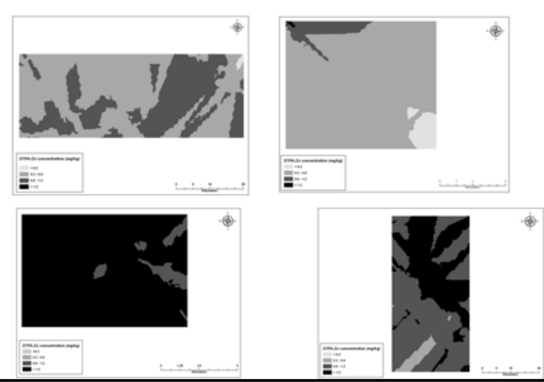
Distribution maps of soil properties in different soil series

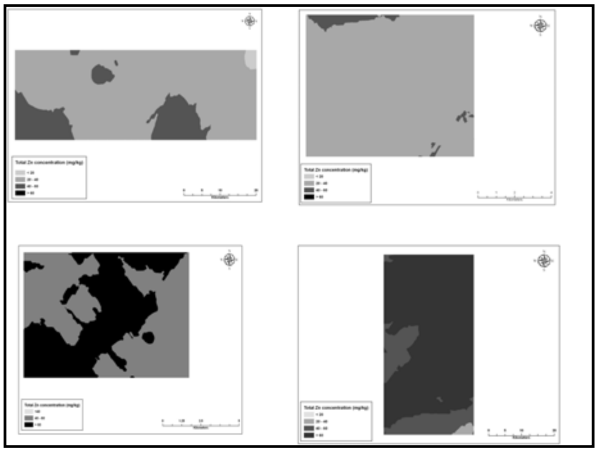


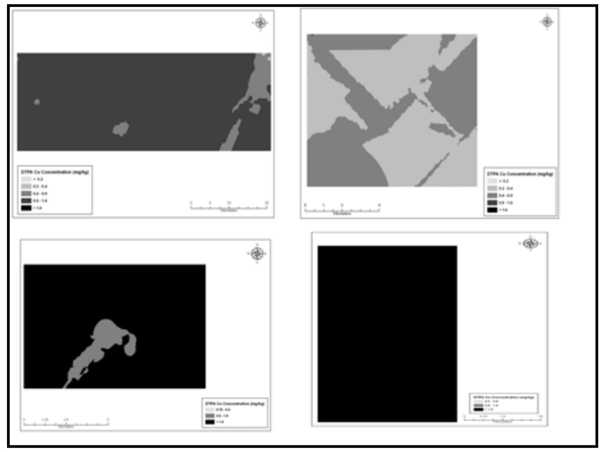


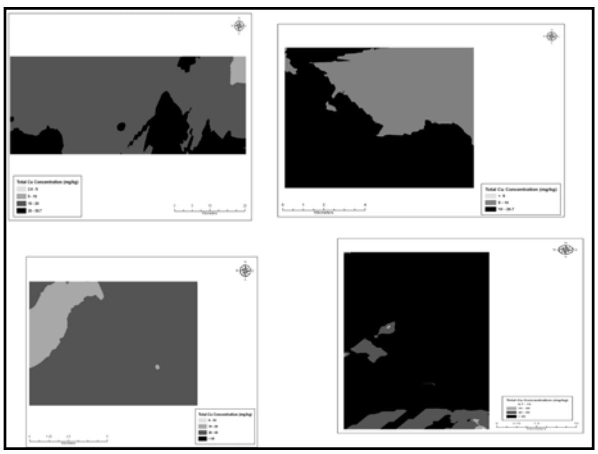


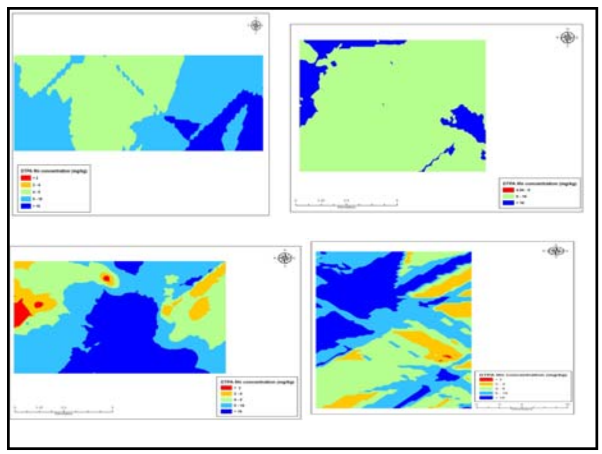
Distribution maps of total and DTPA extractable micronutrients

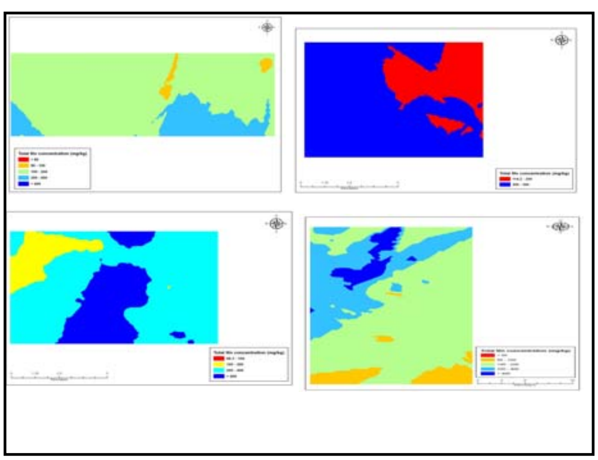


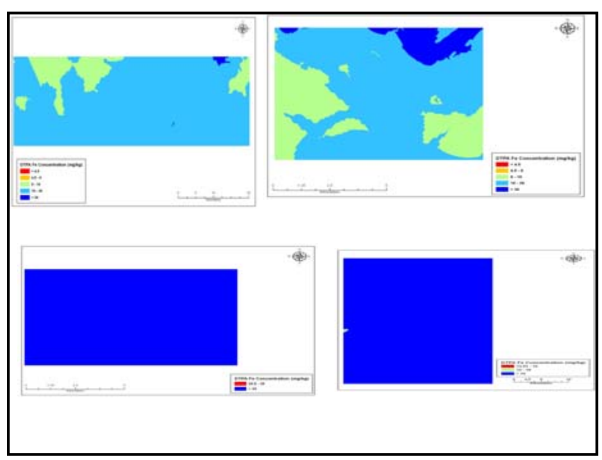


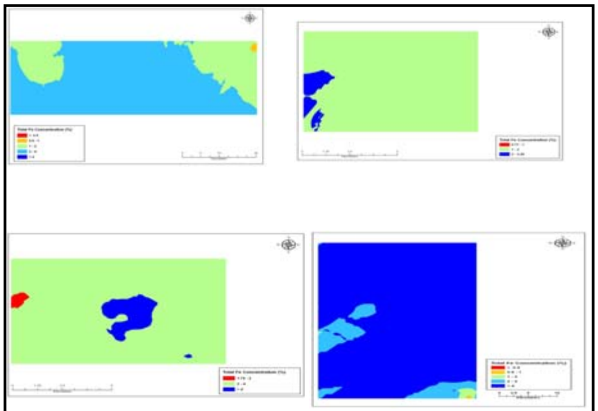










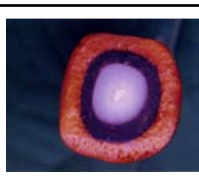


- Soil properties like pH, EC, OC, exch. K. exch. Ca, exch. Mg and total and DTPA extractable cationic micronutrients in acid soils of India had large variability in spatial distribution pattern and were differently influenced by the environmental factors.

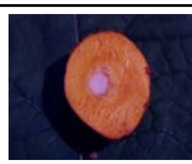
Spatial variability of soil parameters under oil palm cultivation

Oil palm cultivation in India

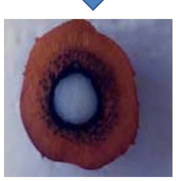
- Oil palm (*Elaeis guineensis* Jacq.) is a high oil yielding humid tropical crop introduced on a large scale in India in 1992-93.
- It produces 4-6 tonnes of edible oil per ha per year and 5 to 8 times of the yield of cultivated annual oil seeds.
- At present 2.06 lakh hectares area in India is under oil palm cultivation covering states like Gujarat, Maharashtra, Tamil Nadu, Kerala, Andhra Pradesh, Odisha, Bihar, Arunachal Pradesh and Mizoram.



Dura



Pisifera

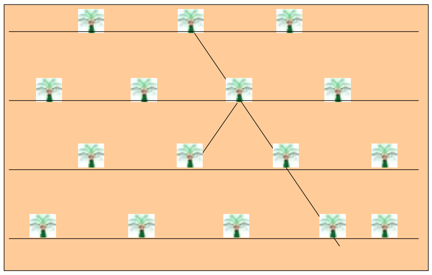


Tenera

Commercially cultivated hybrid

- This perennial crop has an economic life span of about 30 years.
- Comprising of three distinct phases viz., Juvenile period (1-3 years), Stabilizing yield period (4-8 years) and stabilized yield period (9-30 years).
- The economic part of oil palm is bunch of fruits which are commonly referred as Fresh Fruit Bunch (FFB).
- From this FFB, crude palm oil is extracted from mesocarp and palm kernel oil is extracted from palm kernels.

Planting method and plant population



- ✓ 9 m x 9 m x 9 m (equilateral triangular)
- ✓ 143 palms per ha
- ✓ 57 palms per acre

Need of fertilizer management in oil palm

- ❖ Oil Palm is a heavy feeder and requires a balanced and adequate supply of macro- and micro-nutrients for growth and yield.
- ❖ The nutrient requirements of oil palm vary widely
- ❖ It depends on the target yield, type of planting material used, palm spacing, palm age, soil type, ground cover conditions, as well as climate and other environmental factors.
- ❖ It is also associated with the amount of nutrients removed in harvested fruit bunches, nutrients recycled to the soil in pruned fronds, male inflorescences and nutrients immobilized in the palm biomass.

Nutrient content in fresh fruit bunches (FFB)

Kg t FFB^{-1}					g t FFB^{-1}				
N	P	K	Mg	Ca	Mn	Fe	B	Cu	Zn
2.94	0.44	3.71	0.77	0.81	1.51	2.47	2.15	4.76	4.93

(Ng and Thamboo, 1967 and Ng et al., 1968)

- ❖ A site must be able to supply following quantities of nutrients to produce 25 t fresh fruit bunch per ha per year

Nutrient	Quantity (kg/ha)
N	190
P	11
K	210
Mg	40
Ca	70

To avoid depletion of soil nutrient stocks, nutrients removed in the harvested crop must be replaced by:

- ➢ Recycling of crop residues such as empty fruit bunches and dried leaves etc.
- ➢ Addition of palm oil mill effluent
- ➢ Addition of manures
- ➢ Addition of mineral fertilizers

General nutrient recommendation for oil palm

Age of the Palm	Nutrients (g/palm/year)			
	N	P_2O_5	K_2O	$MgSO_4$
1st Year	400	200	400	125
2nd Year	800	400	800	250
3rd Year and above	1200	600	1200	500

- ➢ Borax at the rate of 100g/palm/year is recommended in boron deficient soils or when the boron deficiency symptoms are noticed.

Approaches for fertilizer application

- Soil analysis
- Leaf analysis and

Soil analysis approach

- Nutrient supply capacity of soils varies substantially depending on their fertility status
- The soil parameters are assessed to determine nutrient supplying capacity of the soil

Soil parameter	Acidic	Neutral	Alkaline
PH	<6.5	6.5 to 7.5	>7.5
EC (dS/m)	<2.0 normal		
	Low	Medium	High
Organic C (%)	0.50	0.50 to 0.75	>0.75
Available P_2O_5 (kg/ha)	<20	20 to 50	>50
Available K_2O (kg/ha)	<150	150 to 300	>300
Exchangeable Ca (meq/100 g)	<1.5	1.5	>1.5
Exchangeable Mg (meq/100 g)	<1.05	1.05	>1.05
Available boron (B) (mg kg^{-1})	<0.5 deficient		

Interpretation of soil nutrient status for fertilizer recommendations

Nutrient status	Interpretation
Low	Nutrient deficiency symptoms may occur. Fertilizer response is likely. Increase fertilizer dose by 25%.
Medium	Hidden hunger is likely. May respond to fertilizer. Maintain fertilizer dose.
High	No response to fertilizer. Reduce fertilizer dose by 25%

Leaf analysis approach

- ✓ Most common diagnostic tool to determine nutritional status of oil palm and estimate the appropriate fertilizer rates
- ✓ This is because of significant relationship between leaf nutrient concentration and FFB yield at a site
- ✓ It is further observed that the highest yield appears to be critically dependent on exact leaf nutrient composition
- ✓ Each nutrient has a optimum concentration, and when all nutrients reach their highest values, then maximum yield is attained
- ✓ If nutrient concentration in leaf sample is found to be deficient then it is advised to go for fertilizer application for bringing the leaf nutrient concentration to optimum level

Nutrient concentration of 17th oil palm leaves

Palm Age	Nutrients	Deficiency	Optimum	Excess
Young Palms (< 6 Years)	N (%)	<2.5	2.6-2.9	>3.1
	P (%)	<0.15	0.16-0.19	>0.25
	K (%)	<1.0	1.1-1.3	>1.8
	Mg (%)	<0.20	0.30-0.45	>0.7
	Ca (%)	<0.30	0.50-0.70	>0.6
	S (%)	<0.20	0.25-0.40	>1.0
	Cl (%)	<0.25	0.50-0.70	>1.0
	B (ppm)	<8	15-25	>40
	Cu (ppm)	<3	5-8	>15
	Zn (ppm)	<10	12-18	>80
Old Palms (> 6 Years)	N (%)	<2.3	2.4-2.8	>3.0
	P (%)	<0.14	0.15-0.18	>0.25
	K (%)	<0.75	0.9-1.2	>1.6
	Mg (%)	<0.20	0.25-0.40	>0.7
	Ca (%)	<0.25	0.50-0.75	>1.0
	S (%)	<0.20	0.25-0.35	>0.6
	Cl (%)	<0.25	0.50-0.70	>1.0
	B (ppm)	<8	15-25	>40
	Cu (ppm)	<3	5-8	>15
	Zn (ppm)	<10	12-18	>80

Source: Von Vex Kull and Fair Hurst (1991) IPI Bulletin 12.

Spatial variability of soil parameters under oil palm cultivation

- A total of 64 geo-referenced surface (0-0.15 m depth) and 64 subsurface (0.15-0.30 m depth) soil samples were collected from different oil palm plantations in South Goa and North Goa districts of Goa, India.
- Soil samples were analyzed for pH, EC, OC, exch. K, Olsen-P, exch. Ca, exch. Mg, $CaCl_2$ extractable sulfur (S) and hot water extractable boron (B) by following standard methods.
- Summary statistics were obtained for different soil parameters.
- Spatial distribution characterization of soil parameters were done using geostatistical software (Arc GIS).

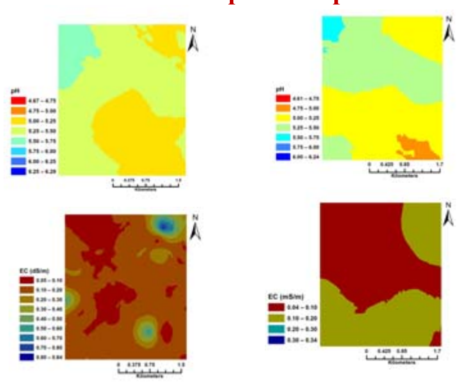
Descriptive statistics of soil parameters

Variable	Soil layer	Min.	Max.	Mean	SD	CV (%)
pH	Surface	4.25	6.77	5.35	0.45	8.64
	Subsurface	4.53	6.52	5.28	0.46	8.63
EC, dS m^{-1}	Surface	0.05	1.06	0.13	0.17	125
	Subsurface	0.03	0.41	0.08	0.06	75.3
OC, g kg^{-1}	Surface	5.07	48.4	19.8	8.77	44.4
	Subsurface	1.95	31.2	13.2	7.33	55.5
NH_4OAc-K, mg kg^{-1}	Surface	58.1	1167	270	29.9	88.7
	Subsurface	16.1	856	199	165	82.8
Olsen-P, mg kg^{-1}	Surface	0.85	141	24.7	31.4	127
	Subsurface	0.85	60.6	9.78	13.2	135
Exch. Ca, mg kg^{-1}	Surface	200	2997	914	588	64.3
	Subsurface	194	5177	795	724	91.1
Exch. Mg, mg kg^{-1}	Surface	36.0	744	203	141	69.3
	Subsurface	24.0	720	225	156	69.4
$CaCl_2$-S, mg kg^{-1}	Surface	3.00	87.7	23.2	16.4	70.7
	Subsurface	1.50	43.5	16.3	10.1	62.0
HWB, mg kg^{-1}	Surface	0.09	2.10	0.70	0.38	54.7
	Subsurface	0.04	2.56	0.64	0.44	68.6

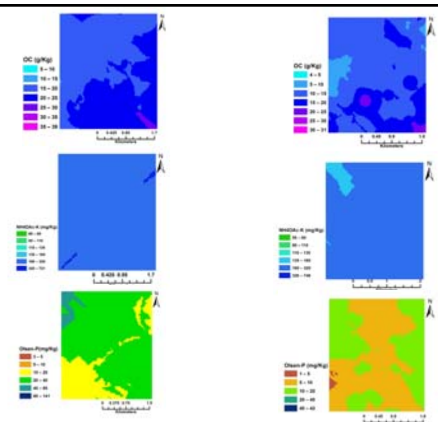
Semivariogram parameters of soil parameters

Variable	Layer	Model	Nugget: Sill ratio	Spatial class	Range (m)
pH	Surface	Spherical	0.715	Moderate	1416
	Subsurface	Spherical	0.687	Moderate	1468
EC, dS m^{-1}	Surface	Spherical	0.025	Strong	554
	Subsurface	Linear	0.750	Moderate	2186
OC, g kg^{-1}	Surface	Exponential	0.797	Weak	1131
	Subsurface	Circular	0.407	Moderate	581
NH_4OAc-K, mg kg^{-1}	Surface	Spherical	1.000	Weak	4530
	Subsurface	Linear	1.000	Weak	4530
Olsen-P, mg kg^{-1}	Surface	Gaussian	0.930	Weak	1996
	Subsurface	Gaussian	0.651	Moderate	770
Exch. Ca, mg kg^{-1}	Surface	Linear	0.000	Strong	1585
	Subsurface	Exponential	0.000	Strong	581
Exch. Mg, mg kg^{-1}	Surface	Gaussian	0.533	Moderate	885
	Subsurface	Exponential	0.959	Weak	1114
$CaCl_2$-S, mg kg^{-1}	Surface	Linear	1.000	Weak	4530
	Subsurface	Gaussian	0.666	Moderate	4530
HWB, mg kg^{-1}	Surface	Gaussian	0.630	Moderate	1424
	Subsurface	Linear	0.755	Weak	1148

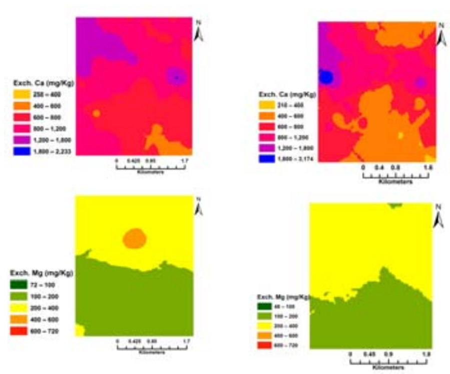
Distribution maps of soil parameters



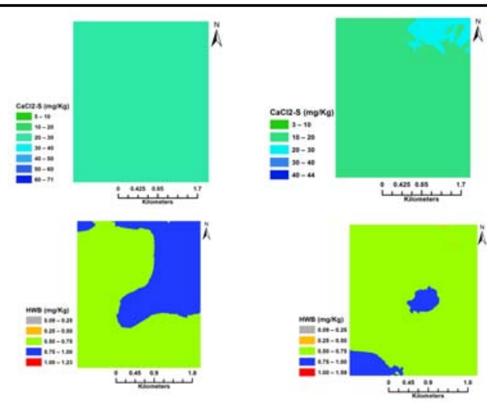
Surface layer Sub-surface layer



Surface layer Sub-surface layer



Surface layer Sub-surface layer



Surface layer Sub-surface layer

Training in the area of sensor based applications

- At DOPR, Pedavegi, we have initiated the work to assess spatial variability of soil properties and leaf nutrient concentrations in oil palm plantations in different agro-ecological regions of India for site specific nutrient management for enhanced oil palm productivity.
- Since the conventional procedure of assessing spatial variability of nutrients includes rigorous field sampling followed by laboratory analysis, which is time consuming and costly.
- Use of sensors to quantify soil properties at the scale required for accurate mapping is a necessity.
- This would facilitate real-time monitoring and intervention in soil nutrient status.

Types of on-the-go soil sensors

- Electrical and electromagnetic sensors - measure electrical resistivity/conductivity, capacitance or inductance affected by composition of tested soil.
- Optical and radiometric sensors – use electromagnetic waves to detect the level of energy absorbed/reflected by soil properties.
- Mechanical sensors – measure forces resulting from a tool engaged with the soil.
- Acoustic sensors – quantify the sound produced by a tool interacting with the soil.
- Pneumatic sensors – assess the ability to inject air into the soil.
- Electrochemical sensors – use ion-selective membranes that produce a voltage output in response to the activity of selected ions (like H^+, NO_3^-, K^+, Na^+ etc.)

Soil properties that have been targeted with various on-the-go soil sensing methods

Sensors	Soil properties								
	Texture	SOC or TC	Moisture	EC or Na	BD or compaction	pH	Res. NO_3 or TN	K	CEC
Electrical and electromagnetic	√	√	√	√			√		√
Optical and radiometric	√	√	√			√	√		√
Mechanical					√				
Acoustic and pneumatic	√				√				
Electrochemical				√		√	√	√	

Exposed to proximal soil sensors

ECa sensors

Mapping apparent soil electrical conductivity and elevation

DUALEM 21S

VERIS EC SURVEYOR

GEONICS EM38

Electrochemical sensors

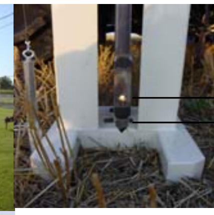
Ion selective electrodes

On-the-go soil Analyser (OSA) using ion selective electrodes

On-the-go moisture sensors

- ❖ Capacitance based sensor allows real-time estimation of near-surface soil water content during any field operation
- ❖ Used for variable depth planting

Hyper spectral soil profiler (P4000 VIS-NIR-EC-Force probe)



Sapphire window
EC contacts

- ➢ The VIS-NIR-EC-Force sensors provide soil profile information.
- ➢ The VIS-NIR spectrometers collect optical measurements through the sapphire window on the side of the probe as it moves into the soil profile.
- ➢ At the bottom of the probe is a cone-tip with soil EC contacts—for collecting dipole EC data.

γ ray spectrometer

- ➢ Earth naturally emits radiation
- ➢ Top 30-40 cm is measured and geographically mapped
- ➢ Selected number of locations and number of soil samples are collected and analyzed in lab. for calibration

- ➢ Measures & maps pH, organic matter, P, K, Ca, Mg, clay%, sand%, water retention, bulk density, etc.

Other hand held sensors

Integrated crop sensors systems

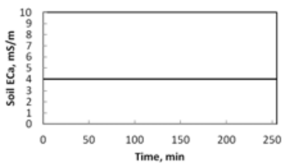
✓Ultrasonic proximity sensors for crops

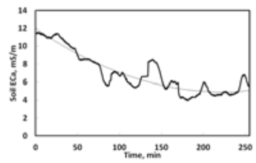
Work done

- ➢ Associated with study to evaluate and compare resistance to operation induced factors affecting soil ECa measurement by different sensors
  - ➢ Drift test
  - ➢ Height test
  - ➢ Rotation test
  - ➢ Tilt test

Drift test: Veris EC vs EM 38 vs Dualem 21S

- Each commercial ECa sensor has operational advantages and disadvantages





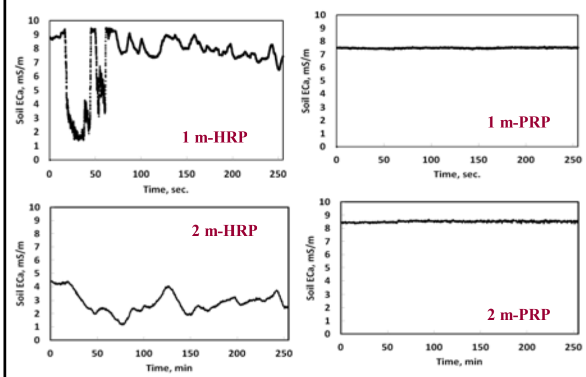
Veris Eca sensor:

- Consistent measurement of 4.0 mS/m

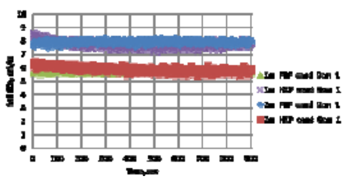
EM38:

- Soil ECa readings fluctuated over testing period
- It reduced drastically for first 180 minutes and stabilized at 5.0 mS/m

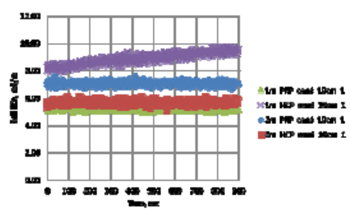
Dualem 21S



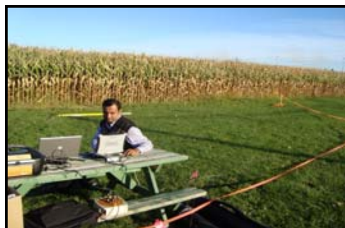
Height test-Dualem 21S

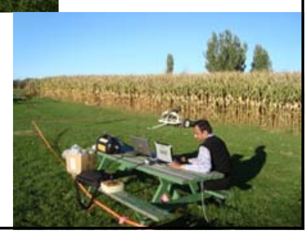


0 cm height

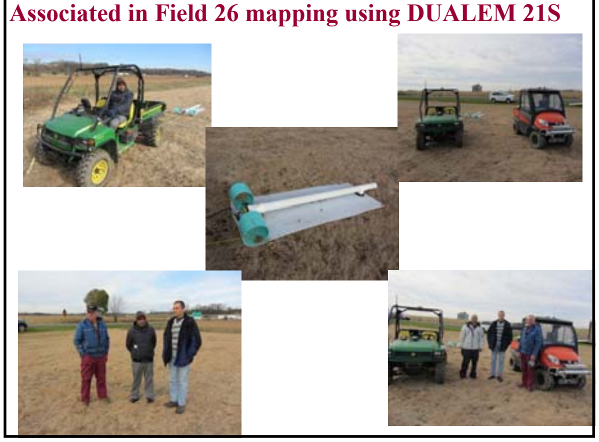


10 cm height

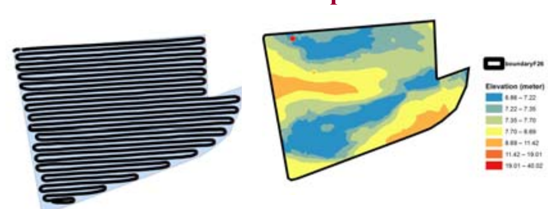




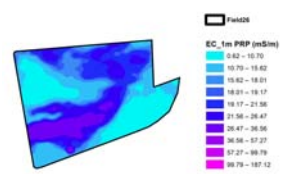
Associated in Field 26 mapping using DUALEM 21S



Field 26 maps



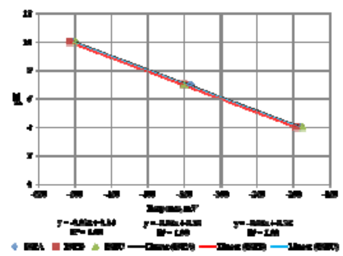
Elevation map



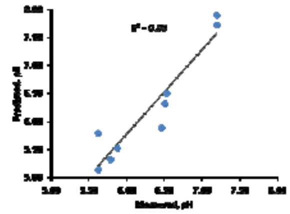
EC map

Associated with use of ion selective electrodes for on-the-go measurement of soil pH

Calibration of three pH electrodes in lab.



Measurement of soil pH on the go



On-the-go soil analyser

- Attended several GIS theory and practical classes
- Learned about geospatial analysis using Arc GIS software
- Prepared a joint journal manuscript on "Applicability proximal soil sensing technologies to improve crop production in India"

Acknowledgement

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