



REMOTE SENSING PROJECT
PHASE C - FINAL REPORT

AGRICULTURE

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REMOTE SENSING PROJECT

PHASE C - FINAL REPORT

AGRICULTURE

by

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This report comprises 10 papers containing results of scientific cooperation between "Instituto Agronômico de Campinas" from the Agriculture Secretary of the State of São Paulo and National Commission for Space Activities (CNAE). This cooperative program is part of a multidisciplinary research program in Remote Sensing coordinated by CNAE. This publication is authorized by the Scientific Director of CNAE.


Fernando de Mendonça
Scientific Director

BRAZILIAN AGRICULTURAL REMOTE SENSING RESEARCH PPOGRAM

PHASE C - FINAL REPORT

SEPTEMBER 1970

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I - INTRODUCTION

Following the January 1970 SERE-NASA meeting at the National Research Council a new phase of work has begun. This new phase, named interphase C-D was aimed to develop fundamental research based upon available equipment and imagery data.

Most effort was concentrated on the more important Test Site 801 "Santa Eliza" Experimental Farm in Campinas (Lines 3 and 5 of the operational flight).

Eleven research papers have been produced and are presented below. The papers are divided as follows:

- 6 practical
- 1 theoretical-practical
- 4 theoretical

These papers are fundamental for the Phase D work programme in which the CNAE "Bandeirante" aircraft and other facilities will be used next year.

The first seven papers are based upon light density measurement and correlation studies with respect to:

- Field measurements
- Coffee spacing
- Soils
- Coffee yields
- Soil Nutrient Status
- Land Use Capability
- Yield Prediction
- Primary yield evaluation

Also four theoretical studies were completed related to synoptic studies of the environment specifically related to:

- Tolerance Theory
- A System for Crop Boundary and Natural Vegetation
- Boundary Recognition

I - PRACTICAL RESEARCH

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BRAZILIAN REMOTE SENSING PROGRAM

PRACTICAL RESEARCH PAPER Nº 1/70

AGRICULTURE

INVESTIGATION INTO THE CORRELATION OF GROUND TRUTH
LIGHT REFLECTANCE AND IMAGE DENSITY ON COLOUR EKTA
CHROME FILM.

Test Site 801 - July, 1969 flight

Hector W. McNeill
(CNAE - Project SERE)
A.G. de Souza Coelho
(CAI - Campinas)

1. SUMMARY

The light density passing through the colour transparency of the Campinas test site at St. Eliza was compared with the ground truth assessments for the percentage of light reflectance on the different colour panels during the time of the operational flight.

Given the constraints of equipment and resolution requirements of the sampling procedure, the results were very encouraging. There exists a strong correlation between the field results and the image point samples.

2. METHOD

Light intensity readings were taken through aluminium foil masks over the colour panels. Each reading represented the combination of two or four panels in aggregate. The reason for this was the difficulty of making an aluminium foil mask which was capable of covering single panels. The best that could be achieved was a resolution cell which was equivalent in area to about 150% of a panel.

The readings were taken under the same conditions of light table intensity and instrument adjustment.

3. RESULTS

Ten point samples were taken and no replications were made.

Table 1 shows the analytical results obtained by programming a 3.500 Burroughs computer.

The density records (d) together with the weighted mean of the ground truth assessments (g) are shown in Table 2.

Table 2 - Density Records (d) and Ground Truth Assessments (g)

<u>d</u>	<u>g</u>	<u>d</u>	<u>g</u>
38	39.61	30	17.87
52	58.27	55	49.04
39	19.80	49	27.80
50	48.94	35	33.43
48	39.06	49	38.44

The correlation between d and g was found to be:

$r = 0.73$ significant at the 2.5% level.

The regression of d on g was found to be:

$$d = 0.472g + 26.95$$

Table 1 - Analytical results obtained by a programming 3.500 Burroughs Computer

```
10 X-Values      1 = Input Code, Transformation Codes 0,0
```

For this programme: $y = d$
 $x = g$

SS = Sum of Squares
DF = Degree of Freedom
MS = Mean Square
FS = F

The regression equation is $Y = 26.94657 + .47154 X$

Mean of X = 37.22600 Mean of Y = 44.50000 Total N = 10.

Variance of X = 167.97088 Variance of Y = 69.16667

95.0 Percent confidence limits for the slope are .1084 and .8347

ANALYSIS OF VARIANCE

SOURCE	SS	DF	MS	FS
Groups	622.5000	9	69.1667	-9999.9999
Linear	336.1302	1	336.1302	9.3901
Dev.	286.3698	8	35.7962	-9999.9999
Error	.0000	0	.0000	
Total	622.5000	9		

SAMPLE NUMBER	X	Y	L1	Y Nat.	L2	Deviation
1	39.61000	38.00000	41.07589	45.62414	50.17240	-7.62414
2	17.87000	30.00000	27.04544	35.37294	43.70043	-5.37294
3	58.27000	52.00000	45.57198	54.42302	63.27406	-2.42302
4	49.04000	55.00000	43.87849	50.07074	56.26298	4.92927
5	19.80000	39.00000	28.53800	36.28300	44.02800	2.71700
6	27.80000	49.00000	34.42905	40.05530	45.68154	8.94471
7	48.94000	50.00000	43.85644	50.02358	56.19072	0.02358
8	33.43000	35.00000	38.03699	42.71005	47.38310	-7.71005
9	39.06000	48.00000	40.85031	45.36480	49.87929	2.63520
10	38.44000	45.00000	40.58564	45.07245	49.55925	3.92756

4. DISCUSSION

The correlation coefficient above is significant but still appears a shade lower than might be expected in such a straight forward comparison. However, the photometer used in the ground truth assessments was sensitive to the infrared region of the spectrum as well as the visible. The film intensities only relate to reflectance values in the visible range.

There was a significant variation in the panel temperatures relating to their different colours (heat balance characteristics) and hence within the infrared range there was a related variation in wavelength within this waveband. The above experiment will be repeated utilising the colour IR film. It is hoped that in this case the correlation coefficient will be higher and that the variation (standard deviation) of the observations about the regression line of d on g will be less.

The standard deviation in the above experiment was calculated to be:

$$S = 6.0$$

5. THE USE OF SUCH INFORMATION

By using the same methodology with different films sensitised to different wavelengths it would be possible to define very accurately the reflectance of terrain within different areas of the spectrum. Since plants, soils and other sensed objects lie in differing areas of the mass spectrum, the filtered films, plus the conversion equations, permit more intelligent typification of the objects concerned. By maximising the correlation coefficient in different wave bands for specific objects

the likelihood of correct classification is also maximised.

6. LIMITATIONS

Although the above experiment is fairly straight forward to carry out, there exist certain complications when application is considered.

In spite of the fact that comparisons within the grounds of films might appear highly significant there is no measure of the variance of density and spectral characteristics which are related to processing.

One reason that this cannot be assessed is that only one sample of films for each waveband exists for each site.

Hence there is a danger that research results achieved in one centre may not be found to be reproduceable elsewhere because knowledge of the processing variance does not exist.

One way of assessing such variations is to take several replications within the same wavebands and testing for a variance with the sample of film gathered. However, a far simpler solution exists to this problem. If the films produced for remote sensing could possess a grey scale relating to processing reactions then the relevant corrections for variance could be made.

Quotation of the "processing value" in scientific research reports would permit intelligent interpretation to be made of research results obtained in different research centres throughout the world operating under variable conditions.

7. CONCLUSION

The above investigation illustrates a method where by it is possible to select optimal film filter combinations

for the sensing of specific objects on the basis of simple regression analysis. It is emphasized that the next step in the method is an inter-film comparison and choice and for this to have any significance from the standpoint of international application and comprehension it is necessary to have an estimate of processing variability. At the present time this does not exist since it is assumed that no such variation exists (especially in the case of automatic processing), or that it is not significant. A method of overcoming this problem is suggested above. Indeed, it might be profitable at this stage attempt to introduce the concept above as an international convention so as to enable relevant corrections to be made on films from various sources.

BRAZILIAN REMOTE SENSING PROGRAM
PRACTICAL RESEARCH PAPER Nº 2/70
AGRICULTURE

INVESTIGATION INTO COFFEE CROP SPACING AND IMAGE
DENSITIES ON COLOUR-EKTA & COLOUR-IR

Test Site 801 - July 1969 flight

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Hector W. McNeill
(CNAE - Project SERE)

1. SUMMARY

Some forty plots of coffee (Coffee arabica) laid out at St. Elisa experimental farm in a randomised block were surveyed utilising Colour Ektachrome and Colour IR images. The images of the plots were tested for light intensity, concluding that the crop spacing significantly affected density readings as did the number of trees per hill.

However, these results were only significant in the case of the Colour IR film (at 2.5% level) whilst with the colour Ektachrome the results were insignificant (50% chance of obtaining such results by chance).

2. METHOD

Using an aluminium foil mask and a standardised light meter, the resolution cell of the mask was made in order to enable the investigator to survey within the plots themselves at random.

3. RESULTS

The following results are only part of those in the process of being calculated since the forty plots within the block represented four separate treatments: Spacing, number of trees per hill, variety, and tree height.

The results below are normalised with respect to tree height and variety so that the remaining variables of significance are spacing and number of trees per hill. All the coffee plots represented below are of the variety "Caturra" and all of them are 40.0 cms height.

Table 1. Spacings and Areas for each Plot

Blocks	Spacings (m)		Area (m ²)
a	1.62	by 0.62	1.0044
b	2.00	by 1.00	2.00
c	2.30	1.30	2.369

Table 2. Colour IR. Related densities for "Caturra" plots with two plants at each hill.

Blocks	Readings from 4 plots				Mean
a	2.40	2.40	2.50	2.20	2.38
b	2.50	2.60	2.30	2.60	2.50
c	3.20	3.10	2.30	2.70	2.83

Table 3. The same readings taken in "Caturra" plots with one plant at each hill.

Blocks	Reading from 4 plots				Mean
a	2.60	2.30	2.60	2.45	2.49
b	2.90	2.35	2.80	2.60	2.66
c	2.85	3.30	3.10	2.75	3.00

The analysis of variance for each of the above series of results proves them to be significant within the 1% to 2.5% range.

The graphical realationships are shown in Fig. 1.

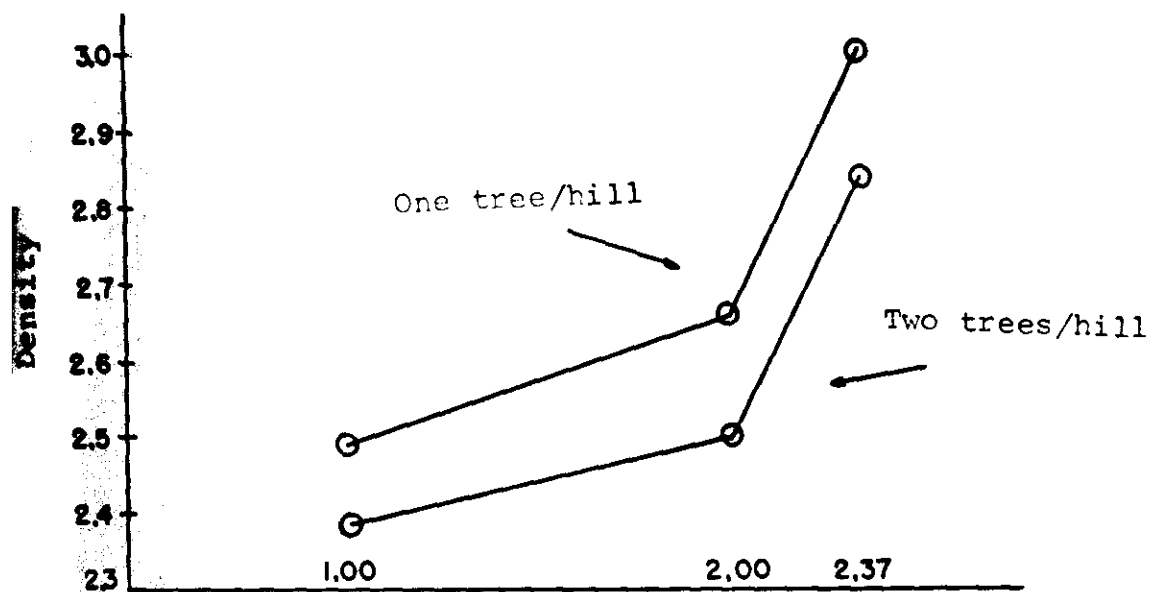


Fig. 1 - Relationship between coffee spacing and trees per hill and density (v. "Caturra").

As can be seen from the above diagram the light densities increase with coffee spacing and also the densities are lower when there are two instead of one tree per hill.

The experiment was repeated with the Colour Ektachrome film but the results were found to be insignificant on the basis of the standard analysis of variance in spite of the fact that the plot of the mean values showed a similar, but less marked, trend as was found with the colour-IR.

4. CONCLUSION

On the basis of density measurements it is possible to discriminate between the number of plants per hill at given spacings in a coffee crop.

Alternatively, at a fixed number of plants per hill it is possible to discriminate different spacings.

These conclusions only relate to Colour IR density readings.

The results of the Colour Ektachrome density readings indicate that this film is not suitable for such applications as discrimination of the above factors.

5. AKNOWLEDGEMENT

The authors thank the Agronomist Sérgio Vasco de Toledo from the Coffee Section of CAI, who provided experimental field data essential for the development of this work.

BRAZILIAN REMOTE SENSING PROGRAM

PRACTICAL RESEARCH PAPER Nº 3/70

AGRICULTURE

INVESTIGATION INTO IMAGE DENSITIES FOR THREE SOIL
TYPES ON COLOUR EKTACHROME FILM

Test Site 801 - July, 1969 flight

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1. SUMMARY

Thirteen bare soil areas were surveyed for image density on colour-ektachrome film. The areas represented three types of soil: Red (highly fertile), Yellow (low fertility), and Bog soil (High Organic Matter).

It was possible, on the basis of densities, to separate the soils into three groups representative of the three soil types.

2. METHOD

Five random samples were taken within each of the bare soil areas through an aluminium foil mask and utilising a light meter to record measurements.

The resolution cell in the mask was made such as to permit this number of random samples to be taken with ease within each bare soil area.

3. RESULTS

The results of the sampling are shown in Table 1, in the form of sample means:

Table 1 - Soils and Relative Densities obtained

SOILS	MEANS							
Yellow	7.30	7.60						
Bog	1.45	3.05	3.00	3.00				
Red	3.83	3.79	4.35	2.70	3.45	4.83	4.15	4.65

As can be seen from Table 1, only few samples were taken in the Yellow soil and Bog areas. The reason for this is that the Bog soils represent only a small area of the total region covered by the operational flight and the Yellow soils only have few bare fields since the majority of the Yellow soil region is in pasture.

Fig. 1 shows the graphical results:

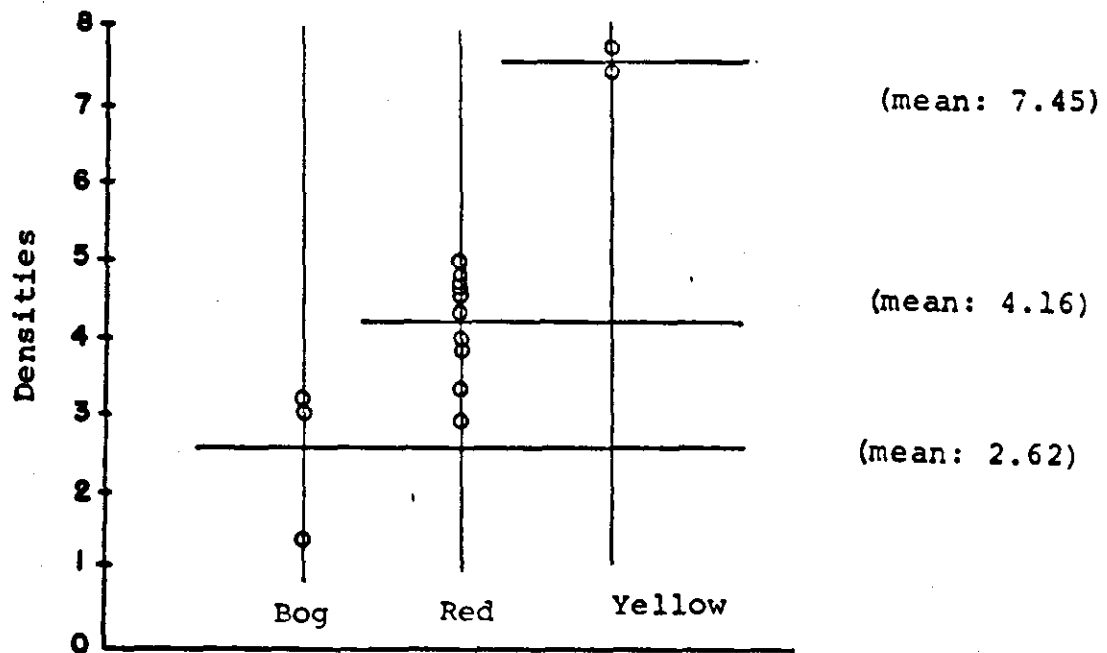


Fig. 1 - Graphical results for the achieved measurements.

Since the mean square or variance between soils was found to be 17.4 and within the soils 1.60 the variance ratio of 10.8 shows a significant difference between the soil density readings (at 1% level).

However, in practice, these variances however significant in statistical terms do not necessarily permit an easy discrimination between soils since there is a large degree of overlap in their ranges, especially the Bog and Red soils. Ideally the situation is shown in Figure 2:

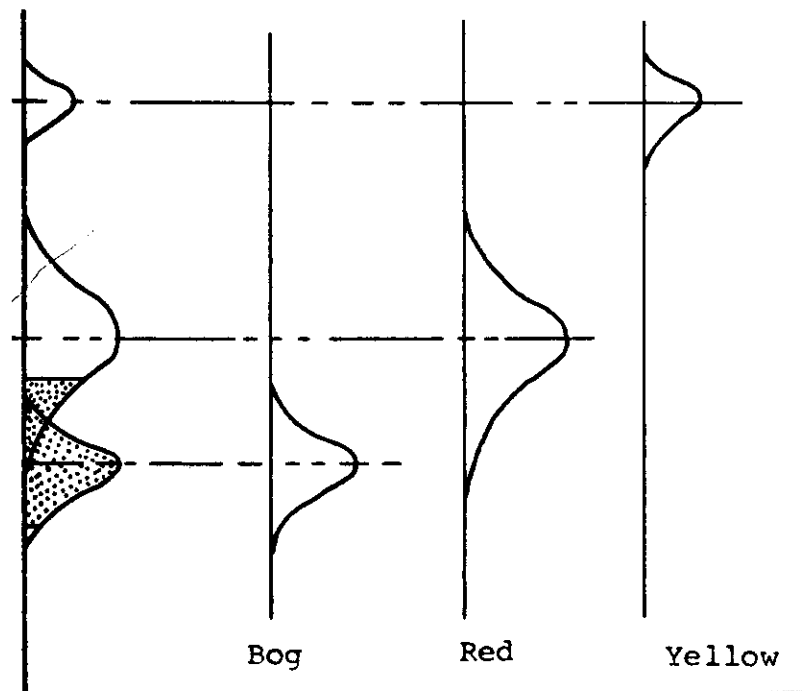


Fig. 2 - Overlapping representation for two types of soil.

If the density means were more dispersed such overlap would not occur or at least would be reduced. The above experiment will be repeated using Colour-Infrared film and the multiband images in an attempt to achieve this wider separation.

4. CONCLUSION

Whereas using the above technique it was possible to separate yellow soil from red and bog soils it was found that there was considerable overlap between the black bog soil densities and the red soil densities records.

In an attempt to simplify the separation of these soils the experiment will be repeated with Colour-IR and the multiband films.

BRAZILIAN REMOTE SENSING PROGRAM
PRACTICAL RESEARCH PAPER Nº 4/70
AGRICULTURE

INVESTIGATION INTO THE RELATIONSHIP BETWEEN IR
COLOUR FILM DENSITIES FOR COFFEE PLOTS AND
YIELDS.

Test Site 801 - July, 1969 flight

A. G. de Souza Coelho
(CAI - Campinas)

Hector W. McNeill
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1. SUMMARY

Forty coffee plots were surveyed on the basis of light density within each separate plot. The main treatment variations for the plots concerned were spacing, variety, height and the number of trees per hill.

The relationship between bean yields and the image densities were investigated.

The results confirm the theoretical basis of crop spacing and yield performance on a field rather than plant basis.

The empirical outcome is that there exists an intermediate density value at which physical yields are higher than those associated with higher or lower density values.

2. METHOD

Light density readings were taken within plots through a standard aluminium mask using a standardised light meter.

3. RESULTS

The density readings of the images vary with yield and crop spacing as well as for the number of trees per hill as shown in Figure 1.

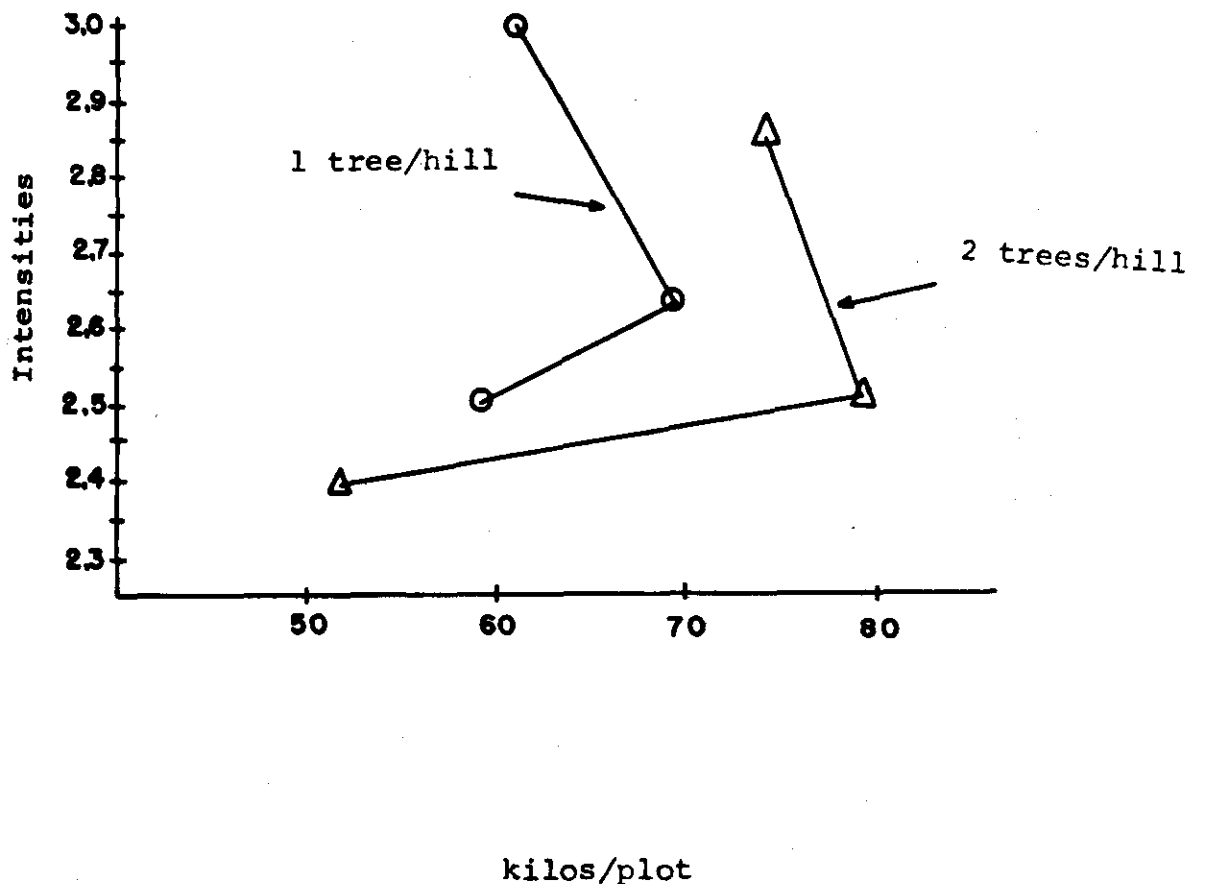


Fig.1 - Relationship between image density and the two variables, yield and number of trees per hill.

As can be seen in Figure 1 higher yields are achieved at intermediate intensity values. On a theoretical basis this is predictable since per plant yield increases to a peak with spacing whilst the spacing effect is to disperse the individual plants over a wider and wider area. For this reason the actual yield per hectare will increase with spacing to a peak and then fall with the remaining increases in spacing. This is illustrated in the second figure.

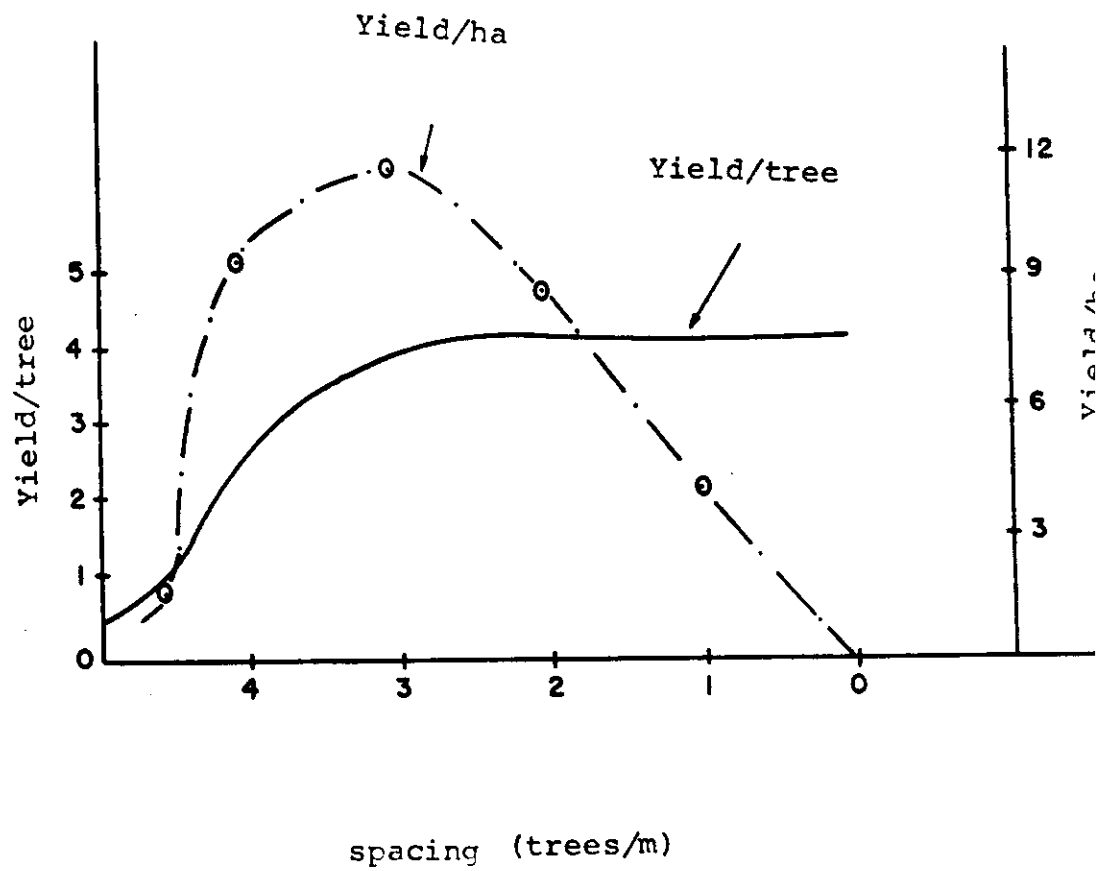


Fig. 2 - Theoretical projections for yield per hectare with different spacings.

Figure 3 shows the relationship between the theoretical curves and the spot readings achieved in this investigation.

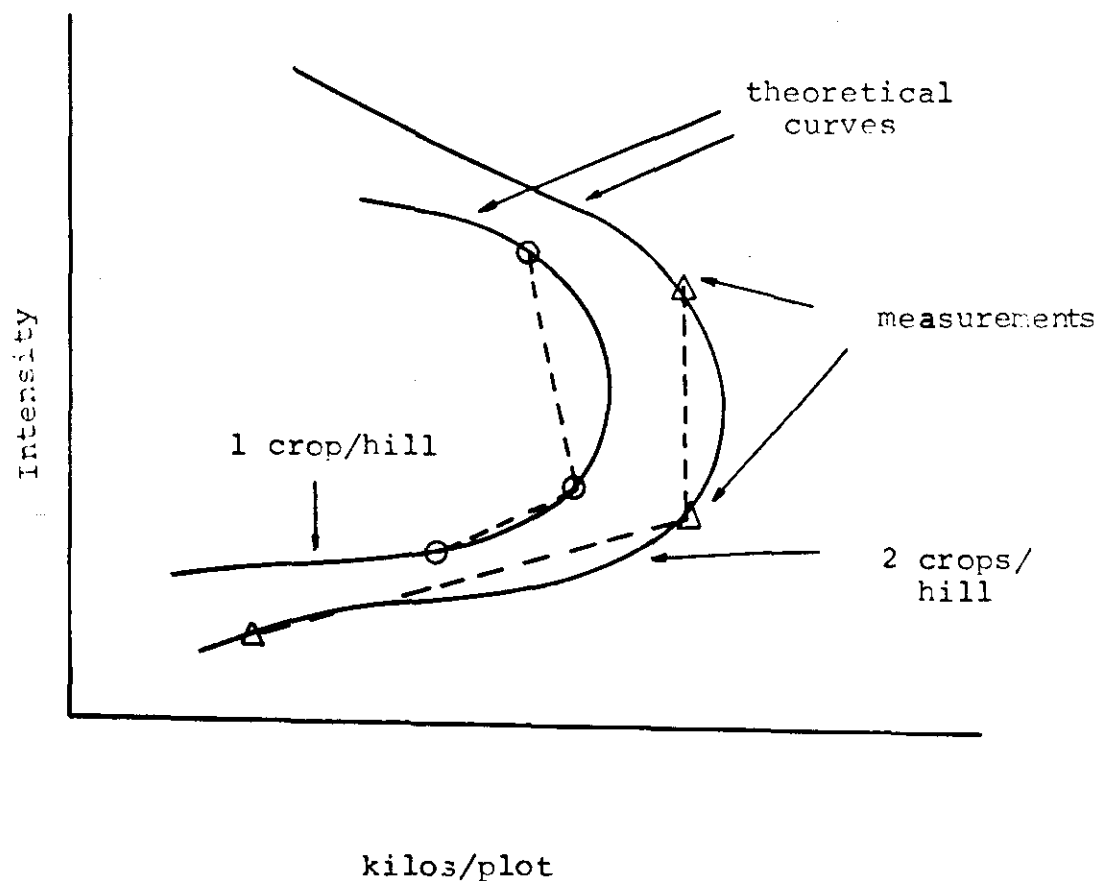


Fig. 3 - Relationship of spot readings in this investigation to theoretical curve forms.

Since the spacings of the plots investigated were at three standard levels it was not possible to achieve a continuous curve as shown in Fig. 3 in theoretical form.

4. SIGNIFICANCE

The results indicate that the light density readings provide a useful indication of yield based on the knowledge of the spacing of the crop (See Practical Research No 2, 70).

5. APPLICATIONS

The capacity to predict yield on the basis of light intensity readings would provide planners and marketing organizations to foresee shortages etc. in the post-harvest months before the time of harvest.

Also, general geographical measures of yield distribution can aid planners to isolate regions with inefficient production.

Such knowledge aids effective corrective action either through economic policy measures or more effective agricultural extension services.

6. LIMITATIONS

Variations in fertility, soil conditions, variety etc. all limit the case which the above system of yield prediction can be applied. However, there is hope that the data which we have at present will clarify the major constraints on such a system and suggest means whereby these can be overcome.

7. AKNOWLEDGEMENT

The authors thank the Agronomist Sérgio Vasco de Toledo from the Coffee Section of CAI who provided experimental field data essential for the development of this work.

BRAZILIAN REMOTE SENSING PROGRAM
PRACTICAL RESEARCH PAPER Nº5/70
AGRICULTURE

SOIL NUTRIENT STATUS STUDIES BASED ON IR-COLOUR FILM
IMAGE DENSITIES OF COFFEE PLOTS

Test Site 801 - July, 1969 flight

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1. SUMMARY

Fifty four coffee plots (Coffee arabica) were surveyed on the basis of IR image densities. The coffee surveyed had undergone a series of fertilizer treatments as a part of the regular research activities of CAI. Use was made of the variations in image density to isolate the main relationships with both soil fertility and coffee yield. The results indicate a capacity to discriminate low nutrient soils from high nutrient status soils with ease. The overall relationship between the intensity and yield was also traced and proves to be of great utility in defining the parameters of the coffee crop production surface in terms of remote sensing variables.

2. METHOD

Light density readings were taken utilizing an aluminium foil mask and a light meter. Plots were surveyed so as to sense within plots so as to remove nutrient fringe effects. The resolution cell of the sensing equipment was designed so as to make this possible.

3. RESULTS

The relationship between the light intensity and nutrient status can be seen in Figure 1.

As can be seen intensity increases with falling nutrient status of the soil.

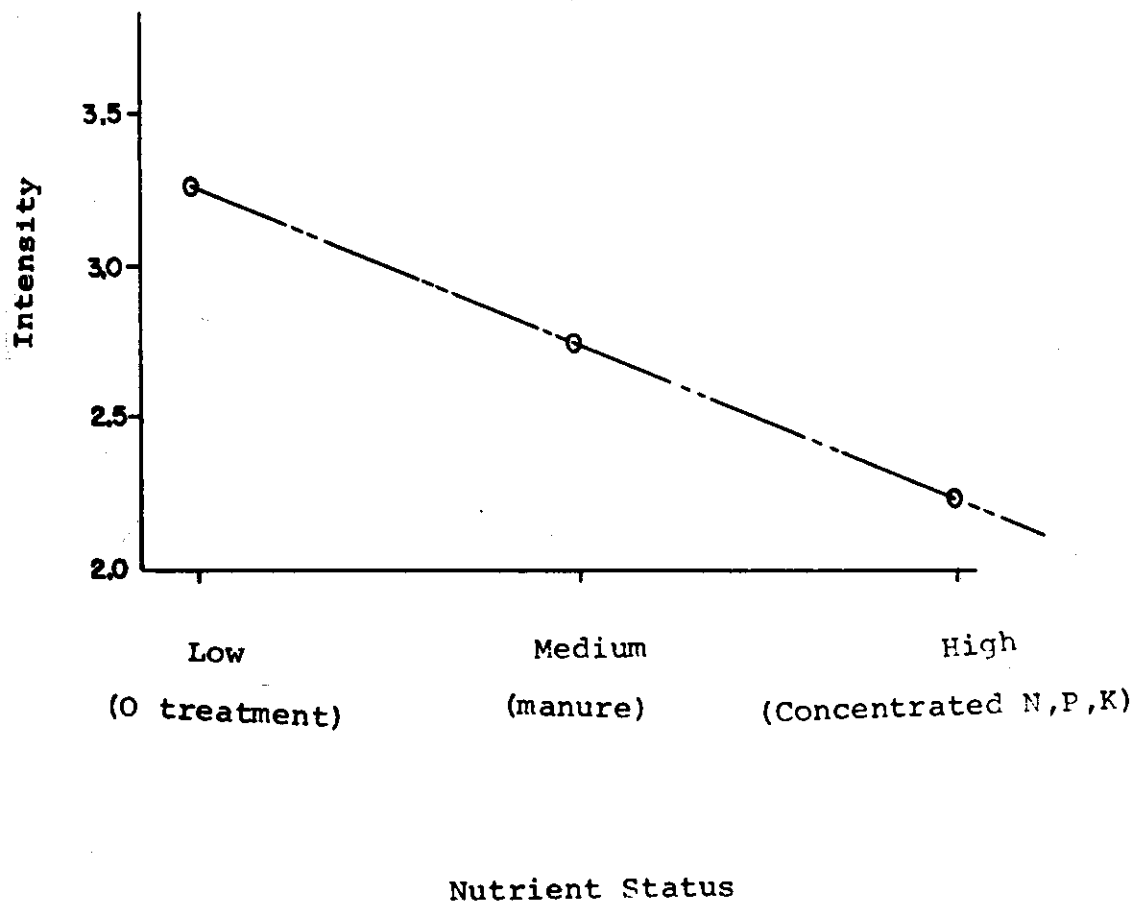


Fig.1 - Relationship between fertility and light intensity.

Similarly the relationship between yields and in tensity is shown in Figure 2.

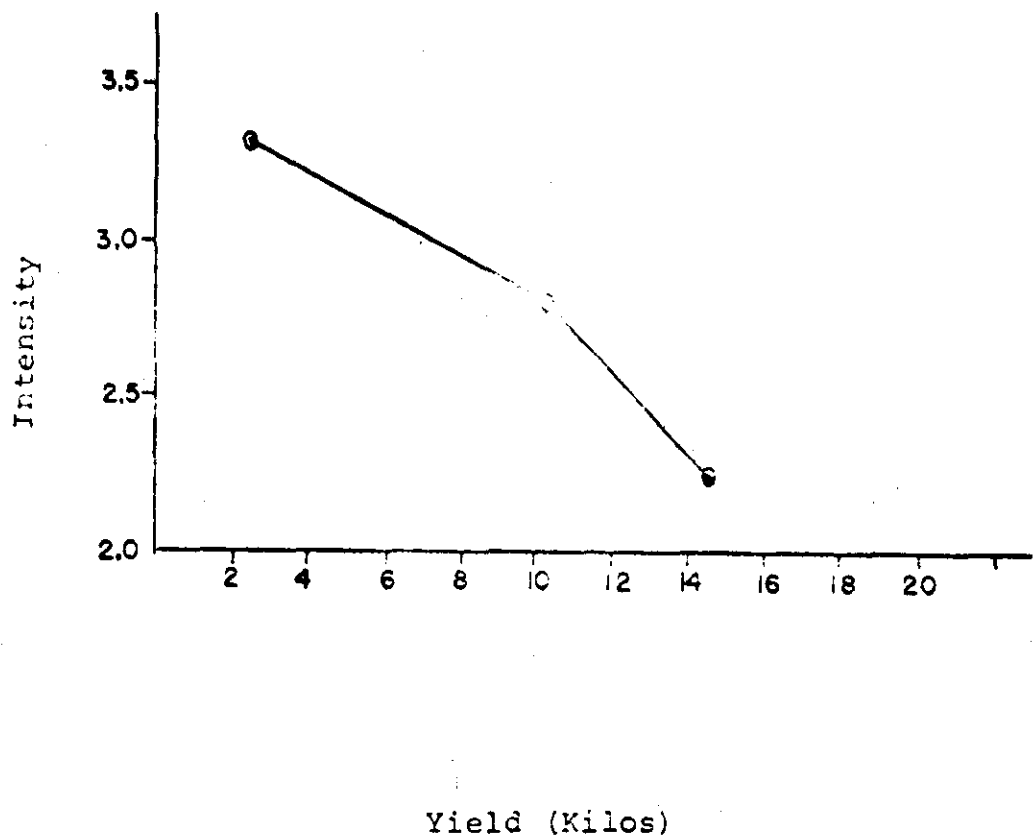


Fig. 2 - Relationship between light intensity and yield.

Hence in order to appreciate the effect of nutrient status upon the crop yield and intensity at the same time it is possible to consider the relationship in three dimensions as illustrated in Fig. 3.

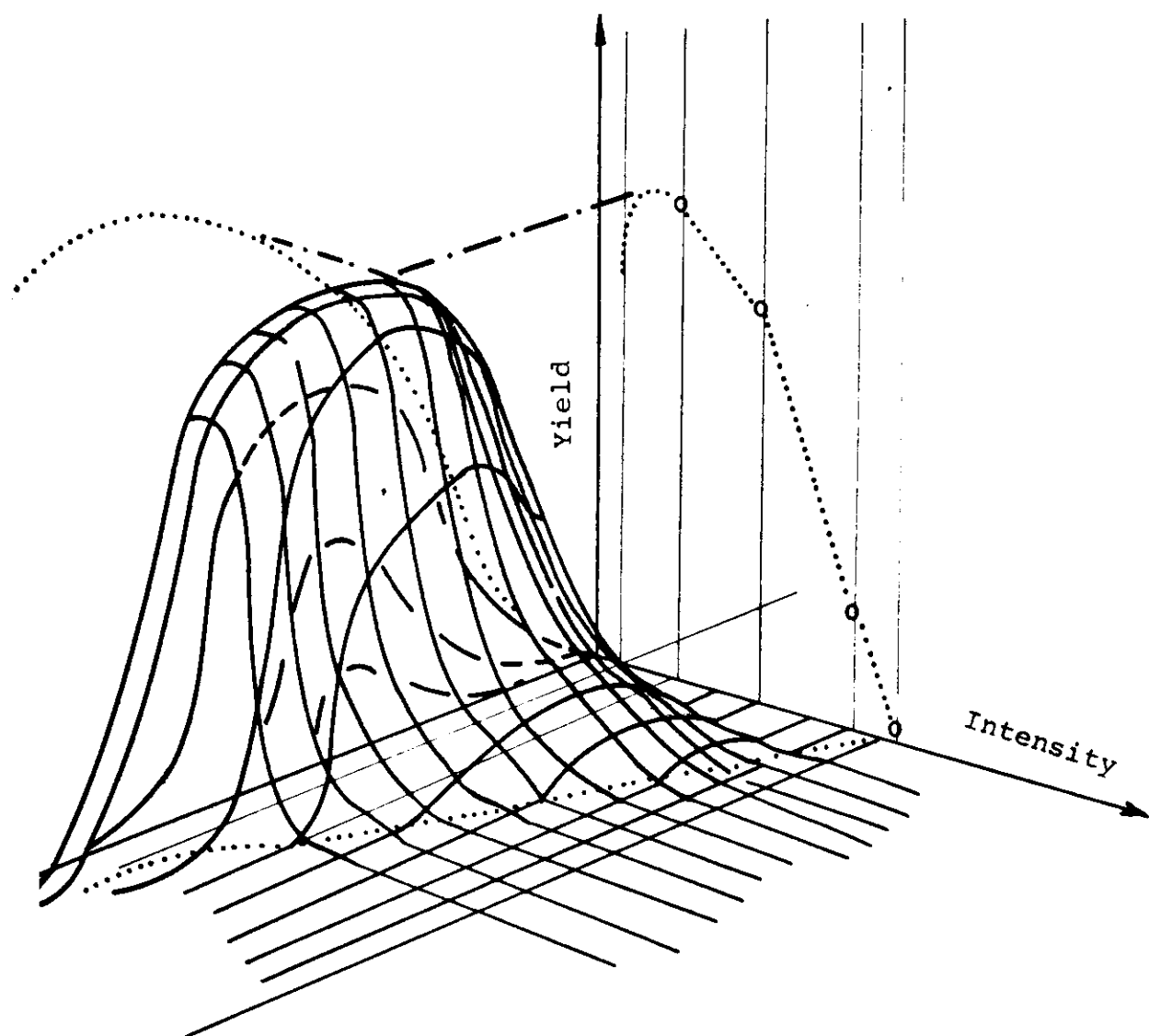


Fig. 3 - Fertility effect on Crop yield and light intensity.

The overall effect therefore is for nutrient status to shift the mean yield for a given intensity or spacing to a higher level.

In other words the production surface (Fig.3) represents the variation in yields which can occur with a given spacing and intensity.

Given that differentiation can be obtained between intensity relating to spacing and intensity relating to actual plant condition then Figure 3 represents the correction function for yield prediction associated with light intensity variations.

4. AKNOWLEDGEMENTS

The authors thank the Agronomist Sérgio Vasco de Toledo from the Coffee Section of CAI who provided experimental field data essential for the development of this work.

BRAZILIAN REMOTE SENSING PROGRAM

PRACTICAL RESEARCH PAPER Nº 6/70

AGRICULTURE

REMOTE SENSING IMAGERY AS APPLIED TO SURFACE GROUND
TEMPERATURE ESTIMATION

Test Site 801 - July, 1969 flight

Hilton S. Pinto
A.G. de Souza Coelho
(CAI - Campinas)

1. SUMMARY

The surface ground temperature is of fundamental importance, mainly to agronomic and hydrologic fields, considering that of the energy balance depends upon the heat flux and water evaporation in plants and in soil.

This paper reports studies done in order to verify the possibility of terrain temperatures using a light table and transparencies, followed by comparisons with ground temperature measurements.

A multiband set of imagery, obtained with four KA-62 cameras and Plus-X Aerographic 2402 film, was taken with the following filters: 47 Blue, 477 mμ ; 57 Green, 530 mμ; 25 A Red, 617 mμ and 89B IR, 750 mμ , besides Infrared Scanner Imagery RS 14, 8-14μ . The imagery set was obtained by the NASA 927 (Lockheed NP 3A) aircraft in July 1969, over the test site 801, lines 3 and 5, corresponding to Campinas. "Santa Elisa" Experimental Station.

An ISCO spectroradiometer was used to obtain readings and the application of linear regression of the type $Y = a + bX$ gave a highly significant correlation coefficient ($r = 0.92^{**}$) for the Infrared Scanner Imagery.

On the other hand, the multiband imagery set showed no significant correlation.

2. INTRODUCTION

The ground surface temperature assessment, as for soils and water, are of basic importance for applied scientific fields such as Agriculture, Forestry and Hydrology, where the energy balance at the surface level has a high correlation

Table 1 - Multiband Data

FILM	FILTEP	WAVEBAND
Plus-X Aerographic 2402	47 (Blue)	477 m
" " " "	47 (Green)	530 m
" " " "	25A (Red)	617 m
Infrared Aerographic SO-246	89B	750 m
IR Scanner Imagery RS-14	-	8-14

For the measurements of light density a light-table was used with a emission spectrum as shown in Fig.1.

An ISCO spectroradiometer was used (Model S.R., calibrated from 0 to 10) to make measurements of light percentage through sample areas in the transparencies, (regardless of the wavelength.

The sample areas in the transparencies were the same as those in which ground-truth surface temperature assessments were made and were as follows:

- Area 1. "Caturra" pruned coffee variety, 1.62 x .62 meters spacing, two trees per hill and tree average height of 1.70 meters.
- Area 2. Idem, 2.30 x 1.30 meters spacing, two trees per hill and tree average height of 1.30 meters.
- Area 3. Plowed and well prepared soil.
- Area 4. Young corn crop with .30 cm of height.
- Area 5. Field with cotton crop debris.
- Area 6. Water surfaces (reservoir)

Using available and right equipment it was made temperature assessments for each of the above areas.

Thermocouples were used for coffee leaf (areas 1 and 2) temperature assessments based upon an average for 12 leaf sample.

with the sensible heat flux and water evaporation.

In the net energy (N) estimation, the surface temperature is one of the most important microclimatic parameters. Any object with a temperature above -273°C (0°K), has a long-wave radiation ($8-13\mu$ for natural surfaces) according to the Stefan-Boltzmann Law ($W_b = \sigma T^4$).

From the above emission, plus the short-wave radiation from the sun ($.3 - 3\mu$), plus the albedo of the surface (R), plus atmospheric emission, will depend the net energy (N) available to the heat transfer and evaporation of the surfaces.

The net radiation (N) would be expressed as follows:

$$N = Q_y(1-R) - \sigma(T_s^4 - T_a^4)$$

where:

Q_y = sun short-wave radiation ($\text{cal.cm}^{-2}.\text{min}^{-1}$)

R = Albedo of the surface

σ = Stefan-Boltzmann constant ($.827 \times 10^{-10}$
 $\text{cal.cm}^{-2}.\text{min}^{-1}.\text{ }^{\circ}\text{K}^{-4}$)

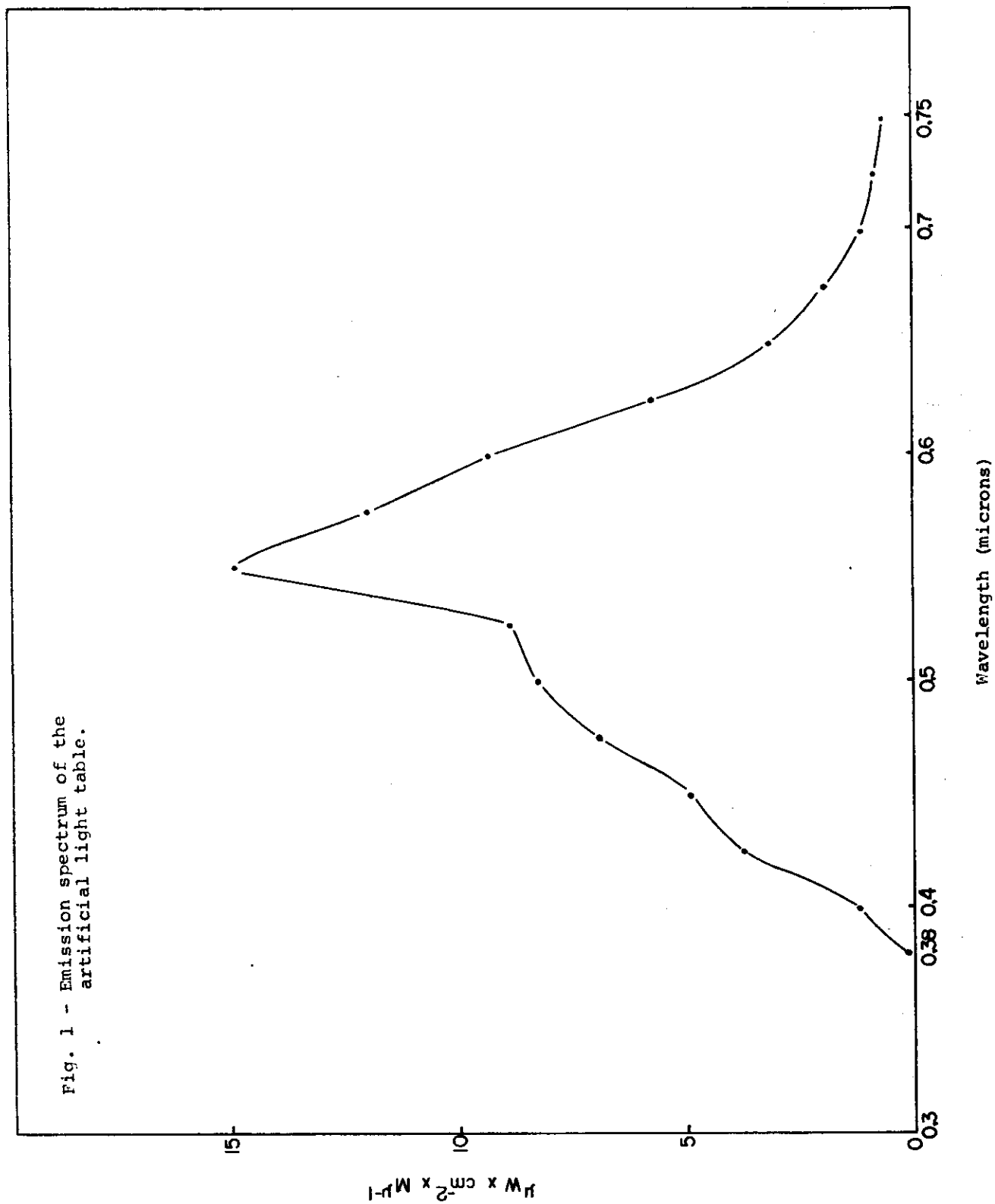
T_s = Surface temperature ($^{\circ}\text{K}$)

T_a = Air temperature ($^{\circ}\text{K}$)

In this research the authors have studied the possibility of T_s determination using remote sensing imagery, with the aim of avoiding field measurements, a difficult task for large areas.

3. DATA COLLECTION AND RESULTS

The NASA aircraft flight over the Test Site 801, Campinas Farm, in June 17, 1969, provided a multiband imagery set as shown in Table 1.



In areas 3, 4 and 5 Foxboro Thermographs were used with sensible heads covered with a slight quantity of sieved soil of the same type.

Finally, water surface temperature in area 6 was taken with a special thermometer.

Table 1 presents the obtained assessments for specific imagery.

4. STATISTICAL CORRELATION BETWEEN TEMPERATURE AND IMAGERY LIGHT TRANSMISSIVITY

The data analysis considering the above parameters was made based in the linear regression of the type $Y=a+bX$.

The surface temperature (T) was measured and the imagery transmissivity of light (L) from a light-table source.

The four multiband camera data showed no significance with a high point dispersion.

The only imagery with correlation coefficient (r) was the thermal one, that is, the scanner data.

Hence it was studied in more detailed way the temperature and thermal imagery light transmissivity, getting the regression below, with correlation coefficient $r = 92^{**}$

$$T = 6.32 + 9.70 L \quad (1)$$

As $r^2 = .8359$, it is possible to explain that 83% of the imagery tone is due to the surface temperature.

Table 2 shows the observed temperature values and, the calculation based on equation (1) at the confidence level limit of 5%.

On its turn, Figure 2 shows the obtained regression line.

Table 2 - Observed and Expected Temperature

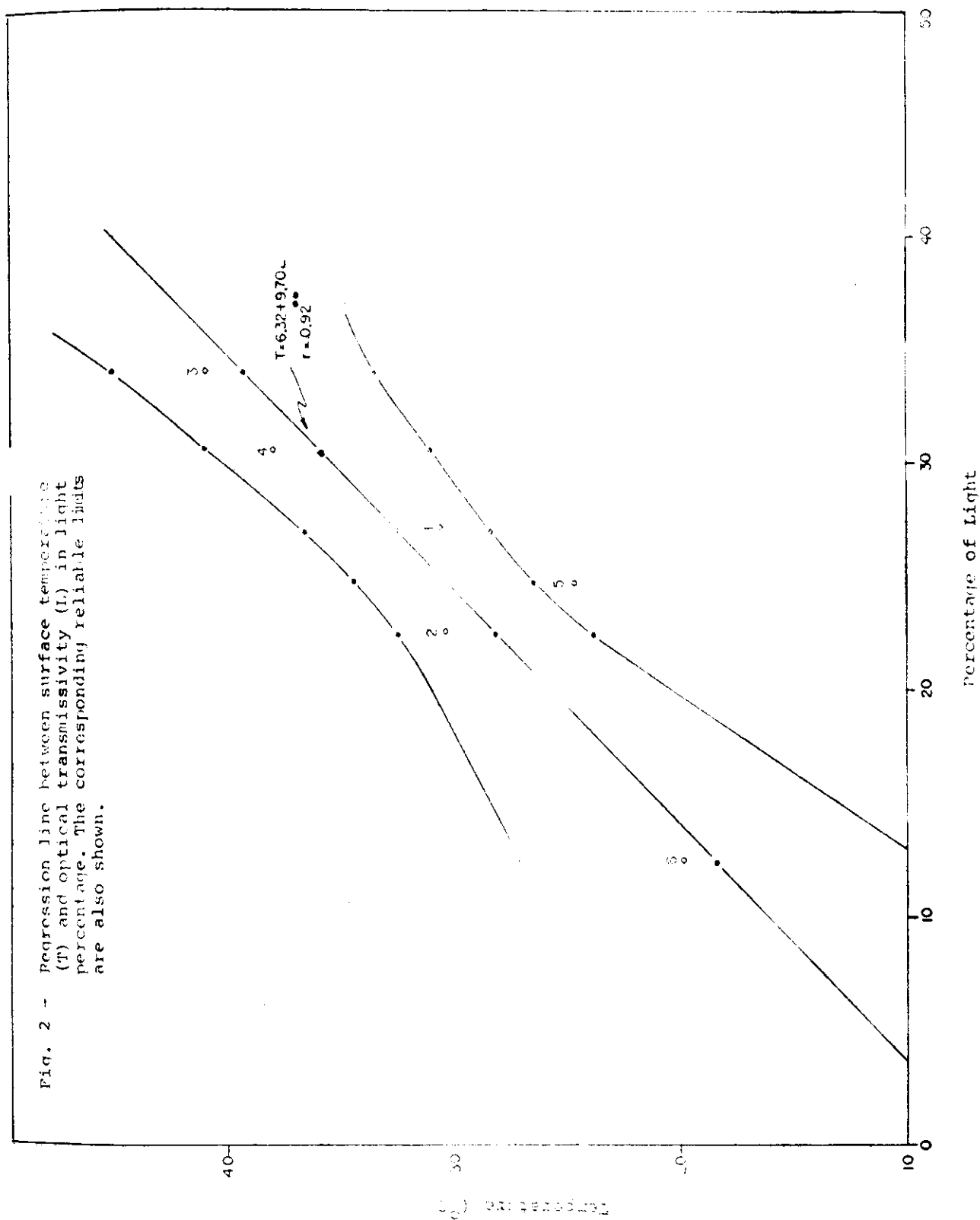
Areas	Observed Temperature °C Y obs.	Expected Temperature °C $T=6.32 + 9.70 L$	Confidence Limit (5% level) $\pm S (Y_i) t_{N-2}$
1	30.50	32.49	± 4.20
2	30.50	28.14	± 4.37
3	41.00	39.30	± 6.64
4	38.00	35.90	± 5.15
5	24.70	30.38	± 4.07
6	19.90	18.44	± 8.60

5. CONCLUSIONS

The linear regression of the type $Y = a + bX$, where Y = Surface Temperature and X = Percentage of Light through the transparencies (Optical Transmissivity), showed correlation when the imagery was thermal one with $Y = 6.32 + 9.70 X$ and $r = .92^{**}$.

Multiband camera system provided with Blue, Green, Red and Infrared filters gave no correlation in the studies done.

New studies can be developed using better data and a greater range of surface temperatures.



ANNEX 1

Table 1 - Ground surface temperature assessments
(°C) and, light imagery transmission (%)

M U L T I B A N D	AREAS	1	2	3	4	5	6
	Surface Temperature	30.5	30.5	41.0	38.0	24.7	19.9
	TRANSMISSION OF LIGHT (%)						
	47 Blue filter (477 mμ)	3.0	2.5	3.0	3.5	4.0	3.5
	57 Green filter (530 mμ)	8.0	8.0	7.0	9.8	10.0	10.2
	25A Red filter (617 mμ)	8.5	7.0	12.5	12.5	13.0	10.0
	89B IR Filter (750 mμ)	9.0	10.5	2.5	4.5	4.5	0.5
	Scanner Imagery RS-14 (8-14μ)	27.0	22.5	34.0	30.5	24.8	12.5

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II - THEORETICAL-PRACTICAL
RESEARCH

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BRAZILIAN REMOTE SENSING PROGRAM

THEORETICAL-PRACTICAL RESEARCH PAPER Nº 1/70

AGRICULTURE

THE BASIS OF FIELD YIELD PREDICTION - A STUDY OF
THE PARAMETERS INFLUENCING THE PRODUCTION SUR -
FACE OF A CROP FROM THE STANDPOINT OF REMOTE
SENSING DATA.

(Based upon Practical Papers Nos. 2 & 4)

Test Site 801 - July, 1969 flight

Hector W. McNeill
(CNAE - Project SERE)

A.G. de Souza Coelho
(CAI - Campinas)

1. SUMMARY

This paper attempts to aggregate previous research results (Practical Research Papers Nos. 2/70 and 4/70) so as to place the individual results obtained in a theoretical perspective.

The overall result is a model with three dimensions incorporating concepts of spacing, light intensity, yield and the number of trees per hill.

2. GENERAL RESULTS OBTAINED PREVIOUSLY

Two basic relationships were obtained from Practical Research Paper No 2/70 and No 4/70. These are summarised in graphical form in Figures 1 and 2.

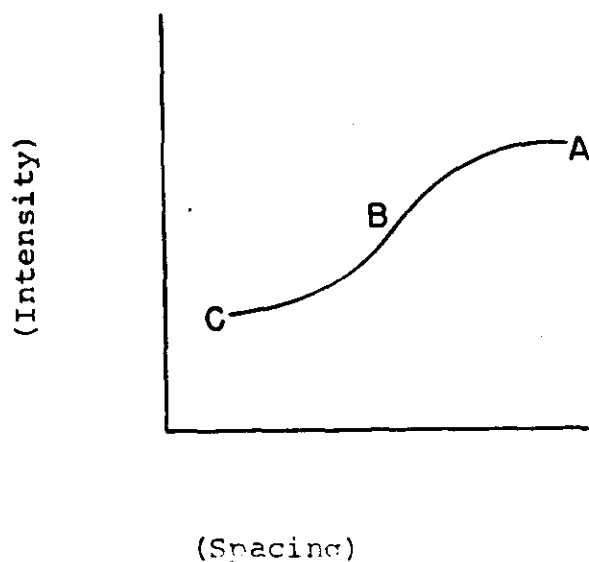


Fig. 1 - Relationship between light intensity and crop spacing.

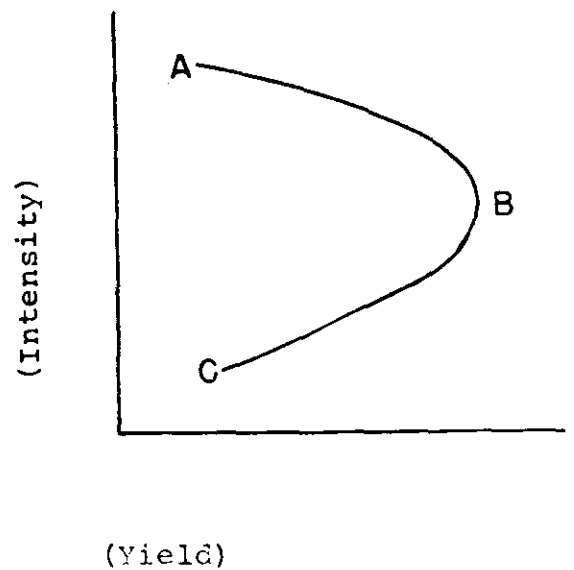


Fig. 2 - Relationship between light intensity and yield

These two graphs can be combined along the light intensity axis so as to form a three-dimensional model. This is illustrated in Figure 3.

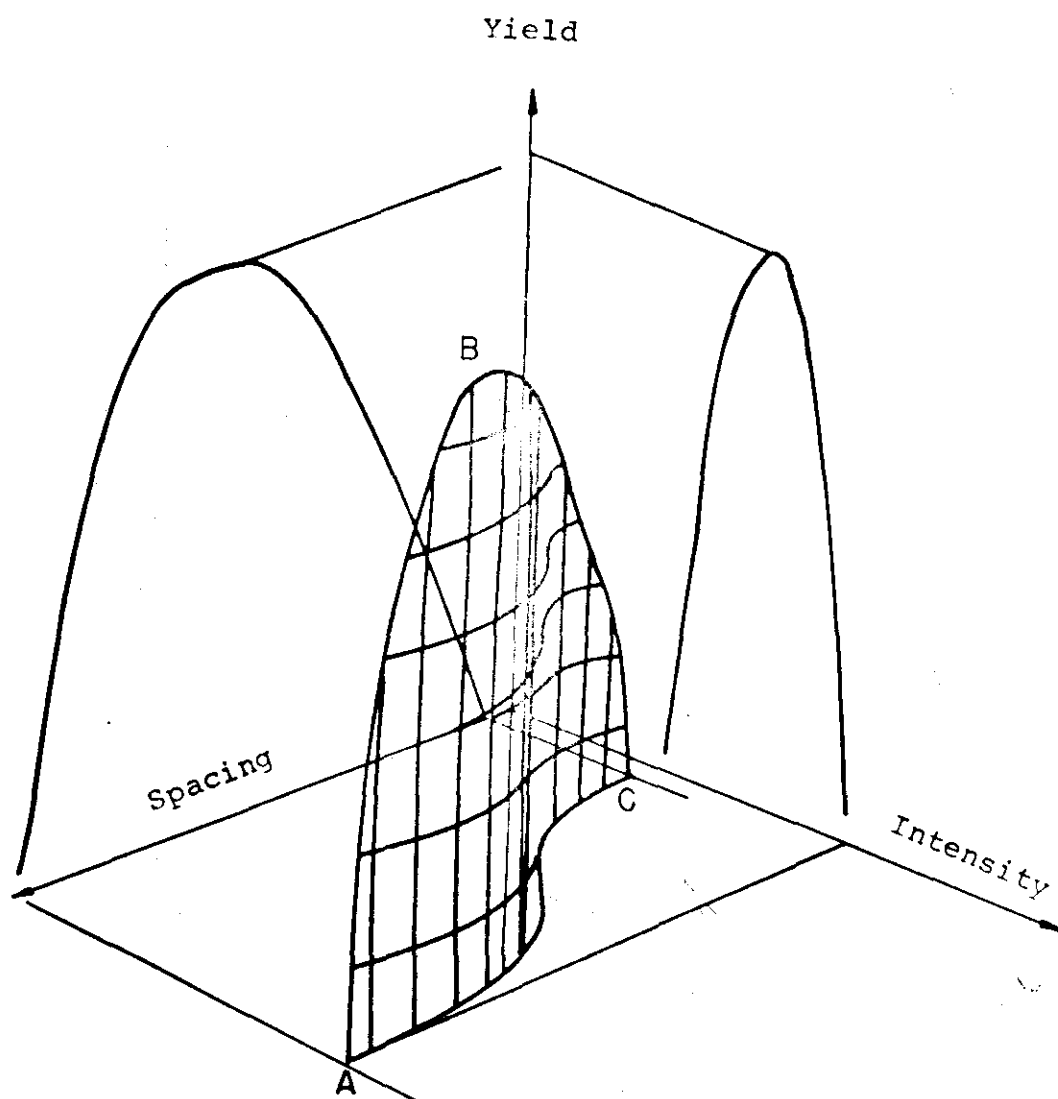


Fig. 3 - The three-dimensional relationship between Yield, light intensity and crop spacing.

Figure 3 is based on spot readings which help to indicate the general shape of a single filament in the production surface on the crop concerned. In fact all readings taken would occur on the parabolic shaped line ABC.

Figures 1 and 2, in two dimensions, are the simple projections of the above three-dimensional function onto the Yield/Intensity plane or onto the Spacing/Intensity plane. The projection of the curve onto the Spacing/Yield plane would be as outlined in Figure 3.

The next stage in the discussion is to develop the rest of the crop production surface without the aid of actual empirical figures. However, some simple reasoning, based on the few figures we possess, is sufficient to form an impression of the actual form.

Returning to the two dimensions, consider the effect of varying numbers of trees per hill or relative sparcity of vegetal growth within trees. With more trees per hill the intensity of image light transmitted will fall until it reaches a constant level which simply represents solid vegetation. Similarly as trees per hill fall and vegetation becomes more sparse the intensity readings will reach another higher level asymptotically which represents the bare soil reflectance (intensity). Hence this can be summarised in Figure 4.

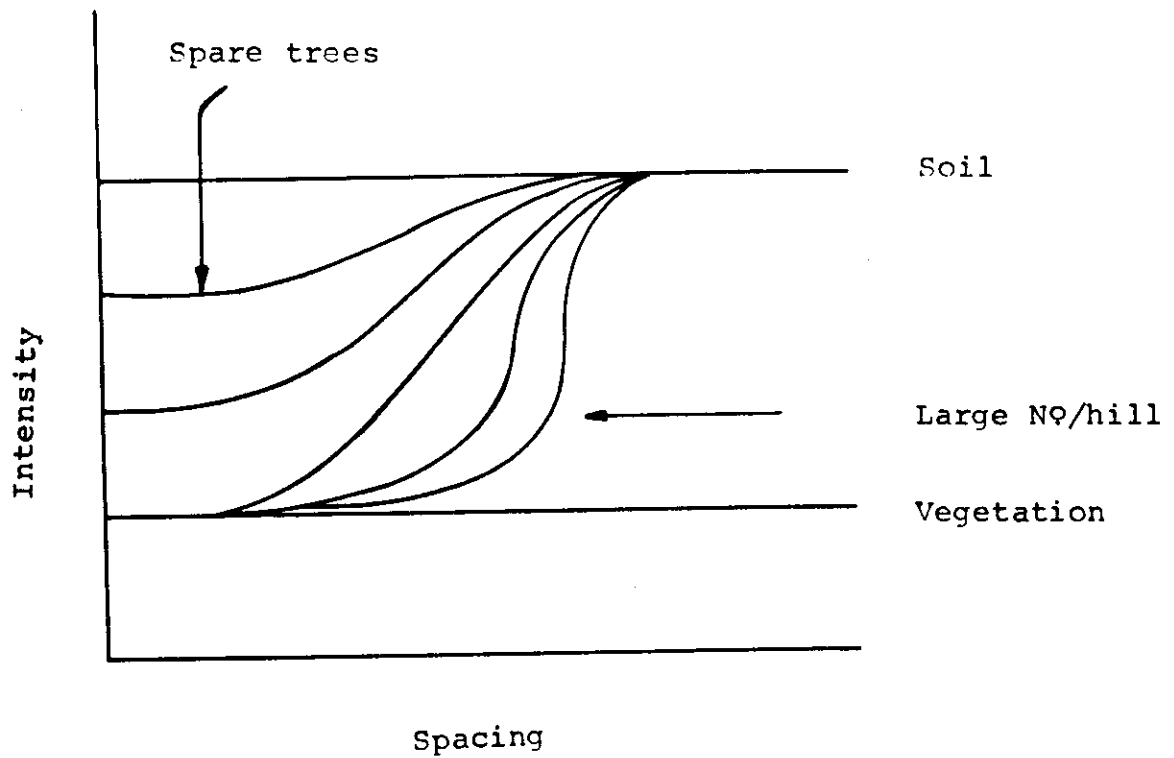


Fig. 4 - Relationship between light-spacing intensity for bare soils (large dispersion) and solid vegetation (maximum vegetal concentration).

Considering the same diagram but now considering associated yields on the various lines drawn it is possible to form an idea of the final form of the production surface.

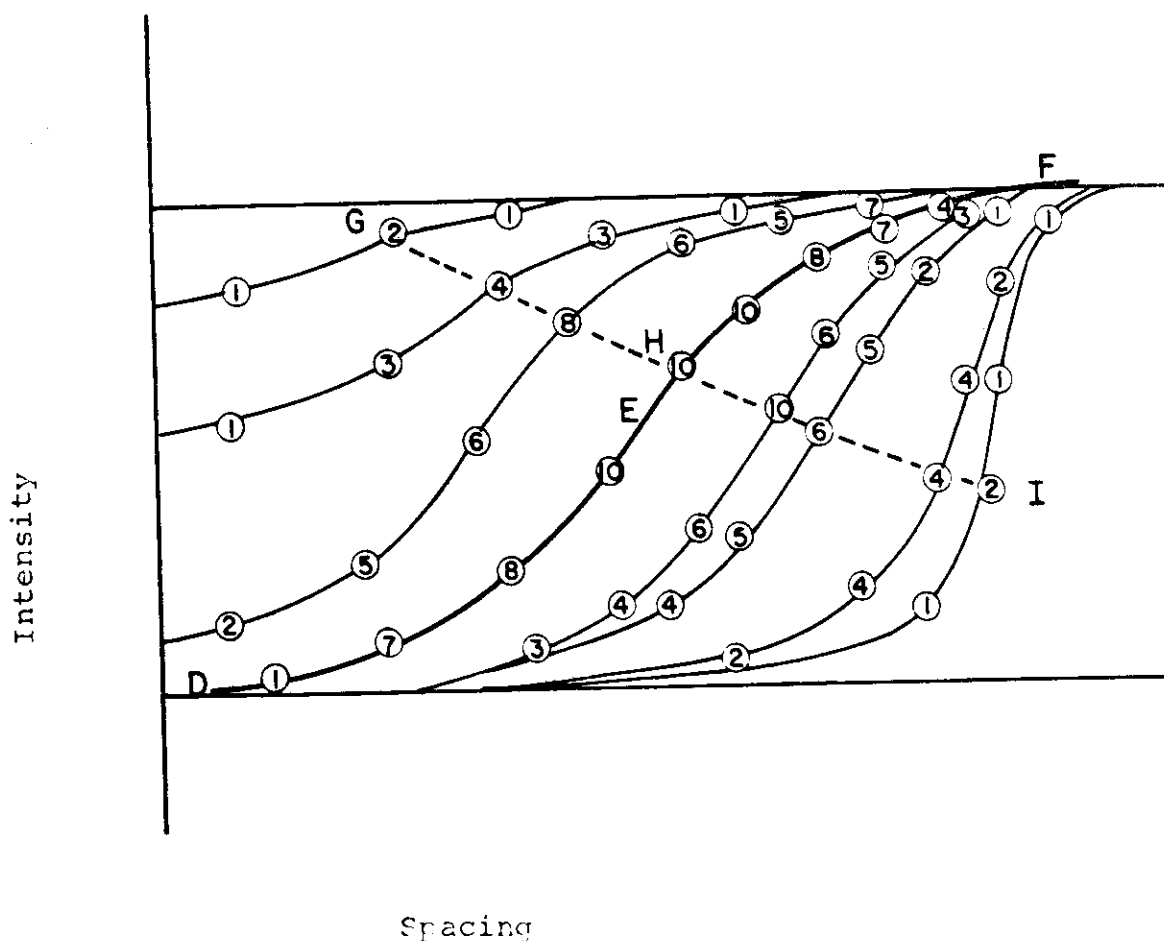


Fig. 5 - Yield variation related to light intensity and vegetal concentration.

Consider yield performance along the line DEF. At high concentrations of plants (small spacing) the individual yield of plants is suppressed through competition for nutrients, light etc. and the overall yield per hectare is low. With better spacing the individual plant yields increase as does the yield per hectare- Above this level, beyond point F, the pro-

duction begins to decrease again since the spacing reduces the overall concentration of plants with an horizon yield.

Hence at point F the production at field level is very low. Similarly, viewing the transition GHI a similar peak function is observed. At G the higher concentration of plants is counteracted by the low numbers per hill and weak foliar growth and hence yield per hectare is low. Point H is similar to E and represents a peak in the yield function. Point I is also a point of relatively lower production because of inter-plant competition such as was observed at point D.

Given this general form of distribution the three dimensional view of the function can be reconstructed and is illustrated in Figure 6.

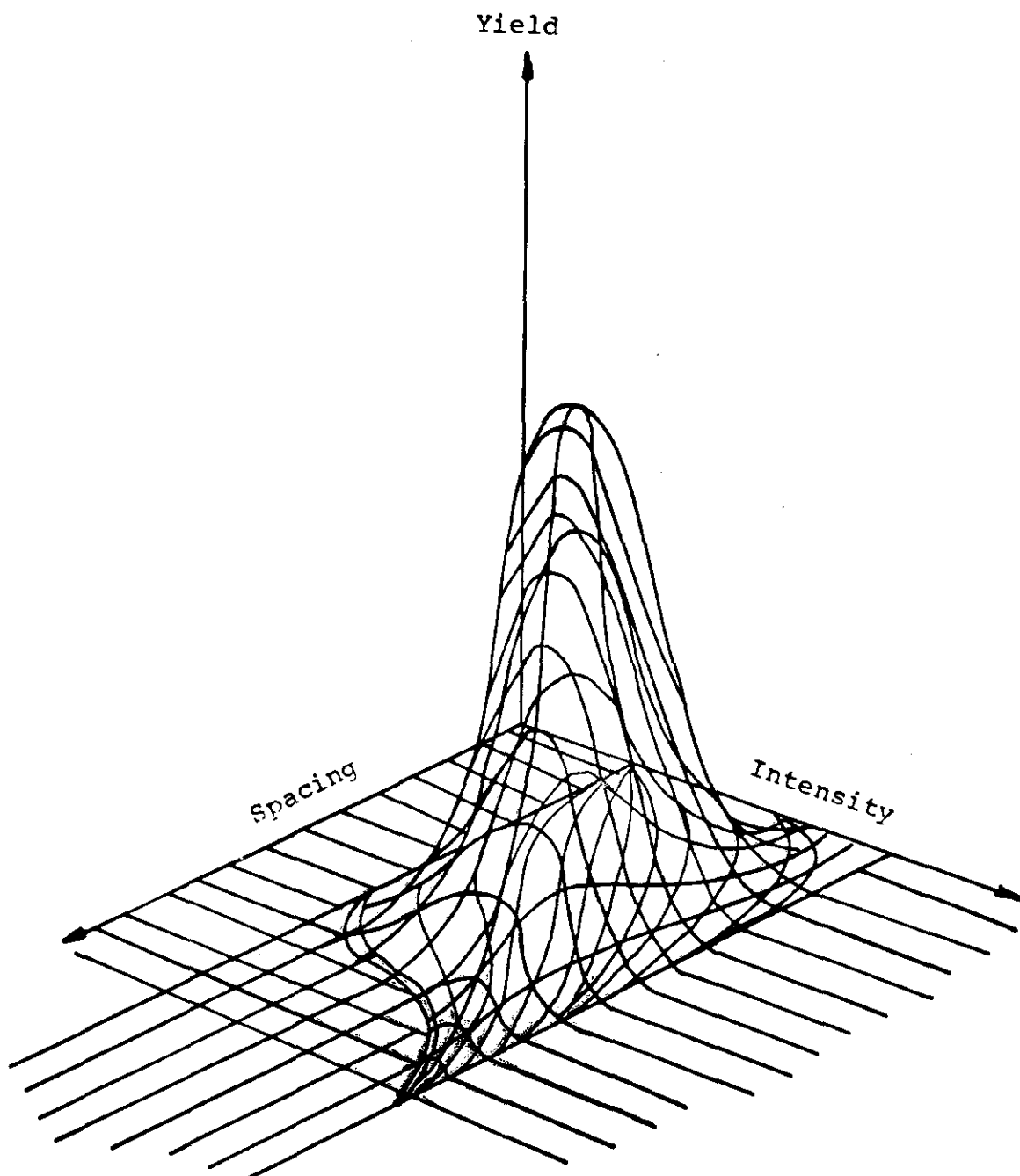


Fig. 6 - Crop production surface relating yield, spacing and image density in coffee.

As can be seen in Figure 6 for any given spacing a particular intensity will define the yield. The production surface is thus a useful model with which to predict yield from two measureable parameters on the basis of remote sensing.

3. LIMITATIONS

The actual form of the production surface presents no problem in terms of applicability to the real world situation. The main problem is associated with its position in space and relative variations in its absolute dimensions associated with variations in basic land fertility and water status etc.

III - THEORETICAL RESEARCH

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BRAZILIAN REMOTE SENSING PROGRAM
THEORETICAL RESEARCH PAPER Nº 1/70
AGRICULTURE

TOWARDS A SYSTEM OF PRIMARY PRODUCTION ASSESS-
MENT AND YIELD PREDICTION USING REMOTE SENSING
TECHNIQUES.

Hector W. McNeill
(CNAE - Project SERE)

1. SUMMARY

It is possible to estimate the Leaf Area Index (LAI) (This is simply the ratio of the Leaf area to the soil area it covers in plan or synoptic view.) of vegetation on the basis of diffuse reflectance in the spectral band width 0.75 - 1.4 microns.

The LAI of vegetation markedly affects the net photosynthesis, (the difference between photosyntheticised carbohydrates and respiration losses) is a direct measure of primary production. The conversion of primary production into "yield" for domestic crops can then be quantitised on the basis of whether the yield corresponds to reproductive tissues (grains, fruits) or to vegetative tissues (grass, foliage, forrage) or both.

The method provides the basis for the estimation of primary production potencial and productivity over large areas of terrain.

In the past the assessment of LAI has been characterised by tedious laboratory procedures. Assessments of primary production potential have also involved detailed time-consuming work capable of being executed only in minute areas of terrain.

2. TOWARDS A SYSTEM OF YIELD PREDICTION

The photosynthesis for single leaves within agricultural crops depends upon light intensity, plant species, temperature, nutrient status and water supply.

According to de Wit (1966) if a crop surface is considered to be large horizontal leaves then the first layer, subjected to a light intensity of about $0.6 \text{ cal cm}^{-2} \text{ min}^{-1}$ on a clear day with the sun at 45° , would produce carbohydrates at

a rate of about $18 \text{ kg CH}_2\text{O ha}^{-1} \text{ hr}^{-1}$. The second layer would produce about 11 kg/ha/hr and including the third layer the total production would be about 30 kg/ha/hr .

However, this idealised profile seldom exists in practice and a crop canopy consists of a multitude of small leaves oriented at many angles. This has the effect of deepening the profile of light action since its intensity is not reduced as rapidly as in the case of horizontal leaves. Consequently, in order to intercept all of the downfiltering light a leaf area index greater than one is required.

Actual potential photosynthesis estimations rely on a knowledge of the actual LAI, the light intensity and its distribution, temperature cycles and the effects of any limiting factors operating on the crop in question.

For Dutch conditions (de Wit) the variation in Kg/ha/day for a crop with an LAI of 5 is shown in Figure 1.

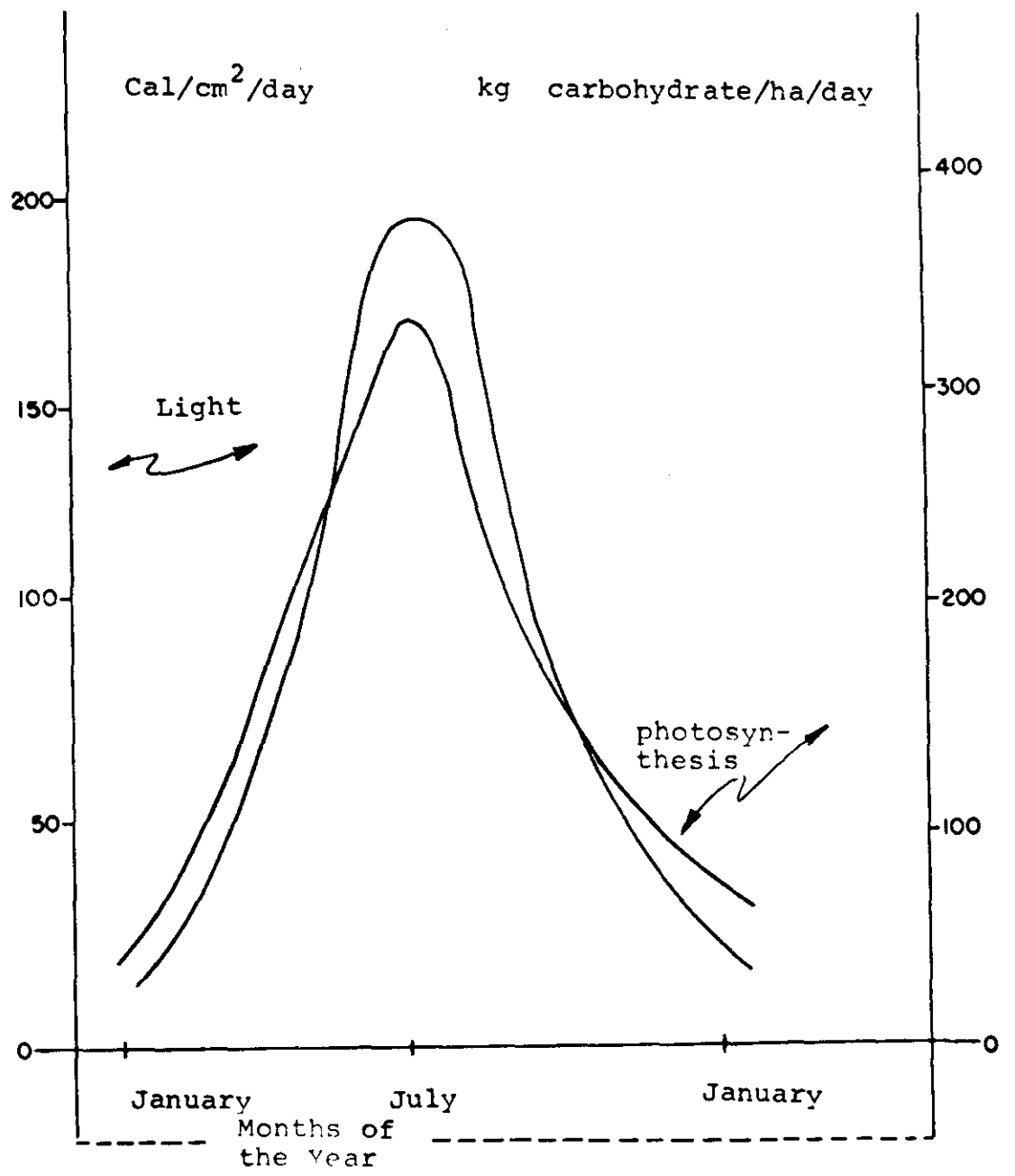


Fig. 1 - Daily total of potential photosynthesis and light throughout the year in the Netherlands.

Source: de Wit C.T. "Photosynthesis of Crop Surfaces" Section M of British Assn. Sept. 1965. Adv, Scn. July 1966. pp 161.

The potential photosynthesis varies from about 375 kg CH₂O per ha/day in June to 40 kg CH₂O ha/day in December. The Potential Photosynthesis with clear and overcast skies for different latitudes are given below in Table 1.

Table 1 - Daily totals of light and potential photosynthesis for a Canopy with a LAI of 5; Tropical Latitudes

LATITUDES		MONTHS			
North		January	April	July	October
0°	HC-1	343	364	342	365
	PC-2	413	426	413	427
	PO-3	219	228	218	228
10°	HC-1	299	375	375	345
	PC-2	376	437	439	411
	PO-3	197	234	236	218
20°	HC-1	249	375	399	313
	PC-1	334	439	465	387
	PO-3	170	235	249	203
30°	HC-1	191	363	411	270
	PC-2	281	437	483	356
	PO-3	137	232	258	182

Where: HC is light on very clear days and is expressed as cal/cm/day.

PC and PO are the daily totals of photosynthesis on very clear and overcast days, respectively, and are expressed in kg CH₂O/ha/day.

According to Figure 2 a LAI of 5, hence in order to appreciate what this assumption means in terms of other LAIs it is useful to understand the relationship.

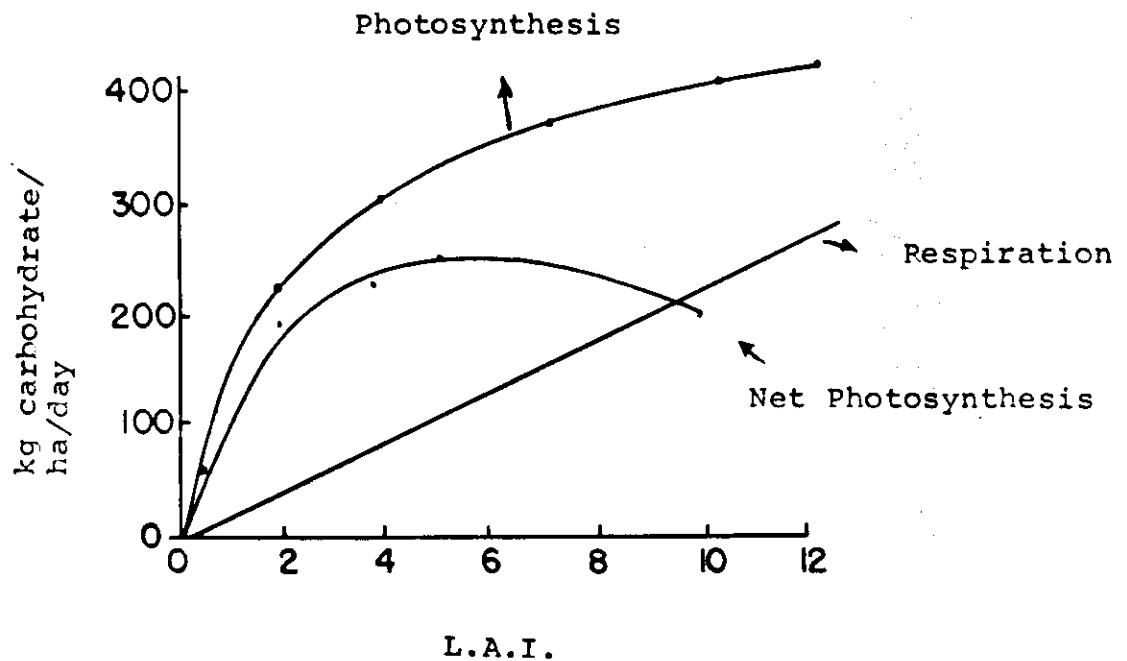
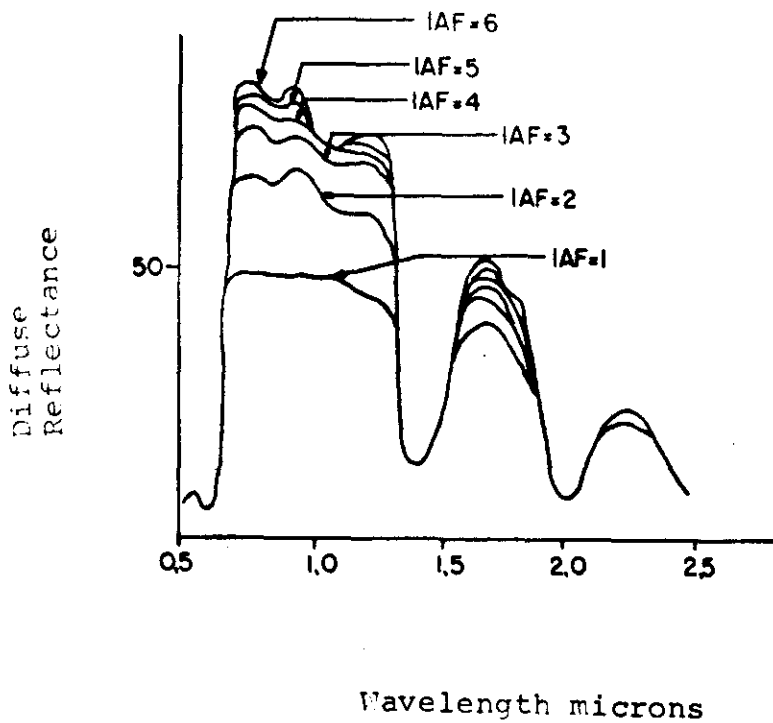


Fig. 2 - The relationship between Leaf Area Index and Photosynthesis.

As can be seen from the above diagram the LAI of 5 is about optimum from the standpoint of net photosynthesis (the component which influence the yield of a crop). The effect of LAI values on either side of this optimum value can be observed to be a movement away from the optimum. Since it is seldom the case that plants maintain this optimum condition it is obvious that the major problem in yield prediction is to estimate the LAI for the varying species of plants covering the terrain in a specific geographical location.

3. REMOTE SENSING AND THE ESTIMATION OF "LAI"

The importance of the transmittance of infrared light through upper leaves and multiple reflection from lower leaves has been demonstrated by leaf-stacking experiments which effectively simulate idealised conditions of different LAIs. One stack of leaves being equivalent to an LAI of 1 and two stacks to an LAI of 2 and so on. The form of the results of such an experiment are shown in Figure 3.



from: Myers et al
(1966), Weslaco,
Texas.

Fig. 3 - Experimental variation of LAI and corresponding diffuse reflexions.

There is about a 30% increase in reflectance in the range 0.5-1.5 with movement from an LAI of 1 to and LAI of 2. With movement from an LAI 2 of 3 there is a further increase in reflectance of about 12% and between LAI 3 and 4 an increase of about 8-10%. Beyond an LAI of 4 the increases become very small (about 3-5%) but still noticeable. Hence it should be possible on the basis of reflection in the 0.75 to 1.4 micron bandwidth to form an assessment of the LAI of plants.

Hence by sensing within the bandwidth 0.75 - 1.4 microns it should be possible to map LAIs for regions undergoing similar photoperiods and photointensities. However, when LAI levels reach values of 6 and above it becomes difficult to discriminate the differences in diffuse reflectance.

On the basis of a map of LAI values it should be possible for each species of plant to assess the net photosynthesis and hence assimilation of carbohydrates for growth of vegetal and reproductive tissue.

Since the actual harvested component in plants varies between species i.e. grains are reproductive tissue and energy stores, grass is vegetative tissue, citrus is reproductive tissue etc. Hence for each species the conversion of net photosynthesis to actual yield values will depend upon the species under consideration and the metabolic pathways utilised in forming what constitutes "yield" for the species concerned.

4. CROP SPACING

In dense stands the amount of light filtering down through the canopy of a crop will be effectively lower than that which impinges upon leaves in a more open stand.

The effect for a given LAI should be to increase photosynthesis in the case of the better spaced crop as shown in Figure 4. Certainly the net photosynthesis per plant should be higher through whether this also means the total production

per hectare is also higher depends upon the relative differentials of yield reduction through larger spacing and individual plant yield increase through the same situation of larger spacing. Through careful experimentation on spacing effects and total yields the correct correction factors can be assessed.

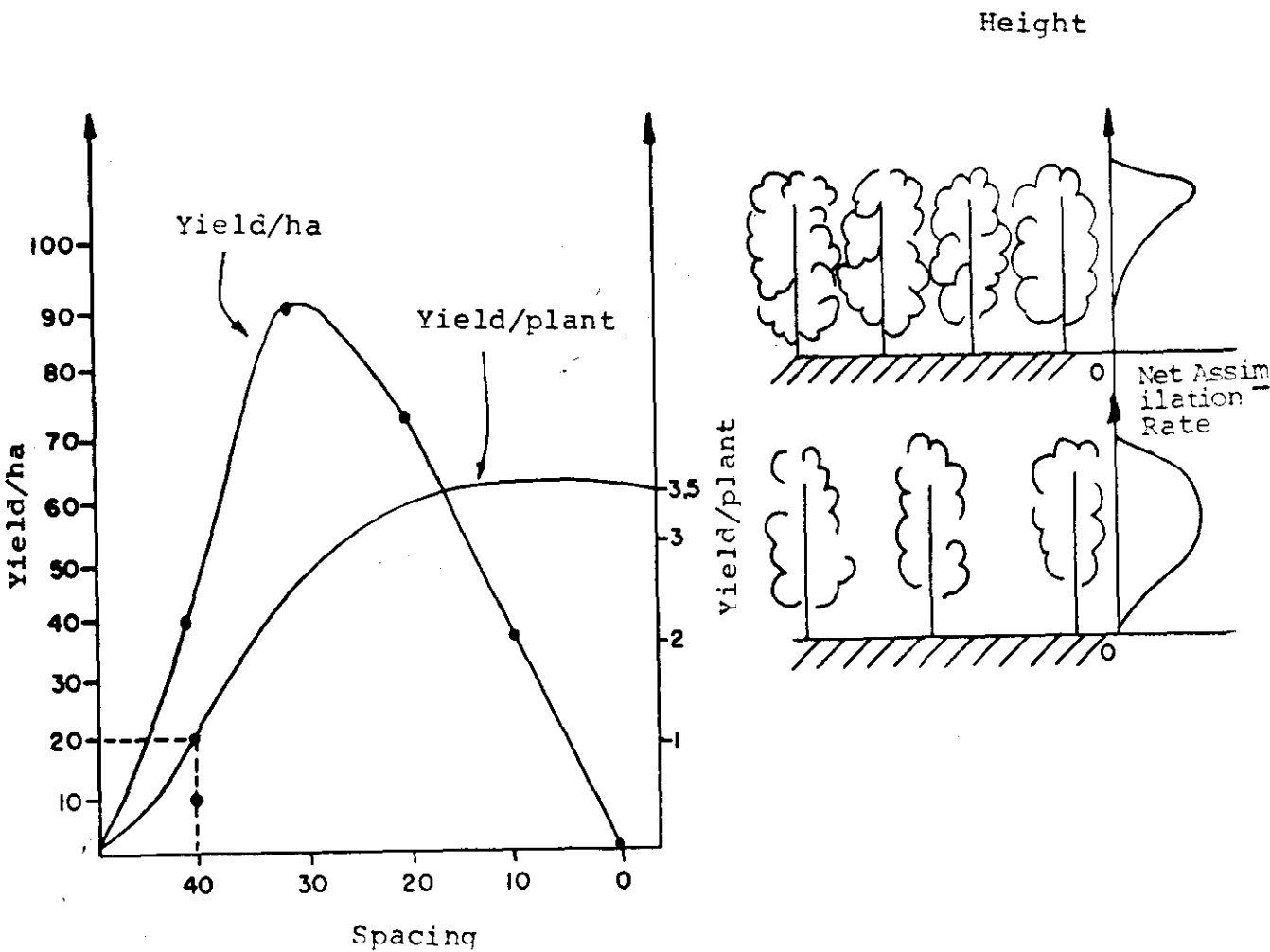


Fig. 4 - Yield probability curves as function of spacing.

5. SOME LIMITATIONS AND THE NECESSITY FOR CORRECTION FACTORS

The species variations in what constitutes yield have been mentioned above. Several other complicating factors however, exists which cause corrections to be necessary on any yield assessments carried out on the basis of the above system.

6. DIURNAL TEMPERATURE VARIATION

Temperature variation has a marked effect upon both photosynthetic rate and also upon the rate of respiration. In general plants undergo a positive heat exchange balance during the early part of the day which is kept in check partially by the transpiration of the plant surfaces. However, often the rate of transpiration is not sufficient to prevent the leaf temperatures from reaching 30 - 32°C the temperature at which effective photosynthesis stops. However, at this temperature respiration continues to increase causing a reduction in the effective net photosynthesis and for a short period the net photosynthesis assumes negative values since the actual photosynthesis is zero and the respiration is positive.

Hence for each region assessments are required as to the diurnal character of leaf temperatures under normal conditions. Of course checks can be made by utilising the thermal regions for remote sensing and attempts could be made at extrapolating spot readings to a diurnal profile. However, for this to be possible it is necessary to have a more exact knowledge than is at present in existence of the relative performance of different environmental objects in relation to their thermal cycles. Plants of different shapes and aspect heat up and cool at different rates. Cool soils of high moisture status heat up

and cool in a time lapse (lagged) fashion as compared with drier soils. Such variations will need to be accounted for in an accurate system of yield prediction.

7. FORM OF THE CORRECTIONS

There is little reason for the correction factors to be no more than summation and subtraction procedures. For example a region experiencing clear conditions during January at the latitude 10°N will have a total photosynthesis of 376 kg C/ha/day. However, daily negative records, because of elevated midday temperatures, may be as much as 65 kg C/ha/day hence the overall value will be 311 kg C/ha/day.

Corrections in water deficiency can also be sensed through the thermal and IR channels so as to construct the necessary corrections to the primary photosynthesis levels fixed for different locations.

8. APPLICATIONS

The application of the above methodology should aid our understanding of the geographical biological basis of productivity. The estimation of primary production is one of the fundamental objects of the International Biological Programme.

One of the limitations upon the success with which this programme achieves its aims is that the tedious and detailed techniques which have been proposed on a standardised basis by several of the scientists working in this programme (IBP Handbook N^o 2 Methods of Estimating Primary Production of Forests; P. J. Newbould; IBP Handbook N^o 6, Methods for the Measurements of the Primary Production of Grassland, C. Milner, R. Elfyn Hughes).

The broad classification possible, on the basis of the technique mentioned above, should provide a useful geographical classification of primary production to complement such work as the two Russian authors L.E. Rodin and N.I. Bazilevich in their "Production and Mineral Cycling in Terrestrial Vegetation" which attempts to collect this information in such a way as to form a geographical picture of the process.

Unfortunately the limited number of reliable research results cover such minute areas of the globe that such an approach can result in only indicative results.

The scale and detail offered by the system proposed above should offer the capability of a more comprehensive knowledge of our environment being built up so as to enable efficient utilisation of our natural resources through an understanding of their basic productivity.

BRAZILIAN REMOTE SENSING PROGRAM
THEORETICAL RESEARCH PAPER Nº 2/70
AGRICULTURE

STUDIES OF THE ENVIRONMENT

- I - TOLERANCE THEORY. PLANT COMMUNITY
DISTRIBUTIONS AFFECTING REMOTE SENS
ING CONSIDERATIONS.

Hector W. McNeill
(CNAE - Project SERE)

1. SUMMARY

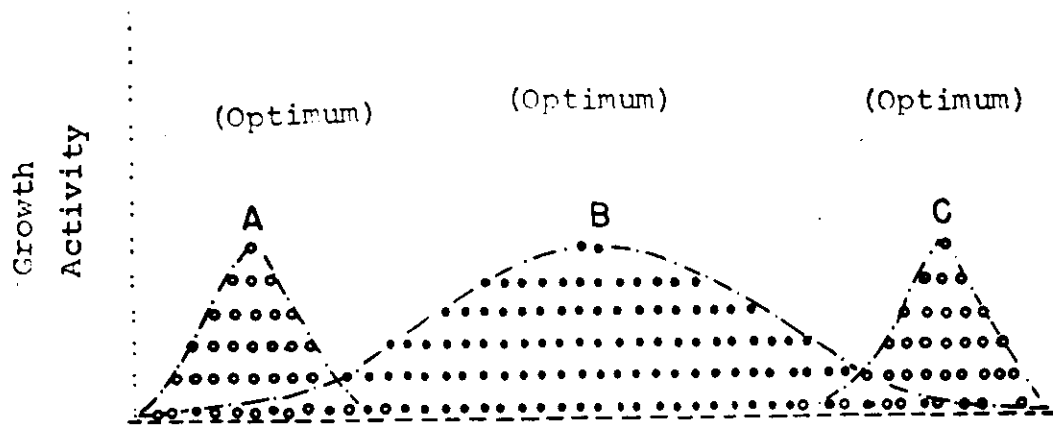
In this paper a basic discussion on the Tolerance Theory is attempted. This theory developed by R. Good in 1931 ("A Theory of Plant Geography", New Phytol. 30:149-171) presents the following basic concept: Each vegetal species is able to grow and to reproduce successfully under limited weather and environmental conditions.

Vegetal association, the plant community concept, and the influences of man on vegetal life will be considered, as well some practical applications of the tolerance theory.

2. THE BASIS OF TOLERANCE THEORY

Each plant species can exist and reproduce successfully only within a definite range of climatic and pedological parameters. This range represents the tolerance of the species to external conditions.

Diagrammatically, this concept is shown in Fig. 1.



Environmental gradient such as temperature, H_2) etc.

Fig.1 - Growth activities of three different species of plant with corresponding overlapping ranges.

Figure 1 illustrates three species of plant whose ranges overlap. From the above it can be seen that species A will more than likely be associated with B. This is also true of C which will in general be able to occur in association with B. The association does not have to be intimate but only locational with respect to the environmental gradient being considered.

At the same time it can be said that the species A will never occur with species C since their ranges do not overlap.

3. THE CONCEPT OF COMMUNITY SETS

In order to clarify the concepts presented before as they apply to remote sensing it is opportune to resort to the symbolism and conventions of set theory.

Figure 1 can be represented in several ways when it is converted into a Venn diagram ⁽¹⁾

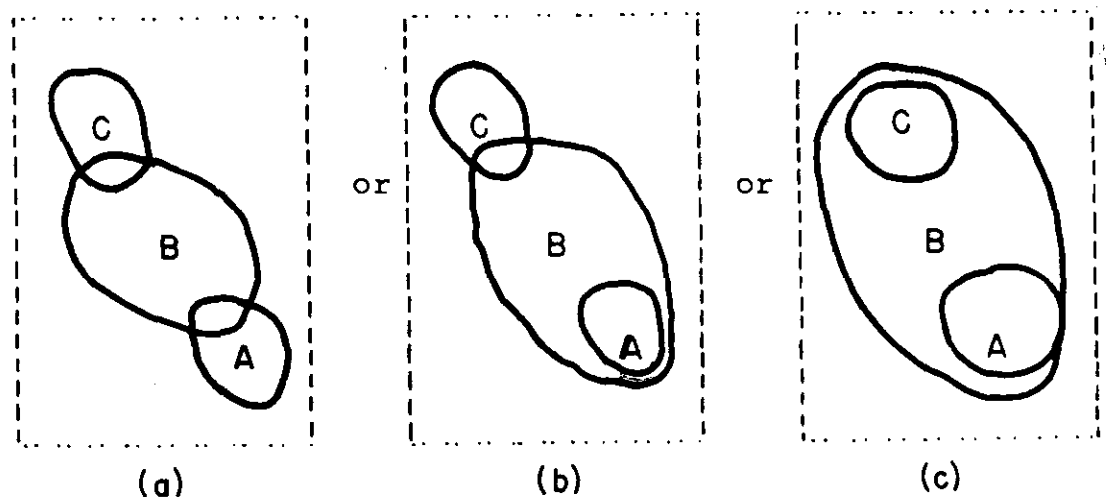


Fig. 2 - Three sets A, B and C according to Venn's diagram.

⁽¹⁾ John Venn (1834-1923) - Introduced a diagram by using overlapping circles. Each circle represents a set.

In Figure 2 the probability of finding A or C in associations which do not include B is quite high. At the same time the probability of finding A and C in the same association is zero.

In Figure 2 (b) the probability of finding A in association with B is 100% whilst a B/C association has a probability of about 25%. Again the probability of an A/C association is zero. In (c) the probability of both A/B association and B/C association is 100% whilst again the probability of A/C is still zero.

In practice, of course, the number of possible plant associations is enormous and might involve ten, twenty or more basic plant species.

However, this very diversity has can be put to use in various applications of remote sensing.

4. CENTRES OF DIVERSITY AND THE INFLUENCE OF MAN

One basic relationship which is of great relevance in modern times is the monitoring of man's interaction with his environment.

Man's ecological situation has progressed with time from one of being dominated by the natural environment to one of dominance of the natural environment. A measure of this dominance is the reduction in natural diversity and also the relative expansion of certain selected species at the expense of others which under normal circumstance would be members of the same community set.

The effect mentioned above can be illustrated by Venn diagrams as is attempted in Fig. 3.

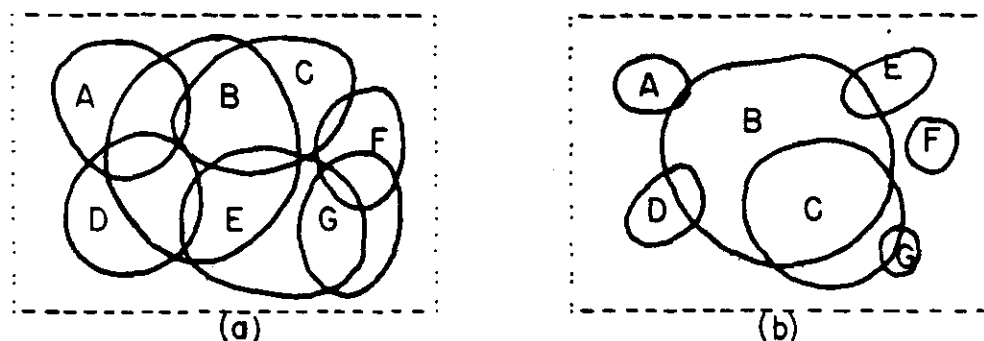


Fig. 3 - (a) Natural situation and diversity.
 (b) Effect of man. Expansion of dominant species and relative reduction in diversity.

The natural diversity represented by the seven competing species in dynamic equilibrium is influenced markedly by man's selection of two of them for domestication (B and C). The remaining species thereafter become weeds competing for the same nutrients as the domesticated crops. The remaining species are relegated to the position of weeds.

For example, Figure 3 indicates species A, D and E to be weeds of the crop B and G of crop C.

Technology might be such as to have completely reduced the effective competition of species F by the application of a selective herbicide.

In other words F can only exist in the absence of crop B and C since such crops normally receive selective herbic

ide.treatments.

For example this situation would exist for dicotyledons in say the two crops wheat and barley which regularly receive treatments of 2,4-D ⁽²⁾.

The effectiveness of this drastic ecological influence of man varies between countries and regions of the world and is related to the degree to which modern agricultural technology is applied to the industry.

Similarly the effective concentration of crops relates to the technology employed on the farms. For example, in undulating or flat terrains, large fields associated with high degrees of mechanisation are utilised in developed nations and certain areas of the developing nations. In countries incapable of justifying large field equipment the general field size is smaller since the main power sources are animals or man himself. Hence the overall effect of the development of agriculture with in the context of extant agricultural technology is to cause large variations in the extent to which single species dominate given production regions and also the degree of homogeneity with in the regions and crops concerned.

In order to clarify the distinctions above view Figure 4.

(²) 2,4-D is a selective herbicide which is toxic to dicotyledons but not to monocotyledons. Its effect is to cause imbalance in the growth hormone activity (auxins) causing dysfunction in this process and the eventual death of the plant.

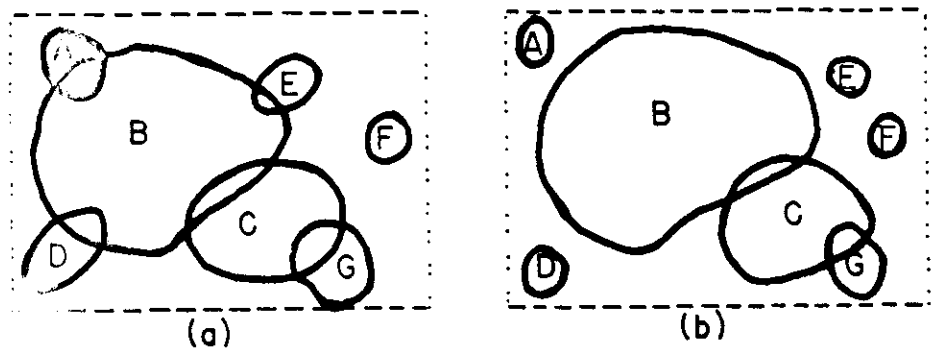


Fig. 4 - Dominant species and technology effects.

In Figure 4, in (a) B is relatively more dominant than C, both of which are the most dominant species in the regions represented above. In the same figure, in (b), B is more homogeneous than C since technology has permitted the complete exclusion of the weeds A, D, E and F from the domain of the crop. In the case of C it would seem that technology has not succeeded in permitting the easy exclusion of G from the crops domain. Indeed, the effect might not be technological but economic. It may be possible to exclude G from C by the region may be too underdeveloped to employ the technique because of pecuniary limitations or indeed information deficits.

5. APPLICATION OF THE ABOVE THEORY

Before such a theory can be effectively applied to remote sensing applications it is necessary to account for locational (bioclimatic) variations in the above processes.

The concept of location has to be interpreted in three dimensions (longitude, latitude and altitude). The overall effect of the latitude/altitude interaction is shown in Fig. 5.

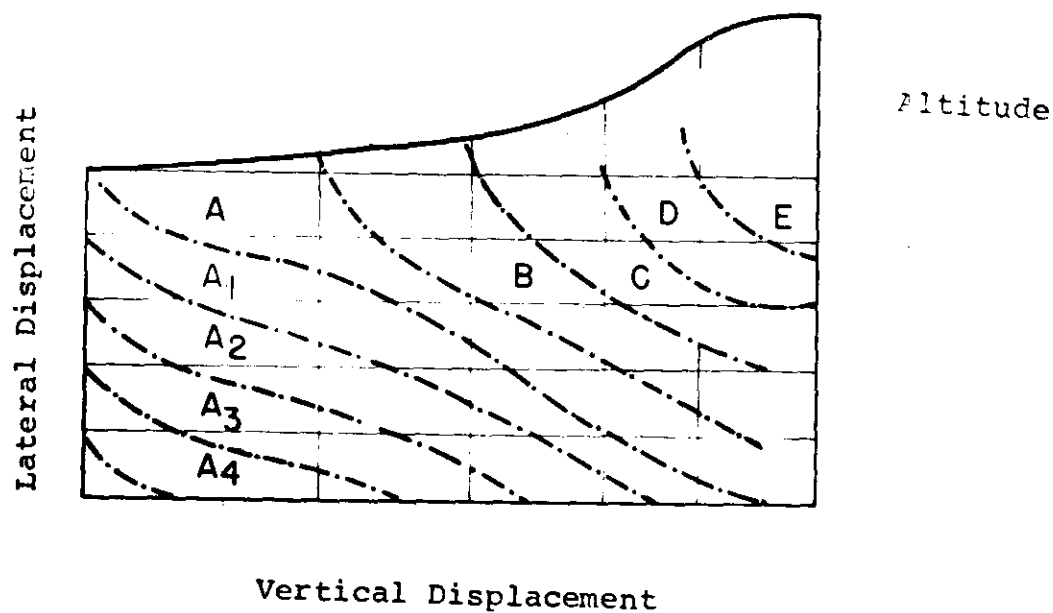


Fig. 5 - Composite effects of latitude and altitude on bioclimatic variations.

The latitude/altitude interaction diagram simply shows the effect of moving to a cooler latitude is the same as moving to a higher altitude. Hence the bioclimates are distributed generally with latitude and longitude and also within homogeneous zones one can find bioclimatic gradients associated with altitude.

With each bioclimate there is an associated community set of vegetation and these bioclimatic variations help to define the actual sets most likely to occur. Secondly, depending upon the type of agricultural development, the actual dominance and homogeneity of the different species can be roughly defined. These three simple interactions provide the basis of a simple differentiation system in remote sensing which is developed in more detail in Theoretical Research Paper N9 3/70.

REFERENCE

Demeter, 1968, "Truth Site Establishment and Ground Data Gathering", pp.3-5.

BRAZILIAN REMOTE SENSING PROGRAM

THEORETICAL RESEARCH PAPER Nº 3/70

AGRICULTURE

STUDIES OF THE ENVIRONMENT

II - THE DEVELOPMENT OF AN IMPROVED SYSTEM OF CROP
BOUNDARY & NATURAL VEGETATION BOUNDARY RECOG-
NITION

Hector W. McNeill

(CNAE - Project SERE)

1. SUMMARY

In the previous paper a discussion of the relevance of plant tolerance theory to the three major variables relevant to the synoptic view of the environment was developed.

- (1) Bioclimatic definition of the plant community,
- (2) Species dominance, and
- (3) Species homogeneity.

This paper develops the actual applications of these three simple concepts to the field of remote sensing.

2. GENERAL CONSIDERATIONS

The capacity for rapid land utilisation survey is of both scientific and economic importance.

The concepts developed in the previous paper provide the basis for such a system.

However, the method of automisation of data collected is different from those previously developed (Purdue Annual Reports for example all rely on an absolute definition of multi spectral characteristics for the various crop plants) as will become clear below.

Consider a large terrain of say a million square kilometers.

The preliminary consideration in any survey is to estimate where natural vegetal zones, cultivated regions and human concentrations exist. From the standpoint of natural vegetation we will ignore in this paper the concepts associated with human habitation distribution.

We are faced with the problem of distinguishing natural vegetation zones from cultivated crop zones.

Referring back to the concepts developed in Theoretical Research Paper N^o 2/70 we are faced with the problem of discrimination between basic plant community sets, community domination and species homogeneity.

Consider the following situations within a bioclimatic zone (Fig. 1).

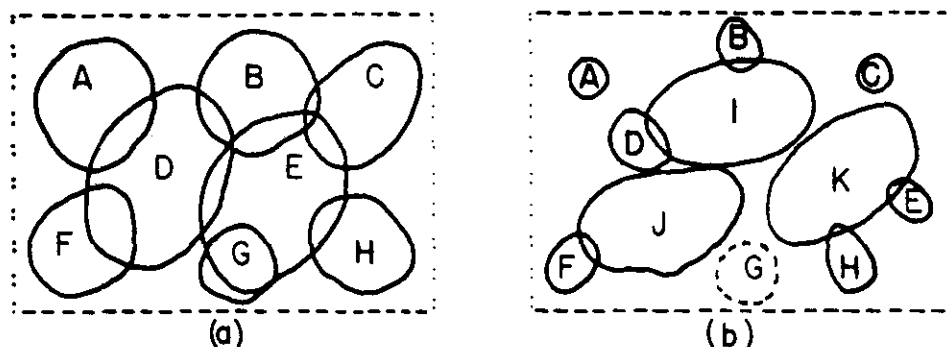


Fig. 1 - Situations: (a) Natural (b) Cultivated

The cultivated zone (b) is markedly different from the natural zone. Three crops have been introduced, all of which dominate the zone (I, J and K). Species A and C only occur in isolation whilst the species F, D, H, E and B remain in association with the crop plants as weeds. Species G has become extinct since its major natural association, E, has been reduced to insignificance. Species E may have been the major shade plant of G for example.

Crop J can be seen to be relatively more homogeneous than I or K (less weed infestation).

3. THE CHARACTERISTICS OF NATURAL PLANT ASSOCIATIONS

The natural situation for plant communities is one of extreme complexity. The associations between species form a multitude of possible combinations. The very aggregate tendency for any bioclimatic zone. A position of dynamic equilibrium is attained with climax vegetal forms associated with predictable subsets of plant communities. The central tendency effects results in a varying but relatively homogeneous plant community (as opposed to a homogeneous species occurrence which is a major variable in crop plants).

Considering a certain region of the energy spectrum we can hypothesise that the overall variation of reflectance and emittance in the natural regions associated with the aggregate plant community is slight.

4. THE CHARACTERISTICS OF CULTIVATED ZONES

In the cultivated zones the plant community subsets are quite distinct. For example, crop I does not occur with J or K in an intimate stand. A field might border the others but they do not form a complex association since man does not permit this. Hence overall, associated with field to field communities, there is a larger variation in sensed reflectance or emittance than in natural zones.

However, within the fields it can be expected that the variation will also be very small and be associated with the relative homogeneity of the crop species concerned. Another influence upon the in-field variance will be cultivation practices which vary from crop to crop.

5. THE SUMMARY OF THE ABOVE VARIANCE
CONSIDERATIONS

Consider two regions bordering one another. One is a natural vegetation zone and the other a cultivated zone. The variation of reflectance with distance is illustrated in Fig.2.

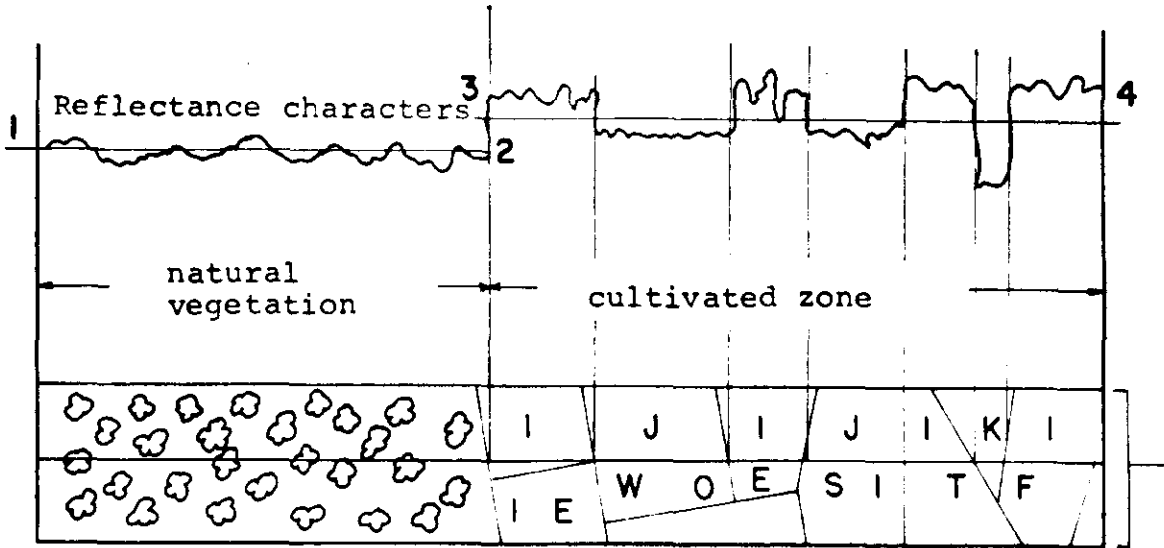


Fig. 2 - Variation of reflectance for natural and cultivated zones.

6. THE SIMPLE THEORY OF BOUNDARY
RECOGNITION

A preliminary step in the recognition of land use and natural resource distribution is the delineation of bound-

aries. In Figure 2 the boundaries between the natural zone and cultivated zone is an obvious jump at the border of the field containing species I. The boundaries between fields are also obvious within the cultivated zone.

To recognise a real vegetal boundary requires two processes. One is the recognition of the change in reflectance between one point and the other and the second is the decision as to whether this is significant or not. Put in other words, is the gradient of reflectance with distance over the terrain indicative of a boundary or of the natural variation within a particular zone?

The solution to this problem is not difficult. At this point is sufficient to note that a significant negative or positive gradient indicates a boundary which will be located roughly at the point of the maximum. However, the accuracy with which the boundaries can be established varies with the resolution of the sensing instrument and several other variables to be discussed.

7. THE EFFECTS OF RESOLUTION CHANGES

The best method of assessing the effects of varying resolutions is on the basis of the concept of the moving average. A resolution of 10 meters will give the same value as one of 20 meters if the 10m readings are converted into a moving average based on pairs of sequential readings. The extremes of the process can be seen in an hypothetical effects of resolution upon the natural/cultivated zone readings illustrated in Figure 3.

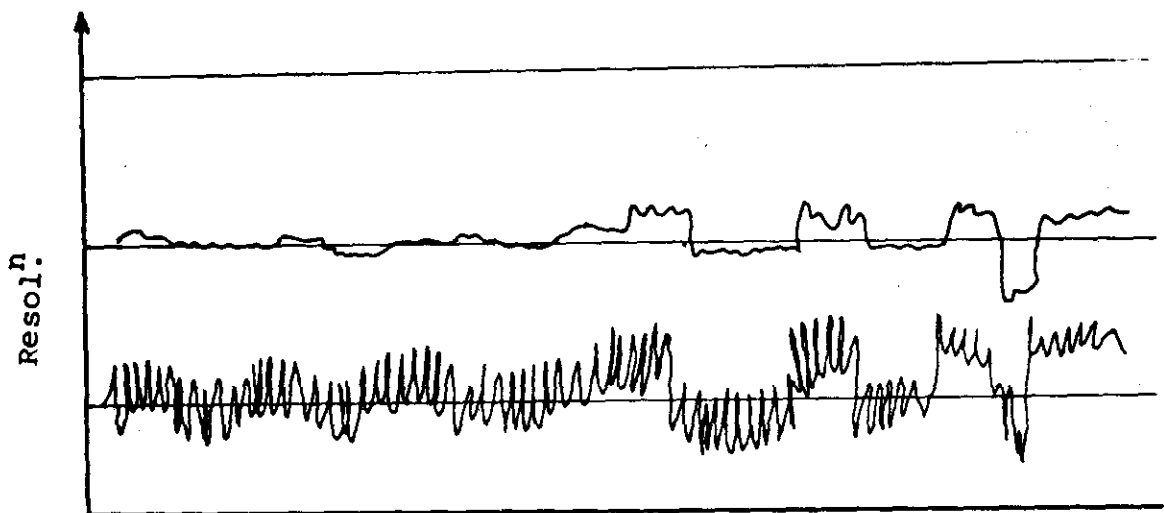


Fig. 3 - Hypothetical effects upon natural/cultivated zones.

The actual gradients of the above three lines are given in Fig. 4 and each represents the change in reflectance with distance:

$$\text{Gradient} = \frac{dP}{dD}$$

where R is reflectance
D is distance

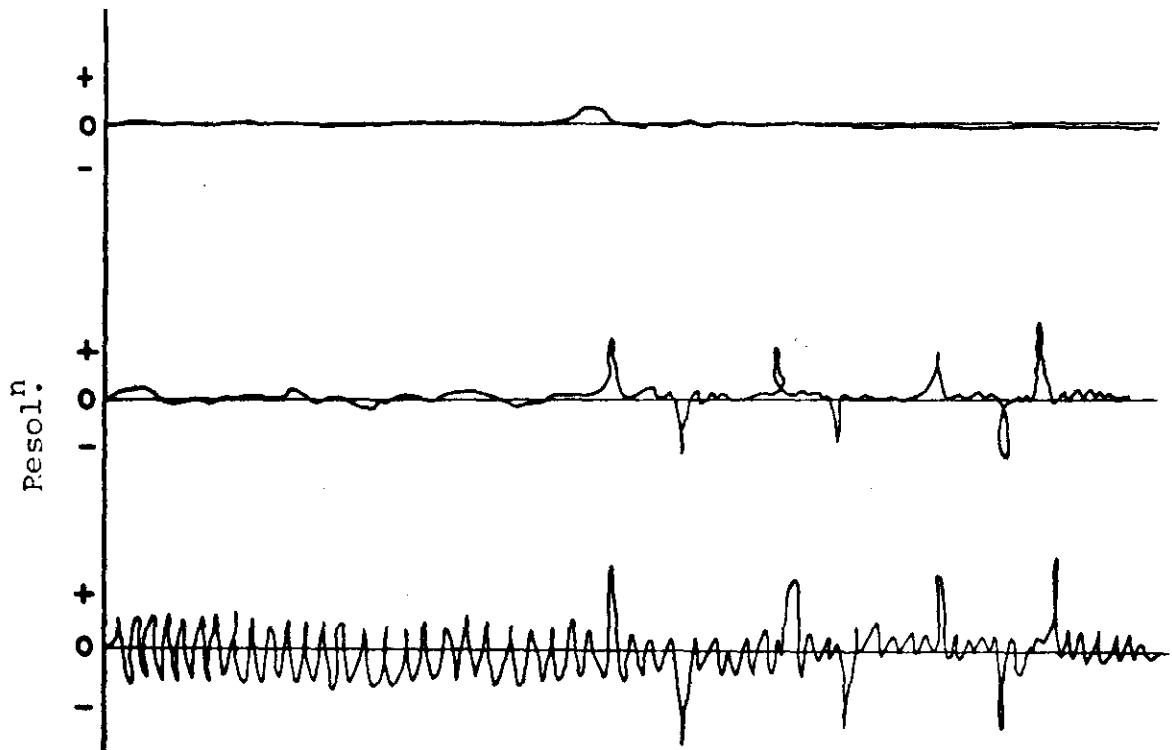


Fig. 4 - Reflectance gradients as function of distance.

As can be seen the large resolution indicates the rough location between the natural vegetation and the cultivated zone.

The middle resolution indicated the location of the natural/cultivation zones as well as those between fields.

In small resolution the dR/dD transforms indicate boundaries between plant association within the natural vegetation region and also within fields.

For the situation represented above the best resolution is that illustrated in the middle of the dP/dD transforms illustrated above. However this resolution will not have universal applications as the following discussion will illustrate.

8. THE EFFECT OF FIELD SIZE

If fields are in general far bigger than those indicated above then the larger resolution used (Fig. 4) might be quite adequate to record field boundaries. In areas with smaller fields the resolution will also need to be smaller in order to record the boundaries on the basis of dR/dD transforms.

The general effect of resolution upon the correct location of boundaries is shown in Figure 5.

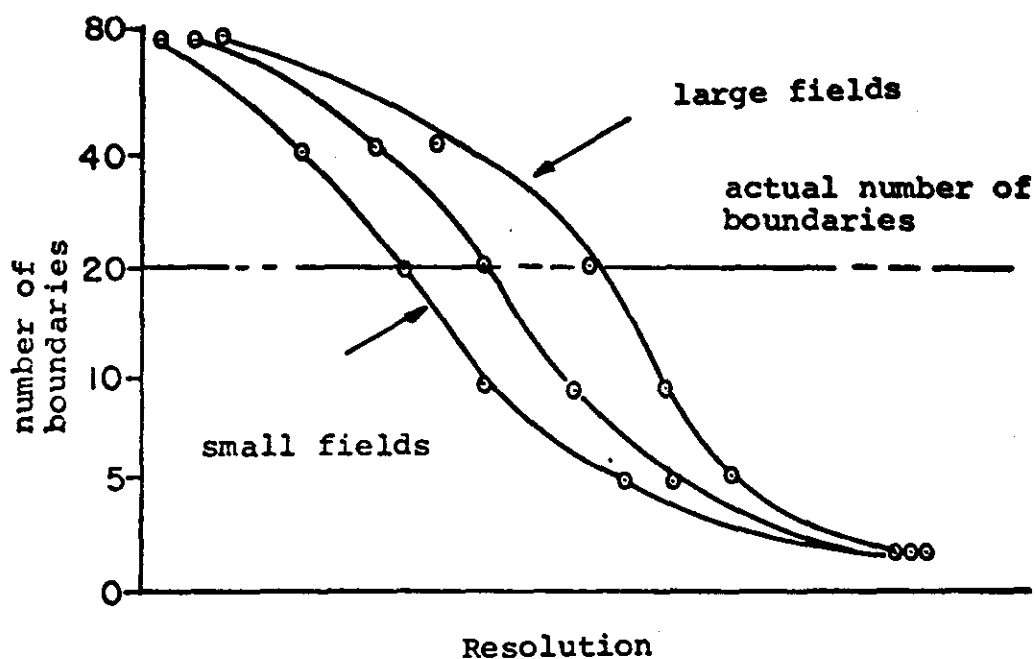


Fig. 5 - Effect of resolution upon the correct location of boundaries.

Hence in order to record the correct number of field boundaries it is necessary to have smaller resolutions in the case of small fields and larger ones in the case of larger fields.

9. THE EFFECTS OF VARIANCE

In both fields and natural regions demonstrate high variance with distance then it may be difficult to locate the actual boundaries with a high accuracy. However, the overall change in mean should indicate a transition into another type of plant association. When both means and variances are the same it is not possible to define boundaries unless they are marked by roads or zones of vegetation markedly different from that existing on either side. When the means are the same the variance change may be sufficient to indicate boundaries.

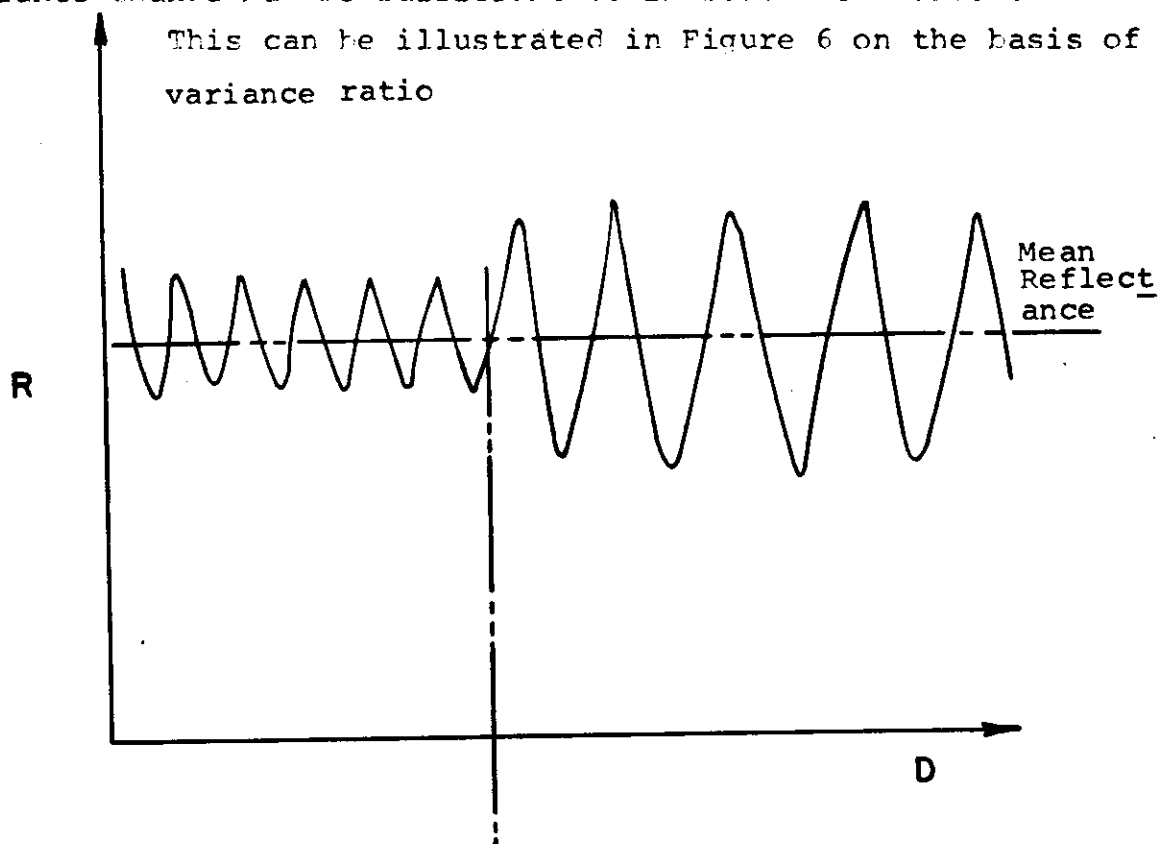


Fig. 6 - Reflectance-distance diagram for boundary detection

With a variance ratio of one there is a zero differential and no apparent difference in the populations and hence on this basis no boundaries exist. With variance ratios differing from unity boundaries can be located accurately. However, for the differences in variance to be measured, it is necessary to sense using instruments which have resolutions smaller than the spatial period over which the main variations occur.

A variance ratio of one however does not mean that the fields are of the same population. The actual means of the targets might be different but their variances might be effectively the same.

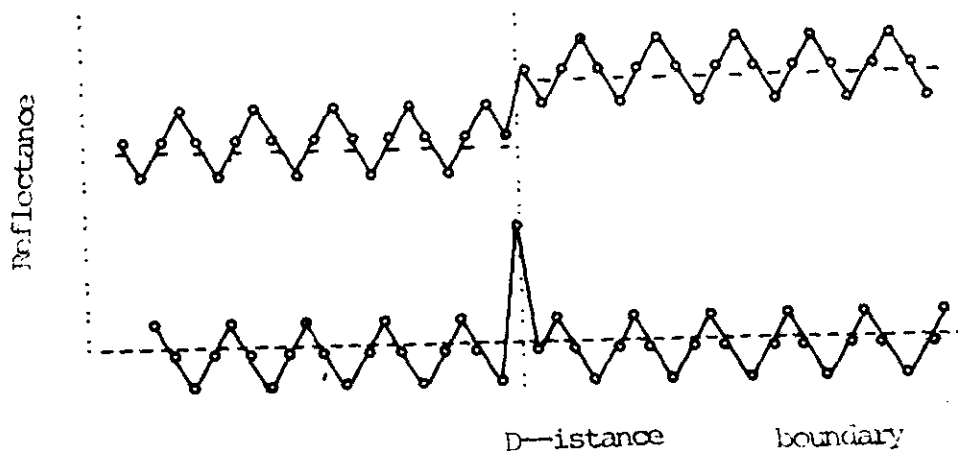


Fig. 7 - Reflectance variation with distance.

In this case the variance ratio is less useful than the dF/dD transform which indicates the boundary very simply as shown in Figure 8.

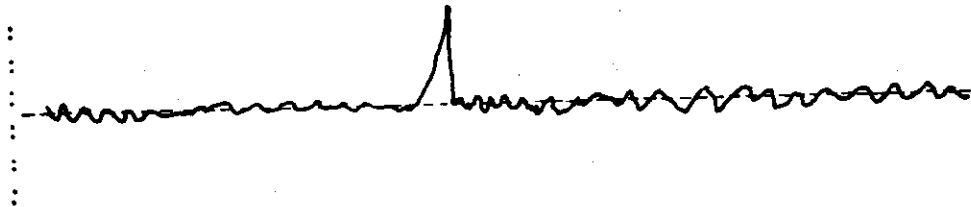


Fig. 8 - Boundary definition according to dR/dD relationship.

10. SPATIAL CONCEPTS OF VARIANCE

If use is made of variance ratio relationships account needs to be taken of the distribution of the values about the mean with distance.

For example both of the following distributions have the same variance but have a different distribution with respect to distance:

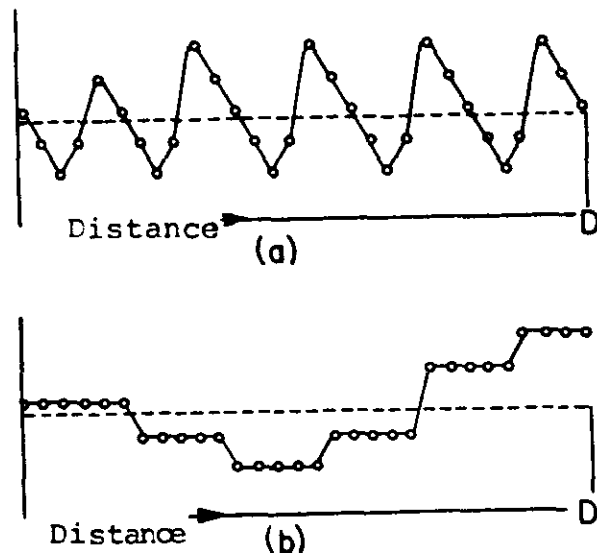


Fig. 9 - (a) and (b) - Different distributions for the same variance.

Hence in order to assess the correct variance for a specific plant community set it is necessary in situation (b) to traverse the whole distance D. In the case of (a) it is possible obtain as accurate to assessment by sensing only about 20% of this distance.

Hence in assessing variance account needs to be taken of the absolute value assessment with respect to distance over the terrain covered with the target variable.

Therefore with differing means it is usually adequate to utilise the dR/dD transforms. If the means are only slightly different or the same, use can be made of the variance ratios V/V .

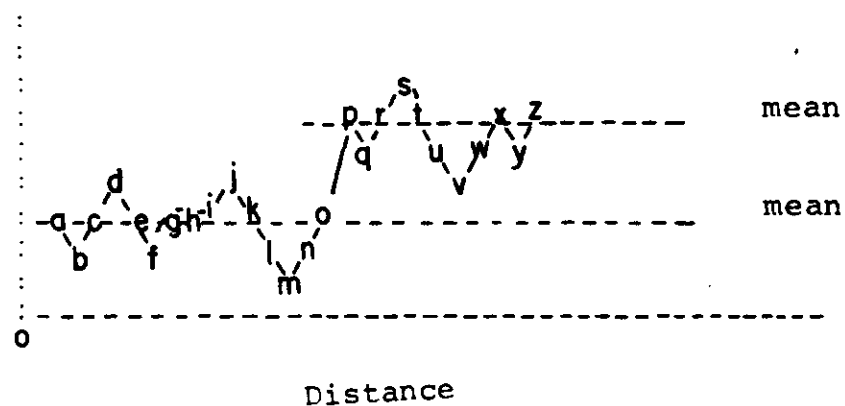
When both the V/V and dR/dD transforms assume values of one and zero respectively, it is not possible to differentiate zones nor indeed classify crops or plants.

4. AUTOMATION

Automation of the above form of data representation is very simple. Consider the following figures from a linear transect which represent reflectance values:

a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p,q,r,s,t,u,v,w,x,y,z.

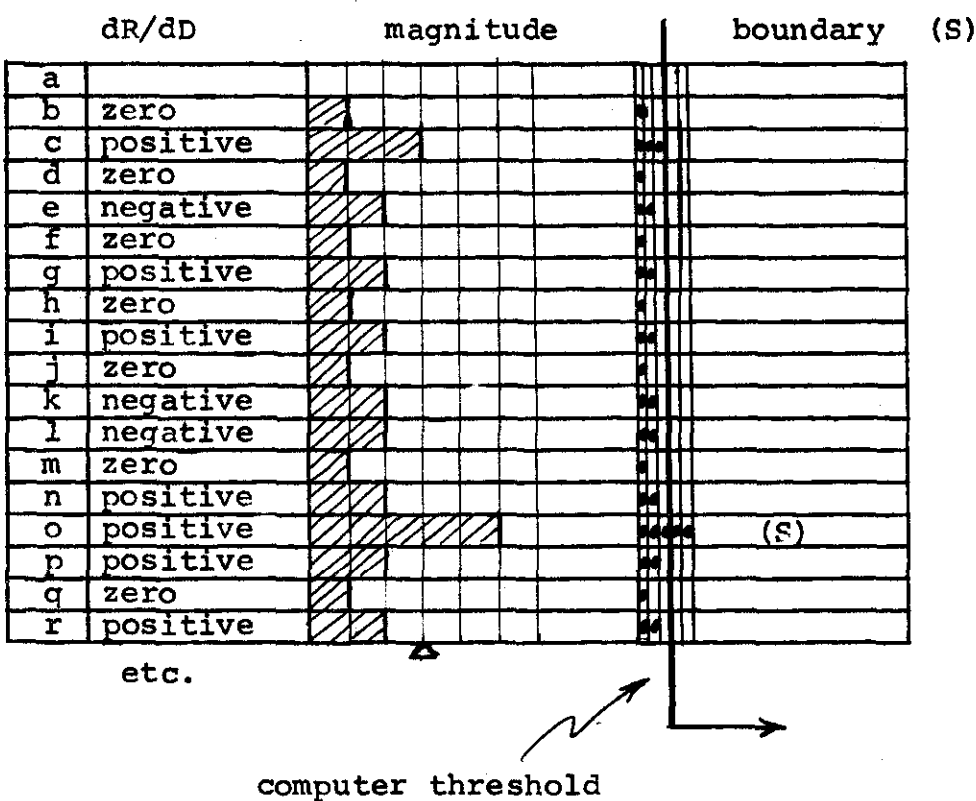
Several of the above figures might have equal values as illustrated in Figure 10.



In order to estimate the dR/dD transform we select a reasonable number of consecutive points. In this case assume the selection of triplets. Hence dR/dD for first sample is: \hat{a} minus \hat{b} plus \hat{c} (dR) divided by the distance covered by samples $\underline{a}, \underline{b}$ and \underline{c} (dD), (where $\hat{}$ indicates the deviation from \underline{a}).

Viewing the sequence of dR/dD transforms they can be seen to be of the following form (Table 1).

Table 1 - Boundary selection by computer threshold.



The computer simply records the boundary symbol when the dR/dD transform reached a specific threshold. According to Table 1 the dR/dD transform locates the boundary at about point o. As can be seen from the diagram plotting the values of the readings this is about right, the boundary occur between o and p. If the dR/dD transform was based upon duals of consecutive readings the location of the boundary would have been more accurate since the dR/dD value recording the highest value occurs between o and p

In order to correct for dR/dD shifts due to absolute variations in record levels it is better to express all of the figures as percentages of the mean (mean being 100%).

In this way the dR/dD transforms at all levels are compareable.

Hence based upon the above principles it is very easy to establish the automatic recognition of vegetal boundaries on the basis of dR/dD transforms.

BRAZILIAN REMOTE SENSING PROGRAM
THEORETICAL RESEARCH PAPER Nº 4/70
AGRICULTURE

INVESTIGATION INTO CLASSIFICATION OF LAND CAPABILITY
ON BASIS OF MULTIBAND DENSITY MEASUREMENTS

Test Site 801 - July, 1969 flight

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1. SUMMARY

The studies of the Practical Research Paper N° 3/70 ⁽¹⁾ are the bases for a new Land classification methodology, according with land use and capability, following a soil discrimination test based on natural fertility.

The present work uses the variable light density measurements obtained from images of different soils, and takes into account multiband imagery. The work is useful in studies of Soil Conservation, Reclamation, and Changes in the Use of the Land.

2. INTRODUCTION TO THE PROBLEM

In Practical Research Paper N° 3/70 ⁽¹⁾ it was concluded that the colour film, by itself, did not offer as clear a definition for the separation of red soil and black soil as desired.

All of the readings taken in the above study were taken from images of bare soil. Since such a simple procedure made possible the separation of the yellow soil from the black and red soils investigation or the uses of these soils provides the basis for an improved methodology for separating soils.

One factor of importance in the approach being considered is the use to which soils are put. For example the yellow soil is inherently less fertile (in Test Site 801) and the

⁽¹⁾ Practical Research Paper N° 3/70 - Investigation into Image Densities for three Soil Types on Colour Ektachrome Film - Page 16.

red soil is more fertile. The black bog soil differs from both since by definition it has a far higher water status and also higher organic matter content (the reason for its black colour).

3. THE APPROACH AND BASIC ASSUMPTIONS

The approach which is likely to provide more conclusive results is one which separates the land usage and capability into categories based upon the variance of densities which relate to the varying complexities of land utilisation associated with different soil types.

For example, the fertile red soil is used for a greater range of crops than the bog soil which limits the range of crops grown because of its high water status. The yellow soils are used even less since they are less fertile and tend to be represented by a ground cover of natural vegetation. Hence the variances of the densities within the three soil types should differ. Hypothetically it would be expected that the variance of the red soil area would be greater than the bog area which in turn would possess a variance greater than the yellow soil area.

The approach will therefore be to measure these parameters by taking random density measures in each major soil area. Use will be made of the multiband films A, B, C and D in order to select the superior film for this purpose.

4. APPLICATIONS OF THE RESULTS

In the results prove to be significant they have various potential applications. A field of particular application is that of conservation and reclamation and land use change.

In general areas of lower fertility have been avoided from the standpoint of agricultural production. In such re-

gions the vegetation has been allowed to attain its climax status which in general is represented by a homogeneous zone covered with grassland, shrubs, small trees or forests depending upon the bioclimate. In some regions, of course, climax vegetation is very sparse because of severe fertility or water restraints result in desert and arid zone formations.

By definition the above description of areas possessing climax vegetation also assumes a low level of variability within the homogeneous zones. On the other hand, adjoining regions of higher fertility will possess a mixture of crops under farm management conditions which result in a region of great heterogeneity. By the same token these regions will possess a higher variance caused by bare soil areas bordering perennial crops which in turn might border annuals in different stages of growth.

Regions which have been used historically for agricultural production, but which since have been abandoned because of reduced fertility, can also be recognised on the same basis as the above observations. In general abandoned regions do not attain their climax natural vegetation form for some time after the beginning of the regeneration of natural vegetation. In favourable regions the climax condition might be reached in about 20 to 30 years whilst in others the process may take 50 or more years. The transition period between abandonment and the attainment of the climax condition is marked by a succession of definite plant community complexes which can be recognised on the basis of density measurements.

Hence, knowledge of the variabilities of different regions based upon spectral densities should provide information on three important facts. 1. Where most agricultural production is occurring. 2. Where the less fertile regions are located. 3. Where the abandoned regions occur together with a measure of how long they have been abandoned.

Such information permits an assessment to be made, in historical perspective, of the rate at which land is being worked out. On the other side of the equation, assessments can also be made, with time, of the rate at which relatively less fertile areas are being colonised in order to maintain agricultural production.

Such facts provide crucial information for studies in conservation and reclamation of land.

5. CONSERVATION

Decisions have to be made upon whether it is cheaper, in the long run, to conserve land fertility through judicious use of fertilizers and soil conservation (by implementing anti-erosion measures) or to spread production to other regions of high fertility.

6. RECLAMATION

Following a continuing process of colonisation of high fertility regions, the marginal land begins to approach levels of lower fertility since more and more of the land left for colonisation is of lower fertility. There comes a point when a decision has to be made as to whether it is cheaper to spread production into lower fertility regions or to reclaim previously abandoned zones and to regenerate the fertility level. In general this might be an expensive process, but, since most abandoned regions are in superior market (in general) locations, this might be justified since by spreading to outlying lower-fertility areas the transport costs might prove to be high for the procedure.

As can be seen from the above discussion the actual use of land is an economic problem as well as one relating to basic primary production potential. Since the economic variables

are often a combination of both primary production potential and locational aspects (markets and communications), the synoptic view of the process and interaction of these variables offered by remote sensing technology is particularly useful for those concerned with conservation and reclamation.

7. CONCLUSION

Although the Test Site 801 data does not represent a normal situation (St. Elisa farm contains far more crops than normal farms would) it is hoped that the proposed study will indicate the feasibility of such an application of remote sensing.

ACKNOWLEDGEMENTS

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