INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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COLLEGE ON SOIL PHYSICS

19 September - 7 October 1983

PAST AND FUTURE CONTRIBUTIONS OF SOIL PHYSICS TO AGRICULTURAL DEVELOPMENT - TRANSPARENCIES

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THE PAST

AN IMPROVED UNDERSTANDING OF SOME PHYSICAL AS WELL AS CHEMICAL AND BIOLOGICAL PROCESSES IN SOILS.

- SELECTED SOILS & CLIMATES (LEVEL TOPOGRAPHY)
- SELECTED CROPS & CROP SEQUENCES (CEREALS)
- SELECTED RAINFED & IRRIGATED SOILS (SMALL PLOTS)
- SHORT DURATION EXPERIMENTS (MORE LAB THAN FIELD)
- EXPENSIVE EQUIPMENT
- LARGE LABOR & RESOURCE REQUIREMENTS

TOPICS STUDIED

- SOIL MORPHOLOGY & COMPOSITION
- SOIL STRUCTURE & CONSISTENCY
- EVAPOTRANSPIRATION
- AERATION
- THERMAL REGIMES
- DRAINAGE
- IRRIGATION & RECLAMATION
- EROSION
- PLANT-SOIL-WATER RELATIONS

THE PRESENT

FIED TECHNOLOGY REMAINS IMMATURE AND MORE OR LESS UNDEVELOPED

- DETERMINISTIC CONCEPTS DOMINATE OVER STOCHASTIC CONSIDERATIONS
- PROCEDURES ARE UNAVAILABLE TO ASCERTAIN LONG-TERM CONSEQUENCES OF PRESENT-DAY MANAGEMENT SCHEMES
- PRESENT-DAY PROBLEMS ARE NOT SUFFICIENTLY LINKED WITH SOIL MAPPING UNITS
- CRITERIA FOR SUCCESSFUL MANAGEMENT OF SOIL RESOURCES SHOULD NOT BE BASED SOLELY ON THIS YEAR'S CROP YIELD

THE FUTURE

WHAT SOIL PHYSICS HAS ACCOMPLISHED IS NOT THE ISSUE

WHAT SHOULD SOIL PHYSICS DO ?

- CONTINUE FUNDAMENTAL RESEARCH THAT UNDERPINS PRAGMATIC DECISIONS IN AGRICULTURE
- BE AN INTEGRATOR OF OTHER DISCIPLINES (CHEMISTRY, PHYSICS, BIOLOGY, MATHEMATICS AS WELL AS AGRONOMY)
- PROVIDE LEADERSHIP IN THE DEVELOPMENT OF A FIELD TECHNOLOGY TO MONITOR, MEASURE & MANAGE OUR SOIL RESOURCES.
- CONVERT OUR THINKING FROM DETERMINISTIC TO MORE REALISTIC STOCHASTIC ANALYSES

ANALYZING FIELD-MEASURED SOIL PROPERTIES WITH GEOSTATISTICAL AND REGIONALIZED VARIABLE ANALYSES

- HOW MANY SAMPLES ?
- WHEN TO TAKE SAMPLES ?
- WHERE TO TAKE SAMPLES ?
- SAMPLE REPRESENTS WHAT SIZE DOMAIN ?
- UTILITY OF OBSERVATIONS IN RELATION TO A CONCEPTUAL MODEL ?
- UTILITY OF CONCEPTUAL MODEL IN RELATION TO OBSERVATIONS ?

TAKING ADVANTAGE OF SPATIAL VARIABILITY RATHER THAN IGNORING IT WHEN ANALYZING FIELD SOILS

OUTLINE

- FREQUENCY DISTRIBUTIONS OF SOIL PARAMETERS
- FISHER VERSUS GEOSTATISTICAL METHODS
- AUTO-CORRELOGRAMS
- SEMI-VARIOGRAMS
- KRIGING
- CO-VARIOGRAMS
- CO-KRIGING
- SPECTRAL ANALYSIS
- SPATIAL OR TEMPORAL CROSS-CORRELOGRAMS
- CO-SPECTRAL ANALYSIS
- USE OF PARAMETERS IN EQUATIONS
- REV AND SCALE OF OBSERVATION
- SOIL MAPPING UNITS
- MEASURE WHOLE FIELDS, NOT SMALL "TYPICAL" PLOTS
- QUESTIONS TO BE ANSWERED BY RESEARCH

FISHER STATISTICAL METHODS USED BY AGRICULTURAL SCIENTISTS USUALLY ASSESS TREATMENTS OR EXPERIMENTAL ALTERNATIVES:

PLANT BREEDER → CULTIVARS
ENTOMOLOGIST → PESTICIDES
SOIL SCIENTIST → FERTILIZERS
HYDROLOGIST → IRRIGATIONS
AGRONOMIST → CROP YIELDS

FISHER STATISTICS OFTENTIMES LEAD TO THE FOLLOWING:

- SELECT A "TYPICAL" OR "REPRESENTATIVE" SITE
- TAKE A "RANDOM" SAMPLE TO AVOID BIAS
- AVOID SPATIALLY VARIABLE LOCATIONS
- VARIABILITY IS "BAD"
- VARIABILITY IS "ERROR"
- CONDUCT EXPERIMENT ON "TYPICAL" SITE REPRESENTING A PARTICULAR SOIL

BASIC ASSUMPTIONS UPON WHICH MOST FISHER STATISTICAL METHODS ARE BASED:

- ASSUME A FREQUENCY DISTRIBUTION IS APPROPRIATE FOR A GIVEN POPULATION
- ERRORS OF OBSERVATION HAVE MEAN = ZERO
- ERRORS ARE INDEPENDENT OF EACH OTHER

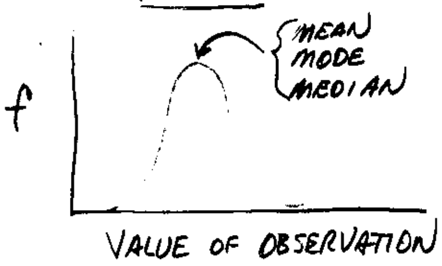
FEW EXPERIMENTALISTS TEST THE VALIDITY OF THESE ASSUMPTIONS!

OBJECTIVES:

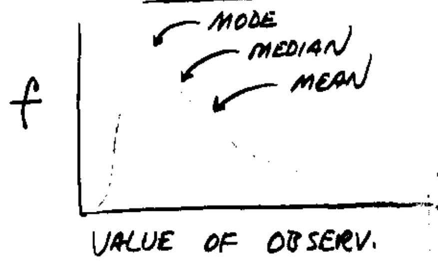
- REMIND EACH OF US THAT SOILS DO NOT ALWAYS SATISFY ABOVE ASSUMPTIONS
- IDENTIFY ADDITIONAL STATISTICAL TOOLS NOT NORMALLY USED IN THE AGRICULTURAL SCIENCES
- PROVIDE EXAMPLES WHICH WILL LEAD TO THE DEVELOPMENT OF A TECHNOLOGY TO SAMPLE AND ANALYZE FIELD SOILS

FREQUENCY DISTRIBUTIONS OR PROBABILITY DENSITY FUNCTIONS

"NORMAL"



"ANORMAL"



CAPACITY PARAMETERS

- SAND, SILT, CLAY
- ORGANIC MATTER
- POROSITY
- BULK DENSITY
- SOLUTES

TRANSPORT PARAMETERS

- HYDRAULIC CONDUCTIVITY
- APPARENT DIFFUSION
- FLUX OF WATER
- SOIL WATER DIFFUSIVITY
- SOLUTES

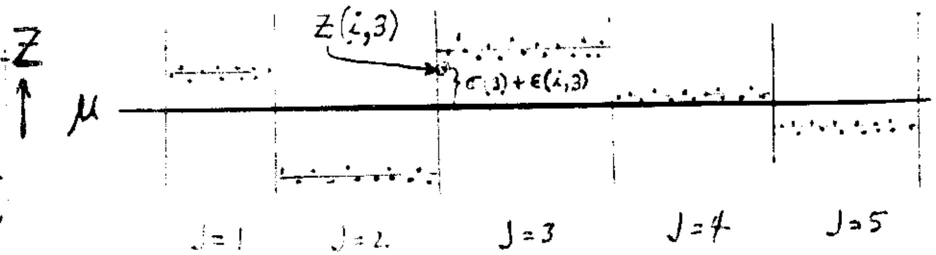
FISHER VERSUS GEOSTATISTICAL CONCEPTS

20-HA FIELD

FISHER	GEOSTATISTICAL
RANDOM SAMPLES	NOT NECESSARILY RANDOM
↓	↓
MEAN VARIANCE	MEAN, VARIANCE VARIANCE STRUCTURE
THROW AWAY LOCATIONS OF SAMPLES	FIND OUT IF LOCATIONS ARE TO BE DISREGARDED

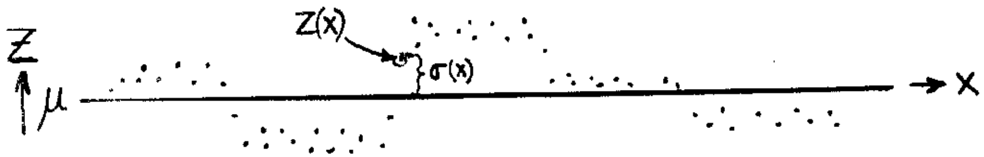
FISHER ANALYSIS OF VARIANCE

$$Z(i,j) = \mu + \sigma(j) + \epsilon(i,j)$$



REGIONALIZED VARIABLE ANALYSIS

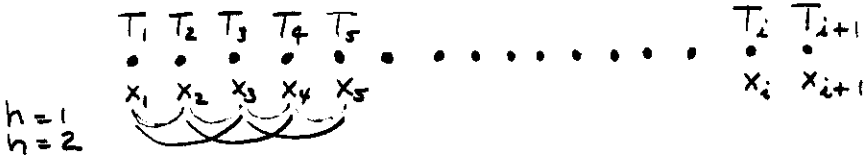
$$Z(x) = \mu + \sigma(x)$$

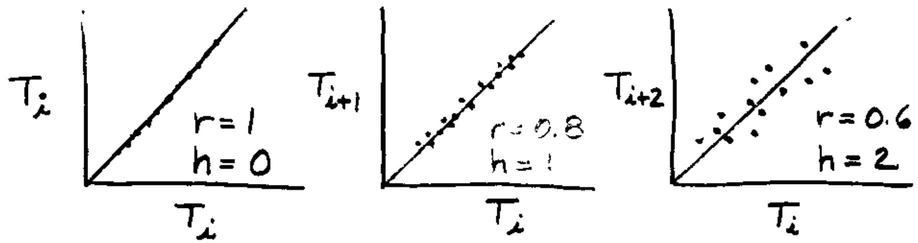


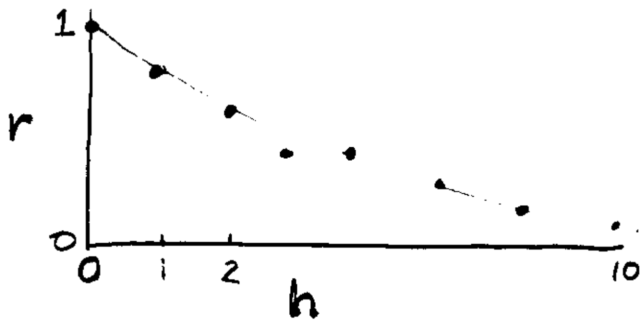
<u>AUTO-CORRELOGRAMS</u>

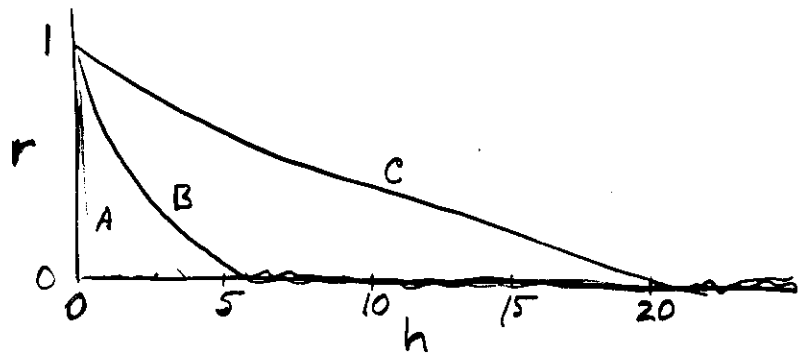
- HOW BIG AN AREA DOES A SAMPLE REPRESENT?
    - HOW BIG A SAMPLE SHOULD BE TAKEN?
- OVER WHAT TIME PERIOD DOES AN OBSERVATION HOLD?
    - HOW OFTEN SHOULD A SAMPLE BE TAKEN?
- SCALE OF OBSERVATION IS NOT SIZE OF MEASUREMENT
- IS IT APPROPRIATE TO COMPARE ONE MEASUREMENT WITH ANOTHER WHEN THEY REPRESENT TWO DIFFERENT SIZES OF AREAS?

$$r(h) = \frac{\text{AUTOCOV}\left[T(x), T(x+h)\right]}{\sqrt{\text{VAR}\left[T(x)\right]}\sqrt{\text{VAR}\left[T(x+h)\right]}}$$





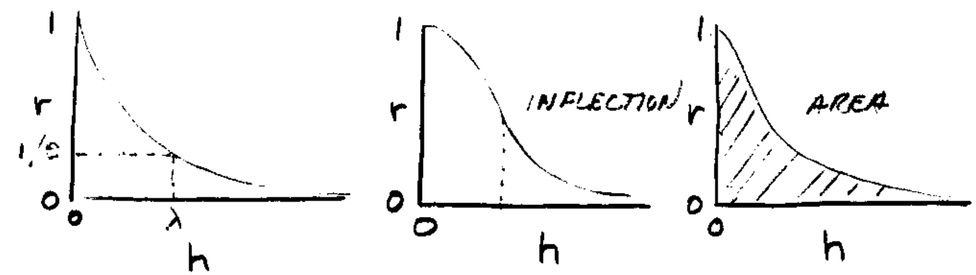




IF EVEN FOR LAG 1, $r \to 0$, USE FISHER STATISTICS

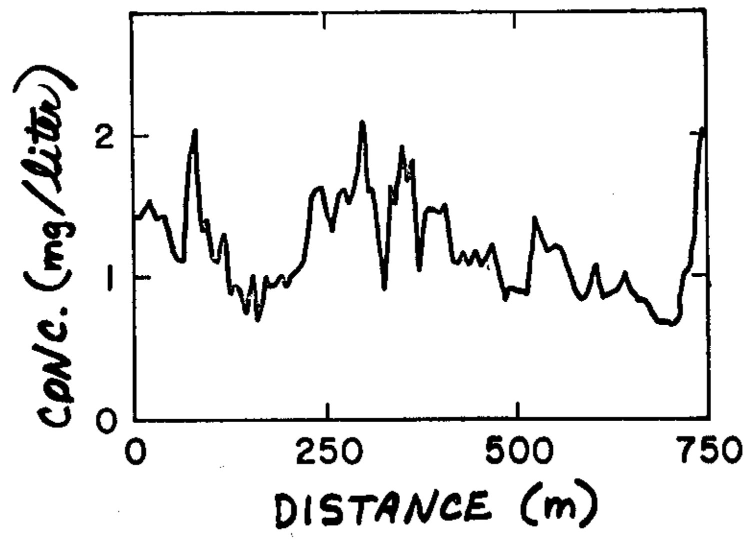
IF FOR LAGS > 1, $r \neq 0$, USE GEOSTATISTICS
(SIZE OF LAG DEPENDS UPON PROBLEM)

<u>SCALE OF OBSERVATION – DEFINITION</u>

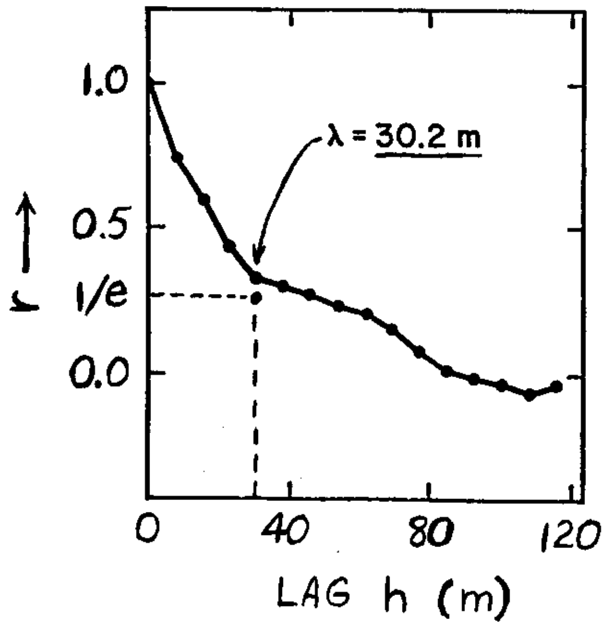


NEED TO IDENTIFY FOR VARIOUS SOILS, THE SCALE OF OBSERVATION OF CHEMICAL, PHYSICAL & BIOLOGICAL PARAMETERS!

SOLUTE CONC. IN WATER



λ3



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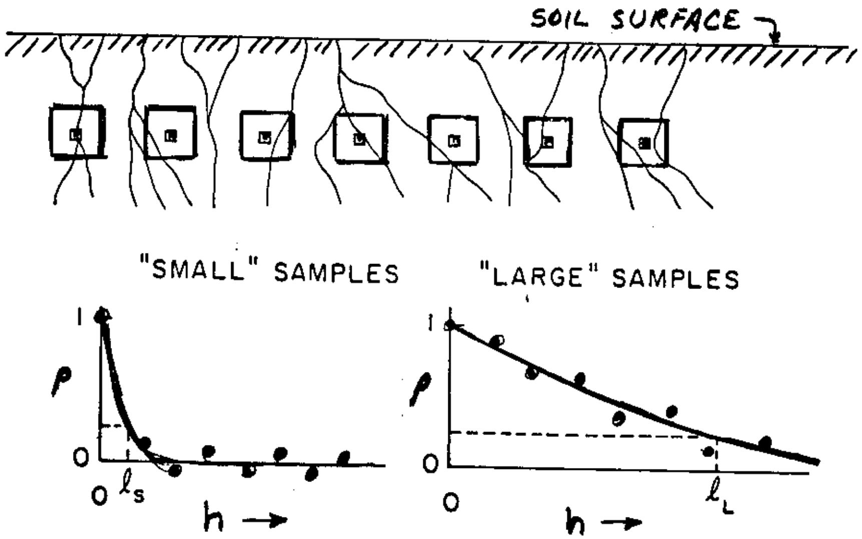
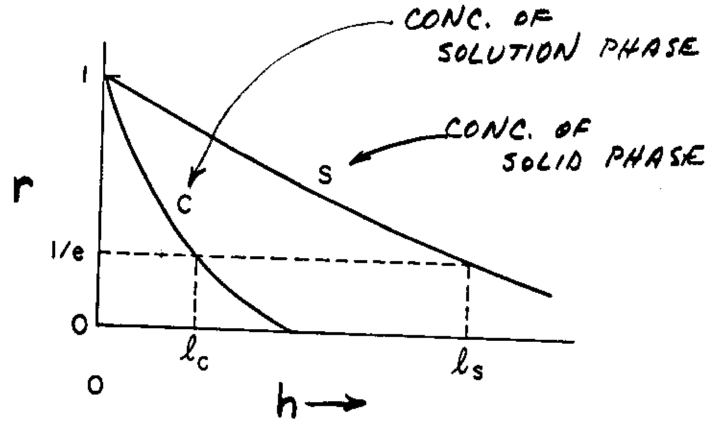
"PREFERENTIAL" FLOW PATHS



$l_s < l_L$

SCALES OF OBSERVATION OF S AND C



IF $l_c = l_s$, $S = RC$

$l_c \neq l_s$, $S \overset{?}{=} RC$

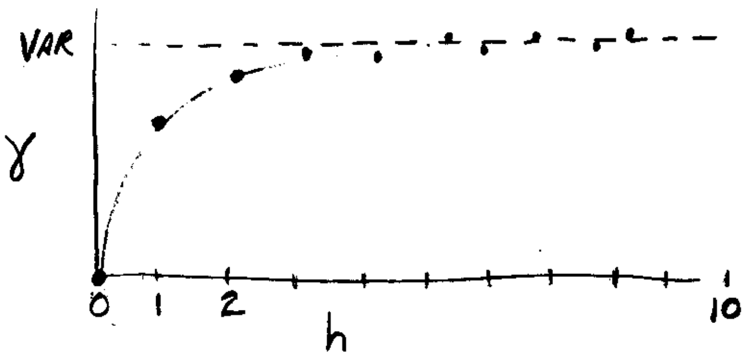
$$J_w \overset{?}{=} -K \nabla H$$

$$J_s \overset{?}{=} -D \nabla C$$

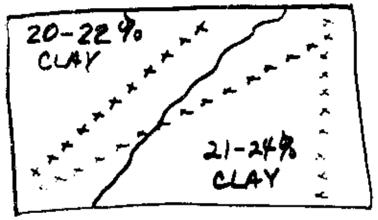
SEMI-VARIOGRAMS

$T_1 \quad T_2 \quad T_3 \quad T_4 \quad \cdots \quad T_i \quad T_{i+1}$

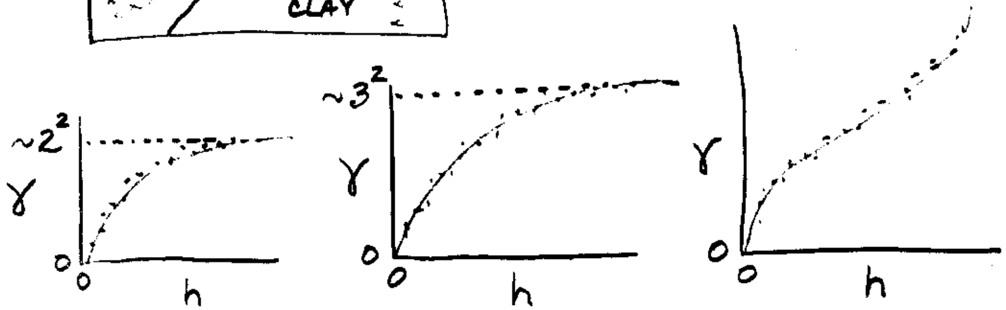
$$\gamma(h) = \frac{1}{2n} \sum_{i=1}^{n+1} \left(T_{i+h} - T_i\right)^2$$

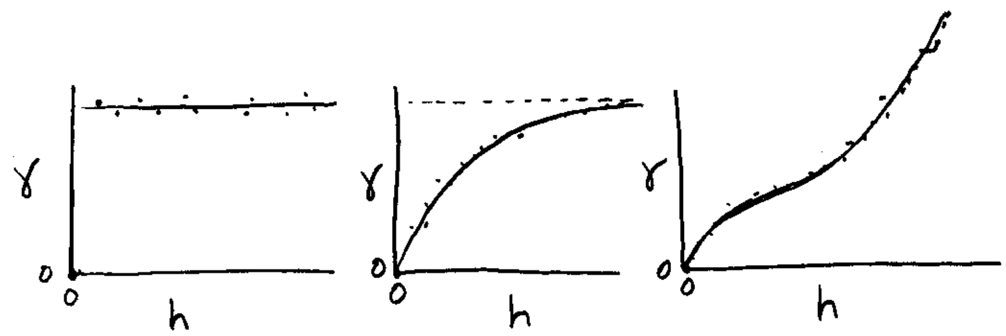


– IDENTIFY DOMAINS WITH SEMI-VARIOGRAMS –



20 HA FIELD





SPATIAL INDEPENDENT IN A DOMAIN

SPATIAL DEPENDENT IN A DOMAIN

CHANGING DOMAIN

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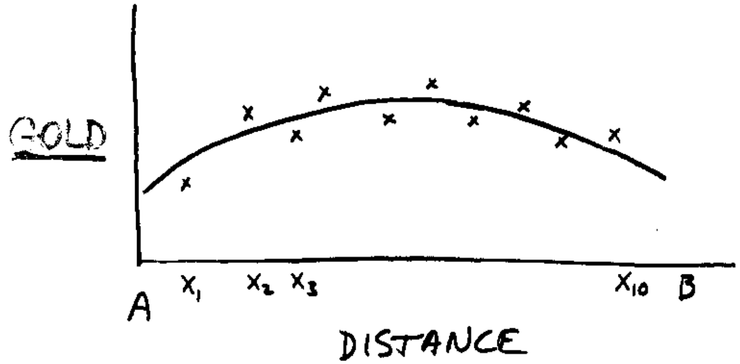
– INTERPOLATE WITH SEMI-VARIOGRAMS – KRIGING –



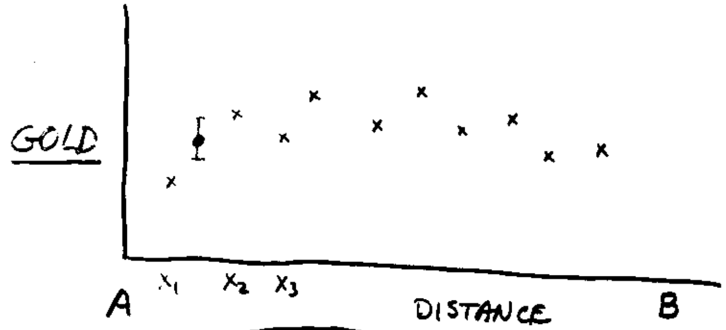
$\underline{\text{GOLD}} = a_0 \qquad r = 0.5$

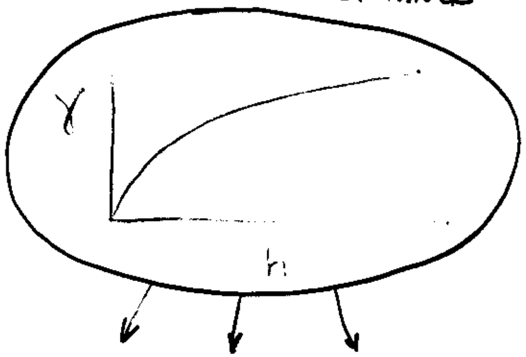
$= a_0 + a_1 X^1 \qquad r = 0.7$

$= a_0 + a_1 X^1 + a_2 X^2 \qquad r = 0.9$

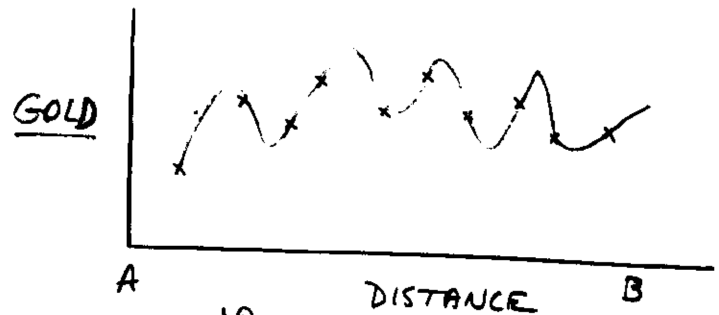
$= a_0 + a_1 X^1 + a_2 X^2 + \cdots \quad a_9 X^9 \qquad r = 1$

KRIGING

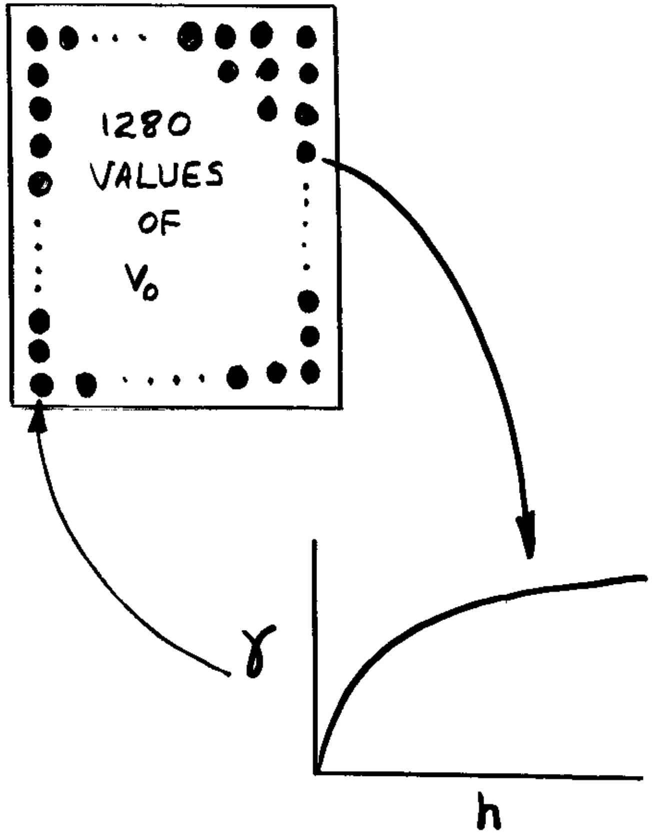




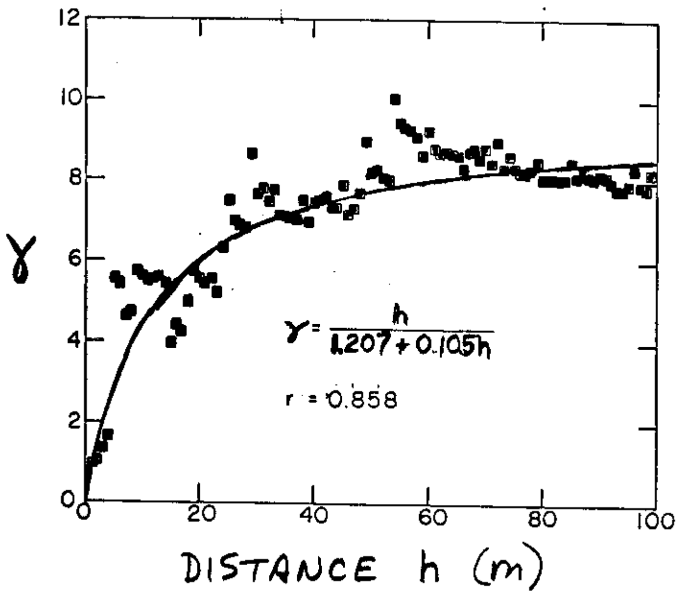
$$\bullet = \lambda_1 X_1 + \lambda_2 X_2 + \lambda_3 X_3 + \cdots + \lambda_{10} X_{10}$$



KRIGING INFILTRATION MEASUREMENTS IN A 1-HA. FIELD



SEMI-VARIOGRAM FOR INFILTRATION MEASUREMENTS



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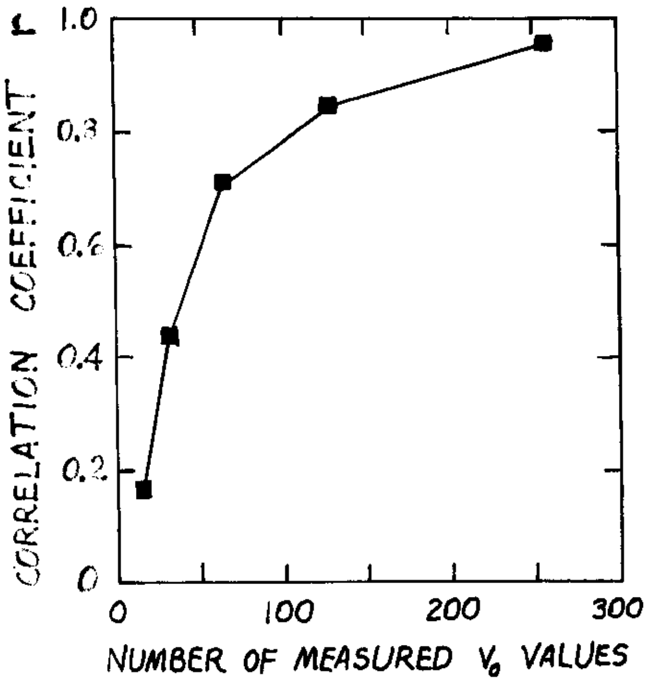

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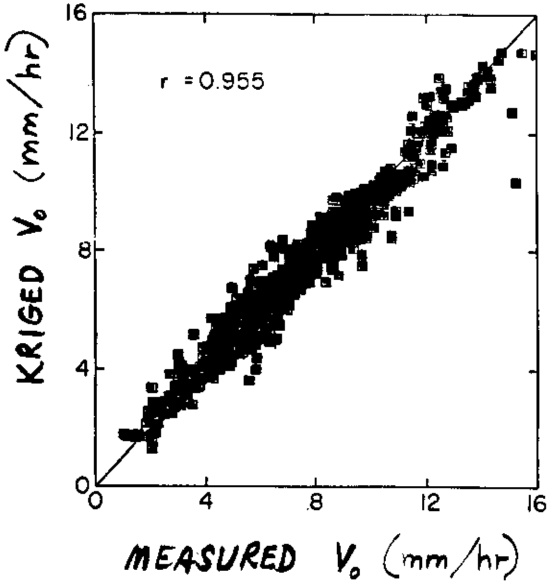
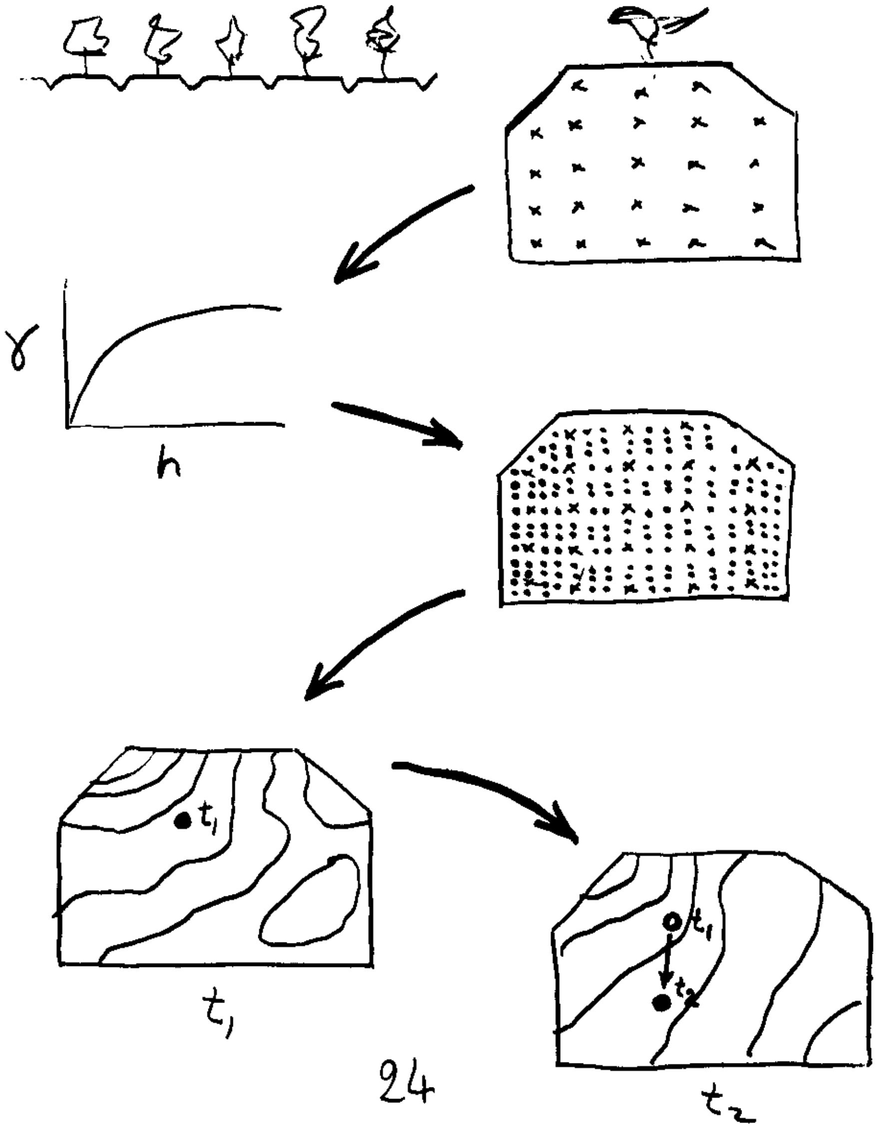


USED 256 VALUES OF V_o TO ESTIMATE 1024 VALUES OF V_o

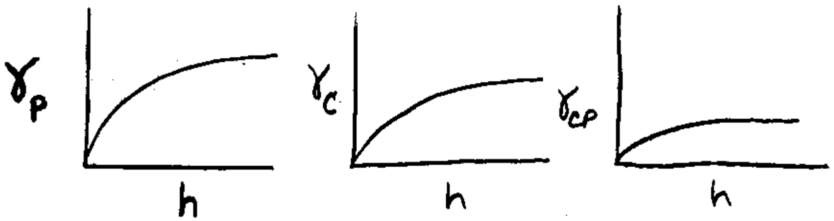
WHERE TO SAMPLE - IN THE ROW, BETWEEN ROWS, HOW DEEP, HOW OFTEN ???

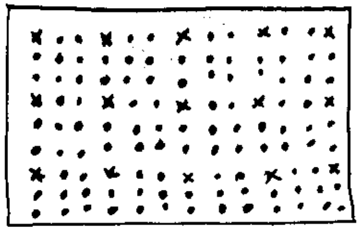


CO-VARIOGRAMS

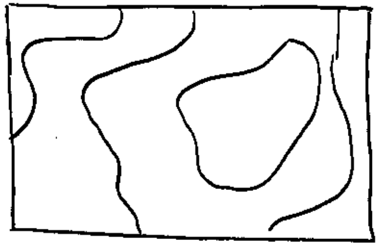
TAKE ADVANTAGE OF ONE EASILY MEASURED PARAMETER TO PREDICT ANOTHER MORE DIFFICULT OR MORE EXPENSIVELY MEASURED PARAMETER.

1. AVAILABLE P AND CLAY
2. PESTICIDE LEACHING AND CLAY
3. SOIL TEMPERATURE AND SOIL WATER CONTENT





$$x^* = \lambda_1 x_1 + \lambda_2 x_2 \cdots \quad + \lambda_1 x_1 + \lambda_2 x_2 + \lambda_3 x_3 \cdots$$



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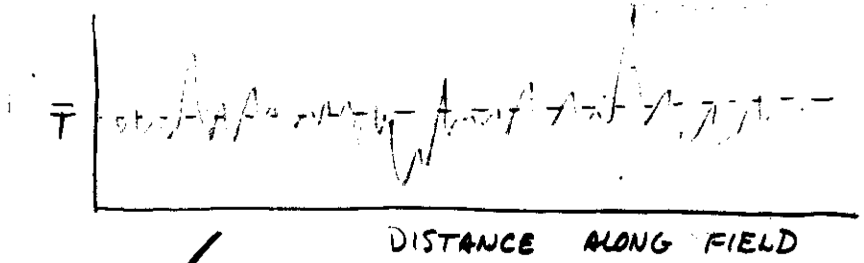
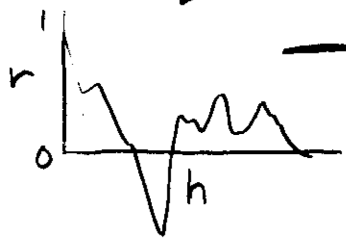
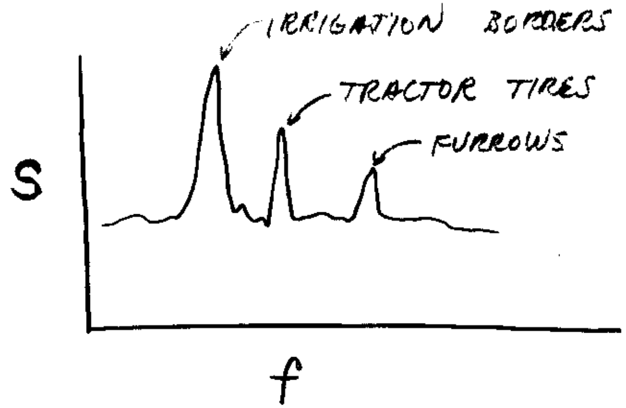
SPECTRAL ANALYSIS



AUTOCORRELOGRAM



$$S(f) = 2\int_0^\infty r(h)\cos(2\pi f h)\,dh$$



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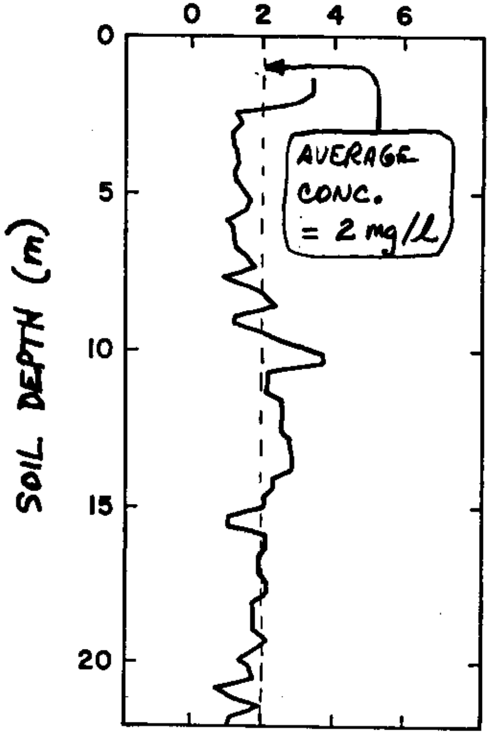
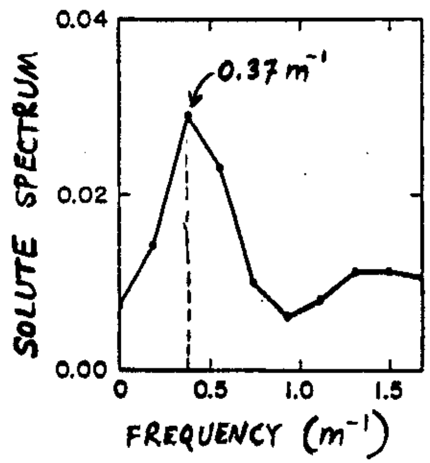
SPECTRAL ANALYSIS OF SOIL SOLUTION

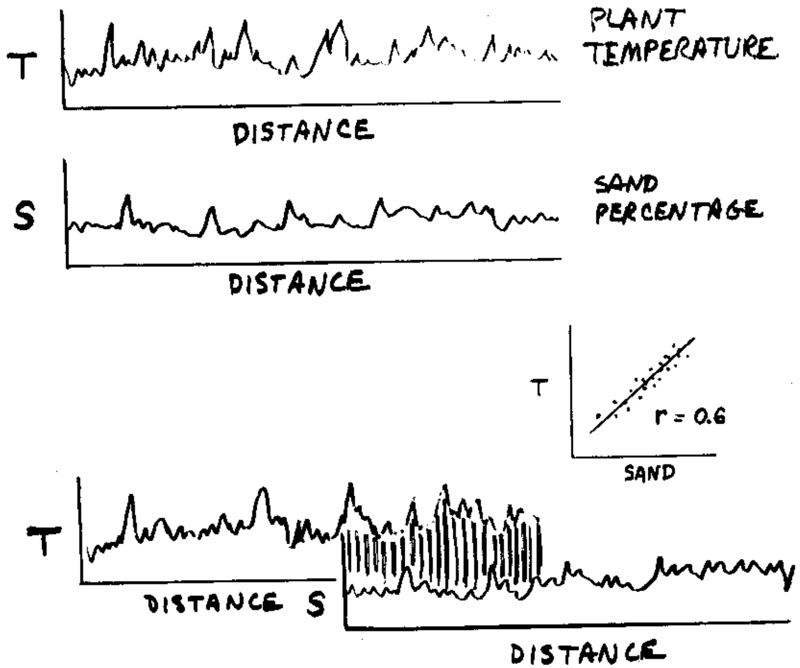


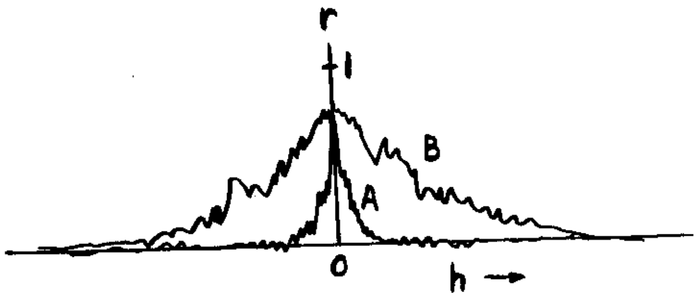
FREQUENCY OF 0.37 m^{-1} CORRESPONDS TO A PERIOD OF 2.7 m.

(AN ANNUAL IRRIGATION SEASON IN DESERT ENVIRONMENT)

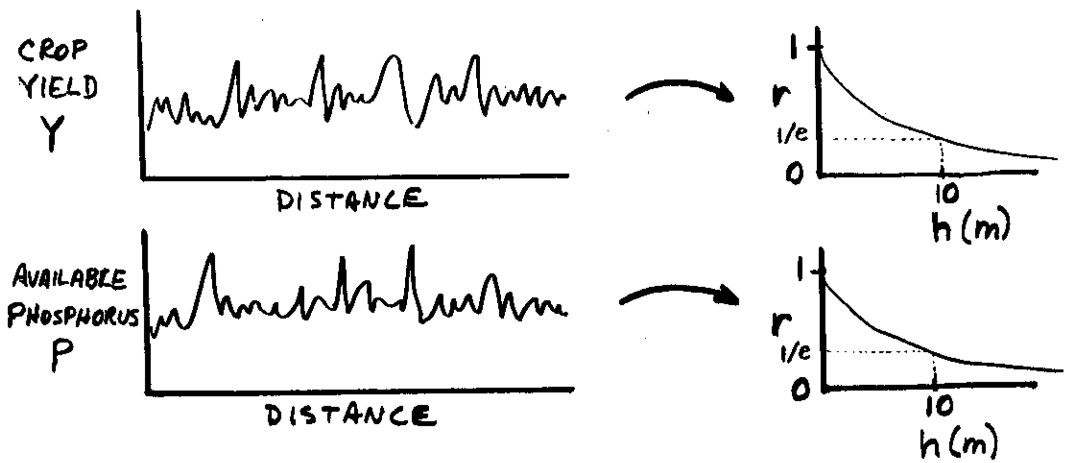


SPATIAL OR TEMPORAL CROSS-CORRELOGRAMS

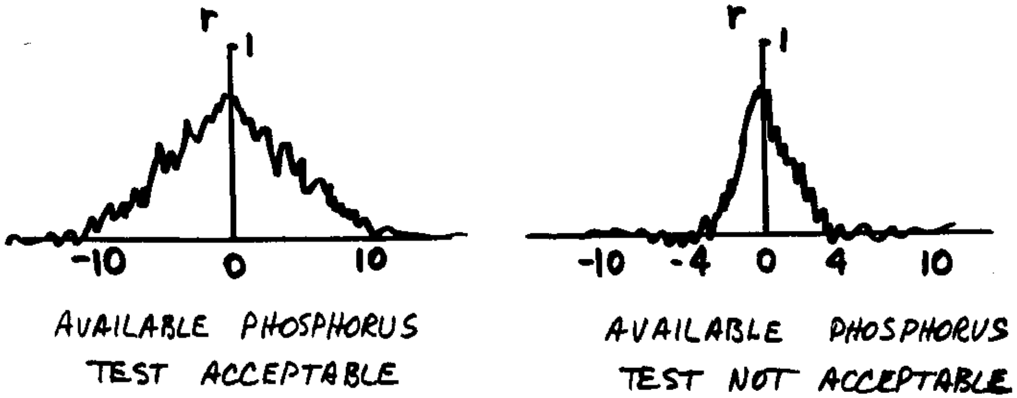




CROSS-CORRELOGRAM – SOIL FERTILITY

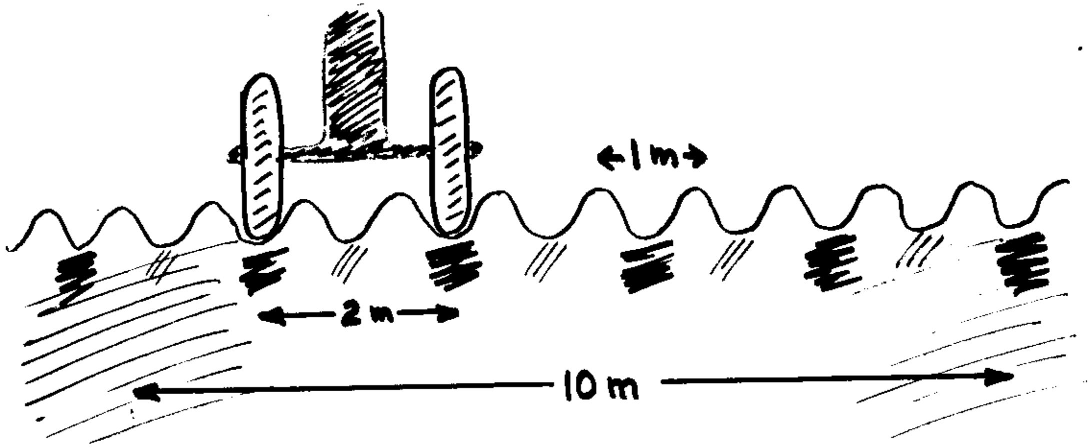


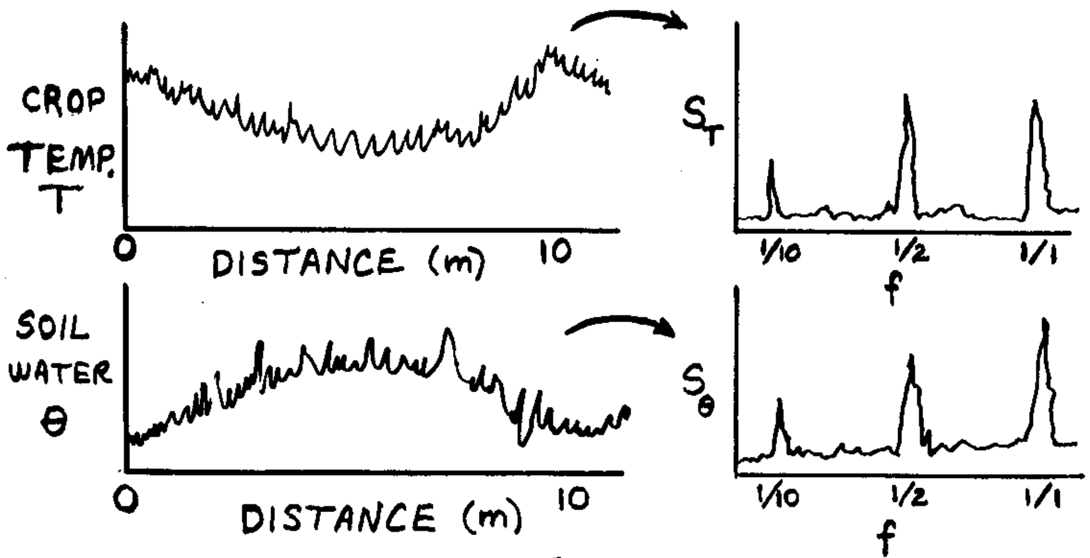
CROSS-CORRELOGRAM



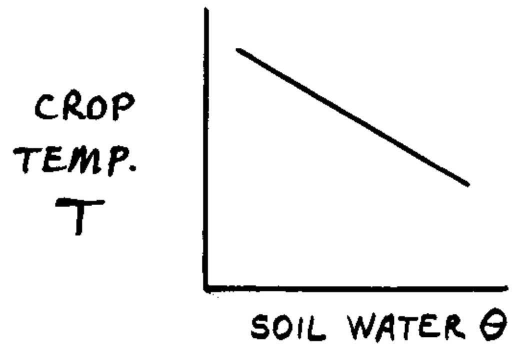
FIELD CROPS, ROW CROPS, TREE CROPS

SPECTRAL AND CO-SPECTRAL ANALYSES





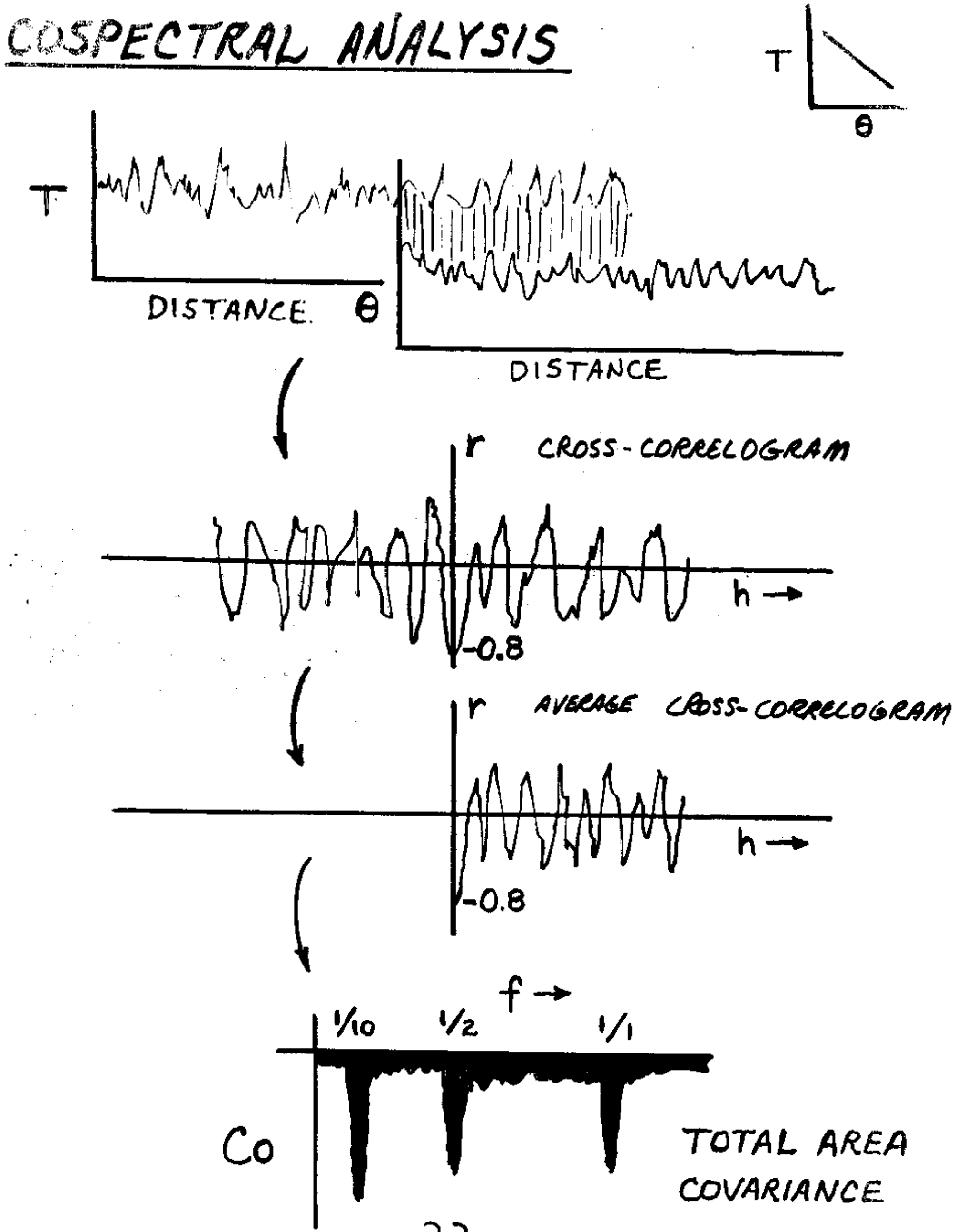
IF:



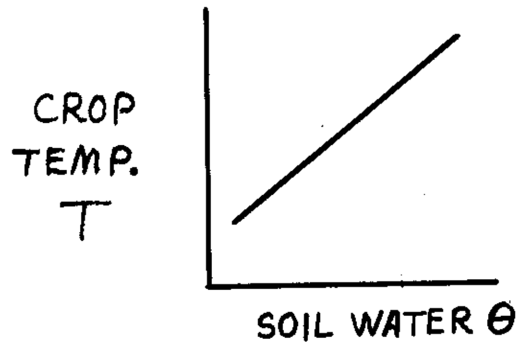
LOWER WATER CONTENT θ

- LESS CROP AVAILABLE WATER
- REDUCED TRANSPIRATION
- GREATER CROP TEMPERATURE T

COSPECTRAL ANALYSIS



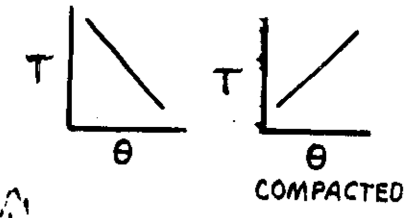
IF IN TRACTOR WHEEL FURROW:

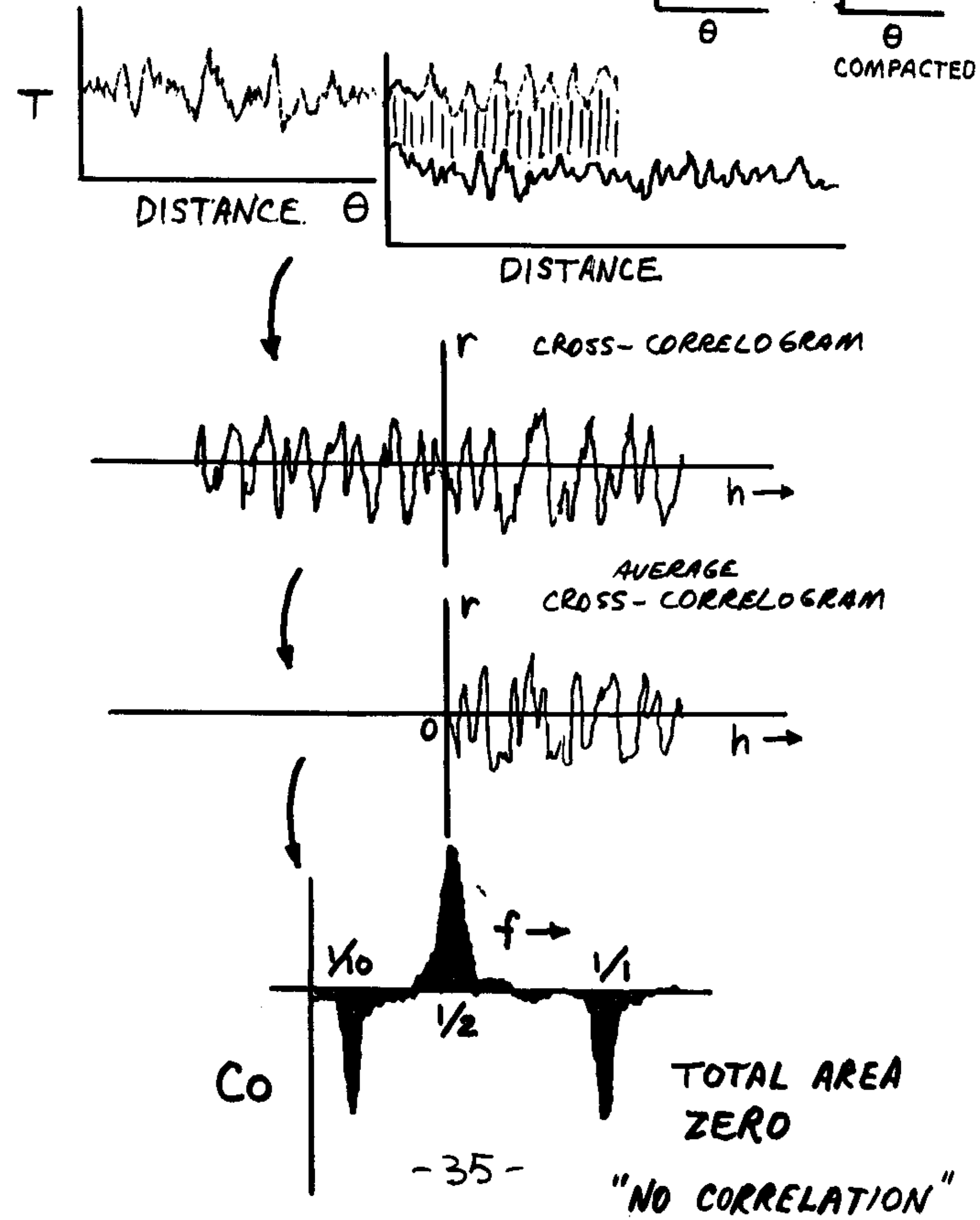


SOIL IS COMPACTED

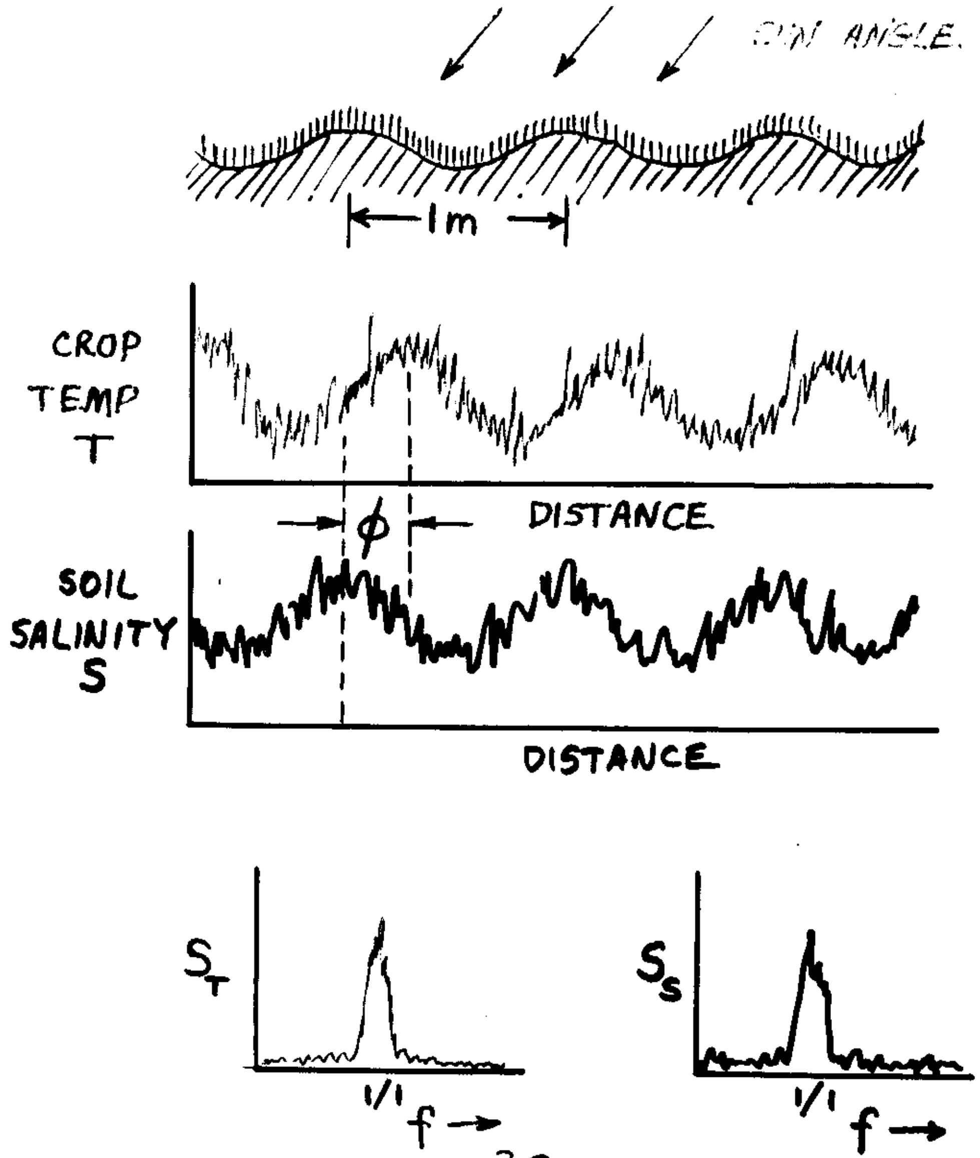
- GREATER SOIL WATER CONTENT θ
- FUNGAL ROOT ROT DISEASE
- POOR WATER EXTRACTION
- REDUCED TRANSPIRATION
- GREATER CROP TEMPERATURE T

COSPECTRAL ANALYSIS



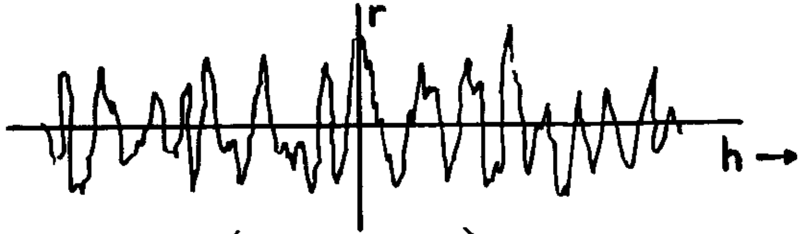


COSPECTRAL PHASE ANGLE φ

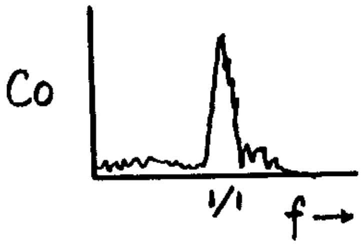


PHASE ANGLE ϕ

CROSS-CORRELOGRAM (CROP TEMP. & SOIL SALINITY)



$$\frac{r(h>0)+r(h<0)}{2} \qquad \frac{r(h>0)-r(h<0)}{2}$$



$$\phi = \frac{1}{2\pi f} \tan^{-1}\left[\frac{Q(f)}{Co(f)}\right]$$

$$Coh(f) = \frac{Q^2(f) + Co^2(f)}{S_T(f)\, S_S(f)}$$

$$0 < Coh(f) < 1$$

WHY SPECTRAL ANALYSES?

- LINK OBSERVATIONS WITH DIFFERENT PHYSICAL & CHEMICAL PHENOMENA
- FIELDS ARE TRAVERSED IN CYCLIC PATTERNS
- IMPACT AND PERSISTENCE OF CYCLIC PATTERNS SHOULD BE KNOWN
- SIZE OF SENSOR SHOULD DEPEND UPON PERIOD OF OSCILLATION
- OVER WHAT DISTANCES SHOULD OBSERVATIONS BE MADE → "MEANINGFUL AVERAGE"
- CYCLIC BEHAVIOR MAY BE MORE IMPORTANT THAN AVERAGE BEHAVIOR
- FILTER-OUT TRENDS ACROSS A FIELD TO LOOK AT LOCAL VARIATIONS, OR VICE VERSA
- ANALYZE ENTIRE FIELD RATHER THAN PLOTS

USE OF PARAMETERS IN EQUATIONS

1. ESTIMATE OF AVERAGE VALUE PLUS ITS RANDOM FUNCTION

$$J_w = -K\frac{dH}{dz}$$

$$J_w + J_w = -(K + K)\,\frac{d(H+H)}{dz}$$

$$= -K\frac{dH}{dz} - K\frac{dH}{dz} - K\frac{dH}{dz} - \underset{0}{\cancel{K\frac{dH}{dz}}}$$

SIMILARLY, $[NO_3^-] = f(\text{RAINFALL, TEMPERATURE})$

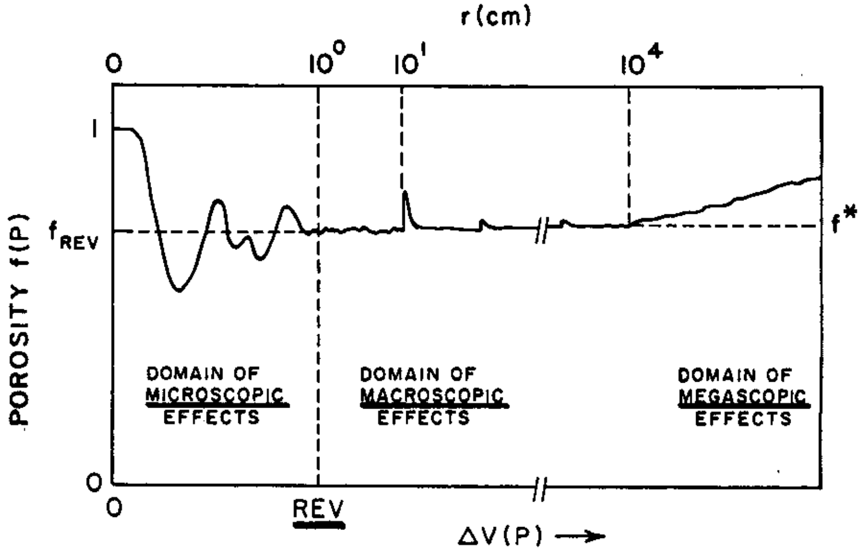
$$[NO_3^- + NO_3^-] = f[(R+R),(T+T)]$$

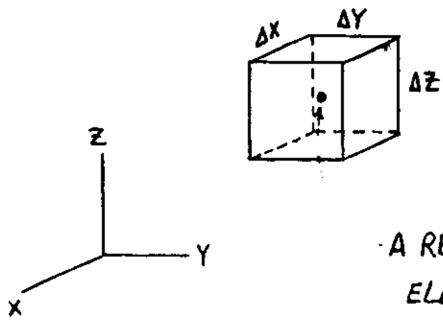
2. PARAMETERS OF EQUAL "QUALITY" OR ACCURACY & PRECISION

$$\frac{\partial(\overset{10}{\theta}\,\overset{100}{c})}{\partial t} + \frac{\partial(\overset{1}{\rho}\,\overset{50}{S})}{\partial t} = -\frac{\partial(\overset{400}{J_w c})}{\partial z}$$

3. COMPATIBILITY OF CONCEPTUAL REPRESENTATIVE ELEMENTARY VOLUME (REV) AND SCALE OF OBSERVATION OR AUTOCORRELATION LENGTH (ℓ)

REPRESENTATIVE ELEMENTARY VOLUME

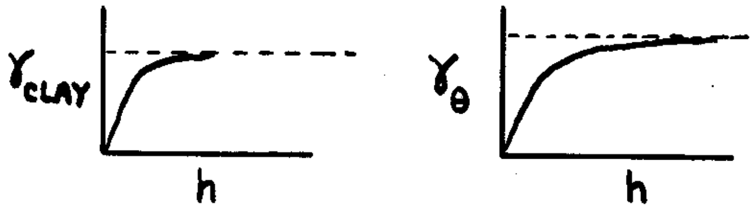




A REPRESENTATIVE ELEMENTARY VOLUME AT POINT $P(x,y,z)$

SOIL MAPPING UNITS

EXAMINE SPATIAL AND TEMPORAL VARIANCE STRUCTURES

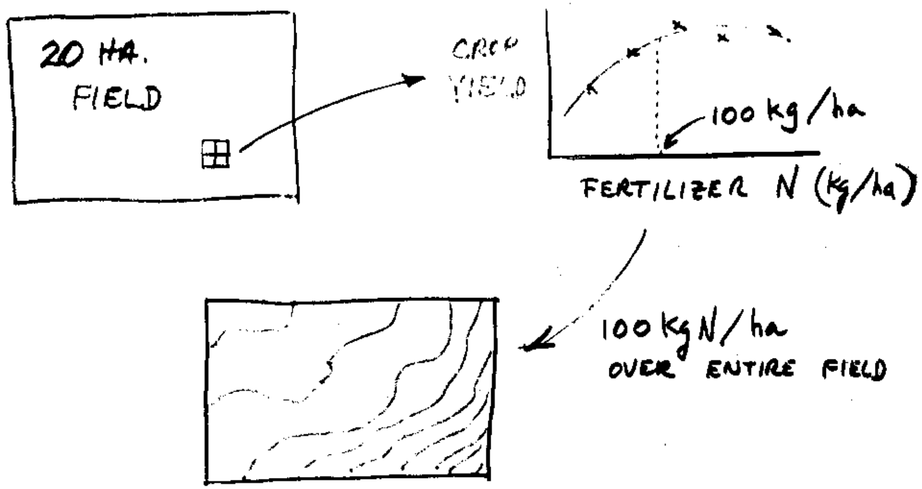


EXAMINE RELATIVE TO HORIZONS

EXAMINE RELATIVE TO SOIL DEPTH

CATALOG SOIL PROPERTIES IN TERMS OF VARIANCE STRUCTURES, NOT VARIANCES AT MODAL SITES

TREAT OR TEST WHOLE FIELDS – NOT PLOTS

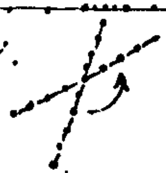


- ANALYZE SEMI-VARIOGRAMS OF YIELD, SOIL MOISTURE, NUTRIENT LEVELS, INSECT POPULATIONS, SEVERITY OF DISEASES, PESTICIDE RESIDUES, ETC.
- SPATIAL CROSS-CORRELATIONS
  a. YIELD VERSUS θ AT TASSELING
- DIVIDE OR INTEGRATE AREAS OF EQUAL MANAGEMENT, ETC.

QUESTIONS ?

- ARE PRESENT-DAY MAPPING UNITS COMMENSURATE WITH THEIR SPATIAL VARIANCE STRUCTURES ?

- SHOULD SAMPLING SCHEMES BE 1-, 2- AND/OR 3-DIMENSIONAL ?
  - EQUALLY SPACED ?
  - FENCE POSTS ?
  - TRIANGULAR, HEXAGONAL, ETC. ?
  - TURNING BANDS ?



- WHAT IS THE FUTURE OF KRIGING & CO-KRIGING?
  - UNDER-SAMPLED OBSERVATIONS ?
  - DELINEATE BOUNDARIES BETWEEN MAPPING UNITS ?

- HOW USEFUL IS SCALING?
  - GEOMETRIC, DYNAMIC, KINETIC ?
  - DETERMINISTIC OR STOCHASTIC ?
  - CORRELATIONS WITH OTHER SOIL PROPERTIES ?
  - LINKAGES WITH MAPPING UNITS ?
  - SIMULATIONS WITHIN A DOMAIN ?

- WHAT IS THE FEASIBILITY OF ASCERTAINING "MEAN" AND "STANDARD DEVIATION" LOCATIONS FOR MONITORING THE BEHAVIOR OF A FIELD ?

- WHAT ARE THE CRITERIA FOR CHOSING A DETERMINISTIC RATHER THAN A MIXED DETERMINISTIC - STOCHASTIC EQUATION ?

- FOR A GIVEN PROCESS OR OBJECTIVE, WHAT ARE THE CRITERIA FOR CHOSING A PARTICULAR REV AND SAMPLING SCHEME ?

DETERMINISTIC VERSUS STOCHASTIC EQUATIONS

SOIL WATER

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K \frac{\partial H}{\partial z}\right]$$

$$\boxed{\begin{array}{l} \theta = \theta_o(z,0) \\ \frac{\partial H}{\partial z}(0,t) = 0 \\ \frac{\partial H}{\partial z}(L,t) = -1 \end{array}}$$

$$K = K_o \exp[\beta(\theta - \theta_o)]$$

(CRP-WATER)

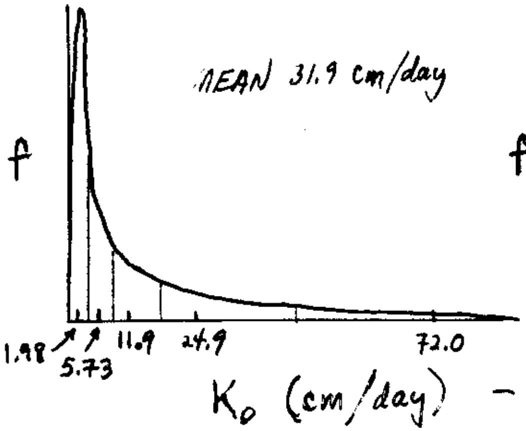
DETERMINISTIC MEAN

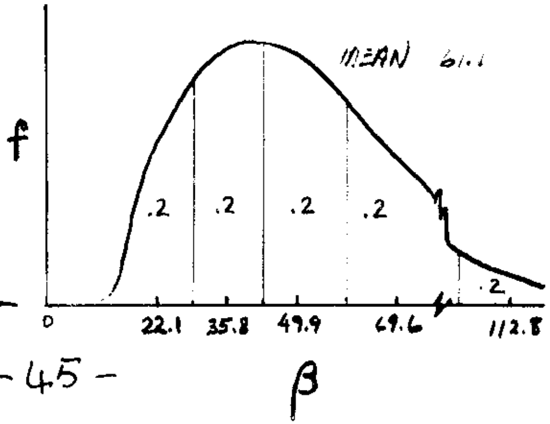
$$\bar{J}_w = \frac{[illegible]}{1 + \frac{[illegible]\, t}{L}} = \frac{31.9}{1 + \frac{(61.1)(31.9)t}{180}}$$

$$= 2.69 \text{ cm/day}$$

STOCHASTIC MEAN

$$\bar{J}_w = \int_0^\infty \int_0^\infty J_w f(K_o, \beta)\, dK_o\, d\beta$$





FOR $t = 1$ day

$P = 0.2$

β \ K_o	1.98	5.73	11.9	24.9	72.0
22.1	1.59	3.36	4.84	6.14	7.32
35.8	1.42	2.68	3.54	4.19	4.71
49.9	1.28	2.21	2.77	3.15	3.44
69.6	1.12	1.78	2.12	2.34	2.50
112.8	0.984	1.25	1.41	1.50	1.56

$P = 0.2$

$$J_w = \frac{1.98}{1 + \frac{(22.1)(1.98)1}{180}} = 1.59$$

$$\bar{J}_w = \sum_{i=1}^{25} J_{w_i} P_i = 1.59(0.04) + 3.36(0.04) + \cdots$$
$$\cdots + 1.56(0.04) = 2.76 \text{ cm/day}$$

$$P_i = (0.2)(0.2) = 0.04$$