FINAL REPORT SUBMITTED TO CPAC

from

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in Agricultural Meteorology

(Jun. ∿ Aug., 1982)

Contents

Methods for Estimating Potential Evapotranspiration from Climatic Data in Cerrados

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## 1. Introduction

Potential evapotranspiration is an important concept in evaluating the upper bound of evapotranspiration under various atmospheric conditions, and it is defined as "the rate at which water can evaporate from any surface which is wet and does not restrict water vapor flow into the atmosphere".

Methods are used to estimate evapotranspiration from climatic data, owing to the difficulty of obtaining direct measurements. However they are valid only for special geographic areas and restricted by the climatic data which are available and none of the models now present seems to be universally applicable.

The observation of actual evapotranspiration rate for entire growth of soybean in Cerrados area was made by Horie an Luchiari (1981) using heat balance method. They report that the actual evapotranspiration from soybean field ranged between 70 ∿ 80% of the potential evapotranspiration estimated by Penman method and that the actual evapotranspiration could be estimated from the potential evapotranspiration and the crop coefficient.

The objective of this study is to determine empirical models which could be used to estimate potential evapotranspiration rates in Cerrados conditions.

## 2. Models

Five widely known methods for predicting potential evapotranspiration are tested by comparing the calculated daily means with corresponding values obtained by means of a lysimeter method for a dry season.

### 2-1 Penman

Penman (1948) derived the well-known equation for the evaporation from an open water surface:

$$E_w = \frac{\Delta}{\Delta + \gamma} \frac{R_n}{L} 1.0 + \frac{\gamma}{\Delta + \gamma} f(u)(e_s - e) \qquad (1)$$

where $E_w$ = evaporation [mm day$^{-1}$];

$\Delta$ = slope of the saturation vapor pressure-temperature curve [mb $C^{-1}$];

$\gamma$ = psychrometric constant [$= c_p P(0.622L)^{-1}$, mb $C^{-1}$];

$R_n$ = net radiation [MJ $m^{-2}$];

$L$ = latent heat of evaporation [MJ $kg^{-1}$];

1.0 = coefficient which converts $(R_n/L)$ to millimeters per day;

$f(u)$ = wind function;

$e_s$ = saturation vapor pressure of air [mb];

$e$ = vapor pressure of air [mb];

$c_p$ = specific heat of air [= 0.00100 MJ $kg^{-1}$];

$P$ = atmospheric pressure[mb].

To compute $\Delta$ and $L$, we can use the following approximate equations (Wright, 1982);

$$\Delta = 33.8639[0.05904(0.00738T_a + 0.8072)^7 - 3.42 \times 10^{-5}], \quad (2)$$

$$L = 2.49 - 0.00214T_a, \quad (3)$$

where $T_a$ = mean daily air temperature [C].

Penman (1956) defined potential evapotranspiration, $E_p$, as 'the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water', and expressed it as

$$E_p = f\, E_w, \quad (4)$$

where $f$ is the empirical factor which was found to be 0.8 in summer and 0.6 in winter.

Rjitema demonstrated that both the magnitude of $f$ and its seasonal behavior are constant with the difference in albedo between an open water surface and ground cover in short green vegetation (Thom and Oliver, 1977). $E_p$, therefore, is obtained using a value of $R_n$ appropriate for a vegetated surface:

$$E_p = \frac{\Delta}{\Delta + \gamma}\frac{R_n}{L} + \frac{\gamma}{\Delta + \gamma} f(u)(e_s - e). \quad (5)$$

In Eq. (5), soil heat flux is neglected, since it is small compared to $R_n$ when daily values are considered.

Net radiation data are usually not available. If measured sunshine hours, temperature and humidity data are available, $R_n$ can be estimated using the following equations:

$$R_n = (1 - A)R_s - R_{ln} \tag{6}$$

$$R_s = [a + b(n/N)]R_0 \tag{7}$$

$$R_{ln} = \sigma T_a^4 (c - d\sqrt{e})[0.1 + 0.9(n/N)] \tag{8}$$

where $A$ = albedo;

$R_s$ = short-wave radiation [MJ m$^{-2}$];

$R_{ln}$ = net longwave radiation [MJ m$^{-2}$];

$n$ = duration of sunshine [h];

$N$ = possible duration of sunshine [h];

$R_0$ = extraterrestrial radiation [MJ m$^{-2}$]

$\sigma$ = Stefan-Boltzman constant, per day [4.90 × 10$^{-9}$MJ m$^{-2}$K$^{-4}$]

$a, b, c$ and $d$ = empirical constants dependent on the general nature of the location.

$N$ and $R_0$ are given by the following equations:

$$N = \frac{12}{\pi} 2\cos^{-1}(-\tan\phi\tan\delta) \tag{9}$$

$$R_0 = \frac{\tau_0}{\pi} Q_0 \left(\frac{r_m}{r}\right)^2 [\sin\phi\sin\delta\cos^{-1}(-\tan\phi\tan\delta) + \cos\phi\cos\delta\sqrt{1-(\tan\phi\tan\delta)^2}] \tag{10}$$

where $\tau_0$ = period of the revolution of the earth [24h];

$Q_0$ = solar constant, per hour [4.97 MJ m$^{-2}$];

$r_m$ = mean earth-sun distance;

$r$ = earth-sun distance;

$\phi$ = latitude (north positive);

$\delta$ = declination.

$(r_m/r)^2$ and $\delta$ can be obtained from the following approximate equations (Duffie and Beckman, 1974):

$$\left(\frac{r_m}{r}\right)^2 = 1 + 0.033\cos\left(\frac{2\pi D}{365}\right), \tag{11}$$

$$\delta = 0.409\sin\left(2\pi\frac{284 + D}{365}\right) \tag{12}$$

where $D$ is the day of the year.

To estimate $R_s$, $R_{ln}$, and $R_n$, Doorenbos and Pruitt (1975) have proposed the following values for $A$ in Eq.(6), and $a, b, c$ and $d$ for Eqs.(7) and (8):

$$A = 0.25, \ a = 0.25, \ b = 0.50,$$

$$c = \begin{cases} 0.56 & \text{for humid climate} \\ 0.34 & \text{for dry climate,} \end{cases}$$

$$d = \begin{cases} 0.079 & \text{for humid climate} \\ 0.044 & \text{for dry climate} \end{cases}$$

For $f(u)$ in Eq.(5), various forms are given:

$f(u) = 0.26 + 0.14u$ (Penman, 1948),

$f(u) = 0.13 + 0.14u$ (Penman, 1956),

$f(u) = 0.27 + 0.233u$ (Doorenbos and Pruitt, 1975),

$f(u) = 0.12 + 0.208u$ (Hansen, 1980),

$f(u) = f_1(D) + f_2(D)u$ (James and Wright, 1982),

where $u$ is the mean daily wind speed [m s$^{-1}$], $f_1(D)$ and $f_2(D)$ are the functions of the day [$D$] of the year.

1-2 Priestley and Taylor

If the air is in contact with a wet surface over a very long fetch, it is saturated, so that the second term of Eq.(5) becomes negligible. Accordingly, Slatyer and McIlroy (1961) suggested that the first term of Eq.(5) represents a lower limit to evaporation from wet surface, to which they referred as equilibrium evaporation, $E_{eq}$:

$$E_{eq} = \frac{\Delta}{\Delta + \gamma} \frac{R_n}{L} \tag{13}$$

The second terms of Eq.(5) can be interpreted as a measure of the departure from equilibrium condition, which would originate from large-scale or regional advection involving horizontal variation of surface or atmospheric conditions (Brutsaert, 1982). Since there is always some degree of advection, equilibrium conditions are rarely encountered even over the ocean. Priestley and Taylor (1972) took equilibrium evaporation as the basis for a empirical relationship giving potential evaporation, $E_p$, and showed that $E_p$ is directly related to equilibrium evaporation under conditions of minimal advection:

$$E_p = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_n}{L} . \quad (14)$$

They reported that α averaged about 1.26 for wet surface when $R_n$ was determined on a daily basis. The fact that α is of the order of 1.26 shows that large-scale advection over a large saturated surface accounts on average for about 21 percent of the evaporation rate (Brutsaert, 1982).

2-3 Radiation

Makkink (1957) proposed the following formula for estimating potential evapotranspiration from solar radiation measurements:

$$E_p = c_1 \frac{\Delta}{\Delta + \gamma} \frac{R_s}{L} + c_2 , \quad (15)$$

where $c_1$ and $c_2$ are the empirical coefficients dependent on the general nature of the location. Obviously, this equation can be derived from equilliblium concept. The radiation method may be useful for areas where measured air temperature and sunshine or cloudiness or radiation are available but not wind and humidity.

2-4 Pan evaporation

Potential evapotranspiration can be predicted by

$$E_p = K_p E_{pan} , \quad (16)$$

where $K_p$ is the pan coefficient, $E_{pan}$ the pan evaporation. $K_p$ varies widely according to the climate type of the location and the pan environment. Doorenbos and Pruitt (1975) proposed pan coefficient for class A pan for different ground cover and levels of mean relative humidity and daily wind (Table 1). The estimation by this method is appropriate for periods of 7 ∿ 10 days, since the daily response of crops and pans is quite different (Wright, 1982).

2-5 Blaney-Criddle

The original Blaney-Criddle model involves temperature, $T_a$, and daily percentage of annual daytime hours, $P = 100N/(365 \times 12)[\%]$, as climate variables to predict the effect of climate on evapotranspiration. This is called the consumptive use factor, $f$:

$$f = P(0.46T_a + 8.13). \quad (17)$$

An empirically determined consumptive use crop coefficient, $K$, is applied to establish the consumptive water requirement, $E_p$:

$$E_p = Kf. \tag{18}$$

Doorenbos and Pruitt (1975) reject the use of crop coefficient normally employed in the original Blaney-Criddle model, and proposed a modified euqation:

$$E_p = K_1 + K_2 f, \tag{19}$$

where $K_1$ and $K_2$ are the empirical constants dependent on the general nature of the location. The values of $K_1$ and $K_2$ proposed by Doorenbos and Pruitt (1975) are listed in Table 2. They also suggested that the use of the Blaney-Criddle method to calculate mean daily $E_p$ should normally be applied for periods no shorter than one month.

## 3. Experimental procedure

The data were collected during the 1982 winter season at CPAC located in Blasilia, Blazil. The site was a flat, 0.92 hectare rectanglar plot of wheat (*Anahuac*). The crop was planted on June 5 in 17 cm rows with 82 seeds per meter. Irrigation was made whenever the soil water potential reached -0.6 bar. Crop development terminated in the beginning of September.

Evapotranspiration was measured by a lysimeter and the Bowen ratio method. The constant water level lysimeter installed in the center of the wheat field consists of a container of which the effective area is 7.2 $m^2$ and the depth 1.5 m, of a constant water level box and of a water reservoir (Luchiari, 1982: Fig. 1). The volume of water delivered from the water reservoir into the container to maintain the constant water level is considered as evapotranspiration for that time interval. Wheat was planted in the container in the same way as the field.

For the evaluation of evapotranspiration by the Bowen ratio method, dry-bulb and wet-bulb temperature were measured at two levels above the surface using resistance thermometers. A polyethylene-shielded net radiometer measured the net radiation. Soil heat the flux was measured with soil heat flow meters. Further details on the instrumentation and measurement program have been given by Horie and Luchiari (1981).

The calculations of potential evapotranspiration from the empirical formulars were made using the daily weather data which are collected routinely at the observation field of CPAC.

## 4. Results and Discussion

During of the observation period, the weather was dominated by cloudless sky and light or moderate wind.

Attention is focussed on July and August during which the crop shaded most of the bare soil. Daily potential evapotranspiration from the lysimeter is shown in Fig. 2. It averaged 4.2 mm $day^{-1}$ during July and August, varying from 2.8 mm $day^{-1}$ to 5.6 mm $day^{-1}$.

### 4-1 Penman

The net radiation data collected at the wheat field and Doorenbos and Pruitt's wind function were used for $R_n$ and $f(u)$ in Eq.(5), respectively.

In Fig. 3(A) values of the lysimeter evapotranspiration are ploted against the penman computed values. The scatter value lies systematically around the equivalence line, which is fitted by the straight line going through origin. The slope of the regression line is 0.98, virtually assumed to be 1.0. It therefore is reasonable to conclude that Penman formular modified by Doorenbos and Pruitt (1975) can be applicable to determine potential evapotranspiration in the Cerrados region.

### 4-2 Priestley and Taylor

Priestley-Taylor parameter, $\alpha$, was evaluated as the ratio of daily totals of lysimeter evapotranspiration and equilibrium evaporation.

The seasonal course of $\alpha$ is shown in Fig. 2. The values of $\alpha$ ranged from 1.14 to 5.19 except the early stage of growth and the date of maturity, and the value of $\alpha$=1.26 was rarely approached. In Fig. 3(B), the equilibrium evaporation is compared with the lysimeter evapotranspiration. The regression line forced through the origin yielded $\alpha$ values of 1.74. It seemed that this overestimate of $\alpha$ depended on the decreasing net radiation caused by long wave radiation exchange at night time (Nakayama and Nakamura, 1982) and/or regional advection.

Before applying the Priestley-Taylor model to the Cerrados, further measurements and analysis are required.

4-3 Radiation

To obtain the coefficients $c_1$ and $c_2$ in Eq.(15), we applied linear regression techniques to the daily values of the lysimeter evapotranspiration and $\{\Delta/(\Delta+\gamma)\}R_s$. The result is shown in Fig. 3(C). Since $c_2$ was very close to zero, the regression line was forced through the origin, and this yielded $c_1$ value of 0.84. Doornbos and Pruitt (1975) have proposed value of $c_1$ for different conditions of mean relative humidity and daytime wind speed. This relation is shown in Fig. 4 with the data collected at CPAC to atempt comparing our value with their value. Since daytime wind was not collected at CPAC, the daily wind speed assumed to be close to daytime wind speed was used. It can be seen from Fig. 4 that the mean daily wind speed was less than 3.5 m $s^{-1}$ and the mean daily relative humidity ranged betwen 40% to 70% during the observation period. The $c_1$ values corresponding to these ranges would tend to fall between 0.76 to 0.88 and average 0.81, which is close to the value obtained on the base of the lysimeter evapotranspiration.

Although observed radiation data were used in this analysis, radiation data are seldom available in the Cerrados region. Eq.(7) which permits a etimate of solar radiation was tested using the data of sunshine duration collected at the observation field of CPAC for June 6 - September 13. Fig. 5 shows the relation between $R_s/R_0$ and $n/N$. The coefficients $a$ and $b$ of Eq.(7) were 0.25 and 0.48, respectively, which were in good agreement with the values ($a$=0.25, $b$=0.50) proposed by Doorenbos and Pruitt (1975). The correlation between the measured solar radiation and the calculated one is shown in Fig. 6. Mean values for each pentad, shown on the same plot, indicate agreement to better than 10%.

Using $R_s$ predicted in this manner, potential evapotranspiration was calculated from Eq.(15) and plotted against lysimeter evapotranspiration (Fig. 7). The satter of values lies quite symmetrically around the equivalence line and is similar to that in Fig. 3(C).

From these results, we may conclude that the radiation method based on simple parameters is applicable to the estimation of potential evapotranspiration in the Cerrados.

4-4 Pan evaporation

Evaporation from three different types of evaporimeters was compared with lysimeter evaporation on a pentad basis (Fig. 8). The pan coefficients for the each pan which were obtained by forcing the regression line through the origin are as follows:

$K_p$ = 0.70 for class A pan,

$K_p$ = 0.83 for GGI 3000,

$K_p$ = 0.73 for Young Screen pan.

Let's compare $K_p$ obtained above with $K_p$ from Table 1. The class A pan of CPAC is located in about 100 × 100 m grass cover withering for lack of moisture, surrounded by irrigated wheat field and others. Mean daily relative humidity and mean daily wind speed in dry season would tend to fall between 40% to 70% and 0 to 2.0 m $s^{-1}$, respectively. These give $K_p$ value of 0.65, which is close 0.70.

The limited amount of data has suggested that pan evaporation is a useful indicator of potential evapotranspiration, and it could be estimated using $K_p$ proposed by Doorenbos and Pruitt (1975).

### 4-5 Blaney-Criddle

The monthly means of the potential evapotraspiration by the Blaney-Criddle method were 4.5 mm $day^{-1}$ for July and 3.9 mm $day^{-1}$ for August, while those by lysimeter were 4.2 and 4.3 mm $day^{-1}$ respectively. Further measurements are required to test the applicability of the Blaney-Criddle method for the Cerrados.

## 5. Conclusion

It was suggested that Penman method and Radiation method are applicable to the Cerrados to predect potential evapotranspiration. However, Penman method requires wind, humidity, and net radiation data which are seldom available in the Cerrados. Thus, Radiation method would be useful for that region. If solar radiation is not measured, it can be estimated from duration of sunshine.

Further experiments are required to assess the water balance for each region of the Cerrados.

## Acknowledgments

This work is indebted to the nice organization of the research by Dr. E. Wagner, Director General of CPAC, Dr. E. Lobato, Director of the Research

Department and Dr. M. Resende, Coordinator of soil-plant-water relationship project.

The authors would like to express the most gratitude to Dr. T.Ogata, head of the Japanese consultant team of projecto da cooperacao em presquisa agricola no Brasil for his continued support.

The kind supports to this work given by the technical staffs of CPAC are acknowledged.

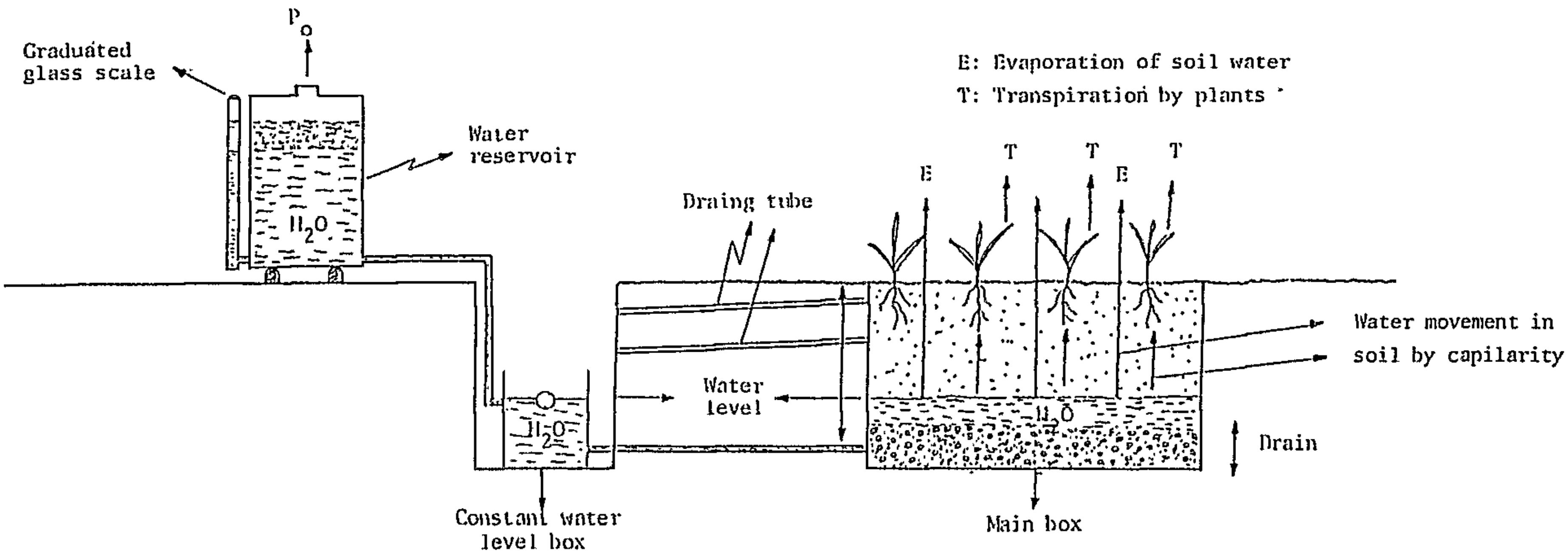


Fig. 1. Schematic representation of constant water level evapotranspirometer (Luchiari, 1982).

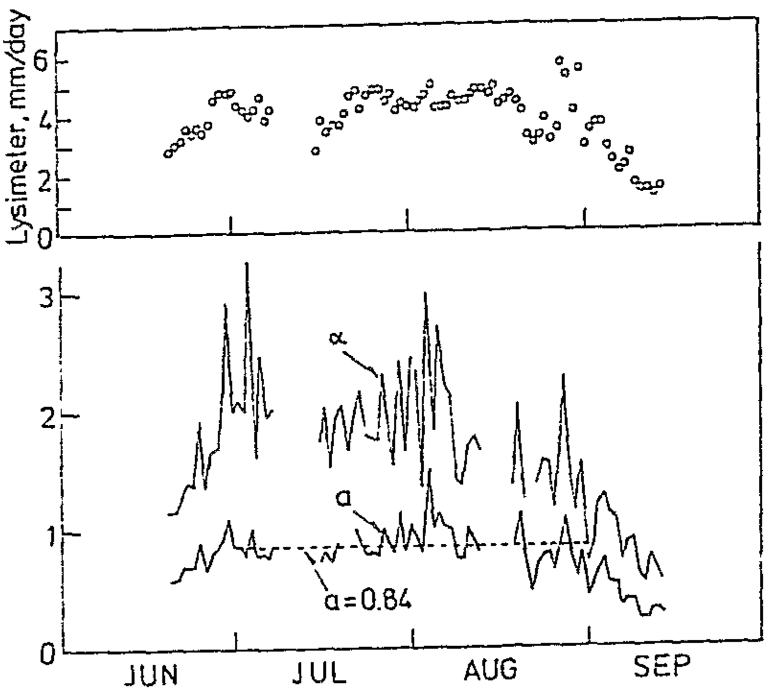


Fig.2. Seasonal trends of lysimeter evapotranspiration, α and *a*.

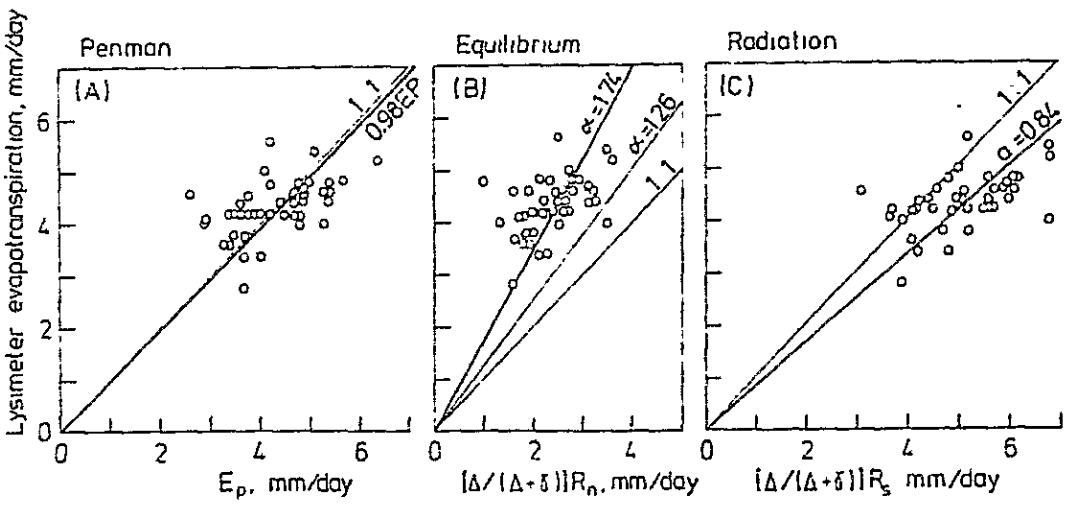


Fig.3. Comparison of lysimeter evapotranspiration with Penman $E_p$,(A), equilibrium evaporation,(B), and $[\Delta/(\Delta + \gamma)]R_s$,(C).

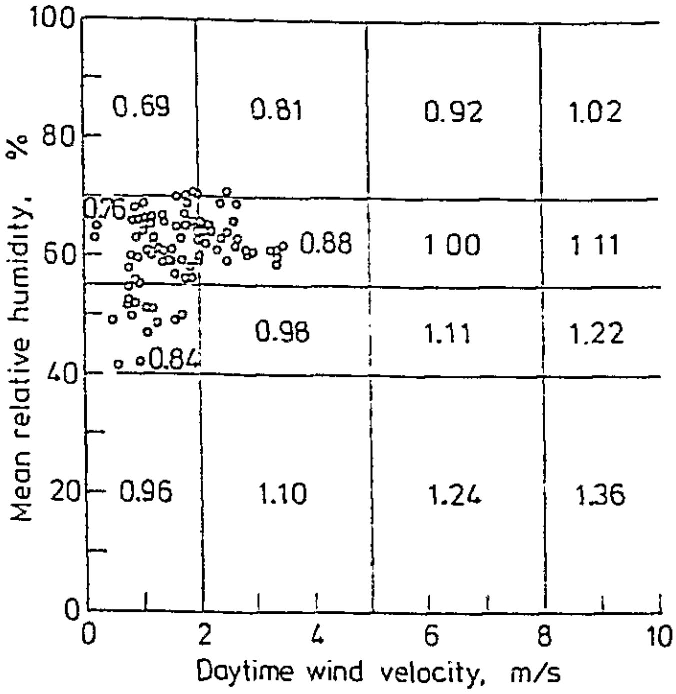


Fig.4. Relationship for obtaining $c_1$ in Eq.(15) from daytime wind speed and mean relative humidity (adapted from Doorenboth and Pruitt, 1975). The circles indicate corresponding values obtained from the obsevation field of CPAC during June 6 - September 13.

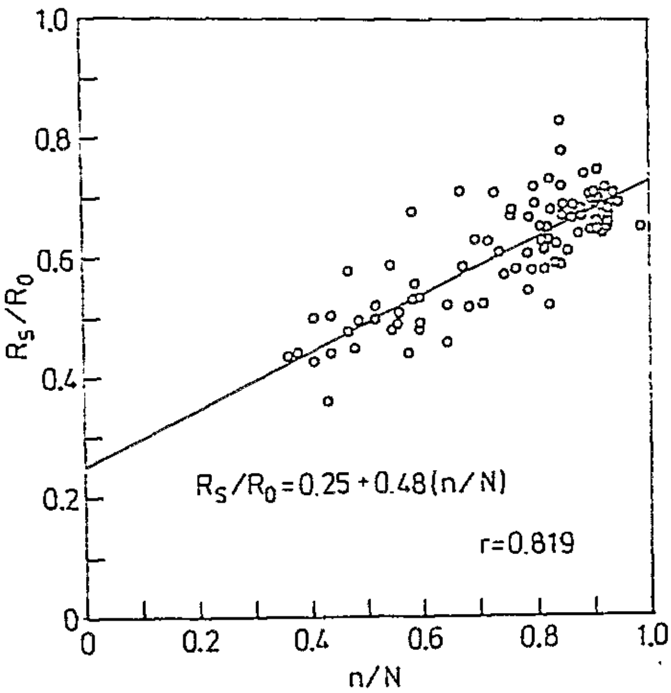


Fig.5. Relation between $n/N$ and $R_s/R_0$.

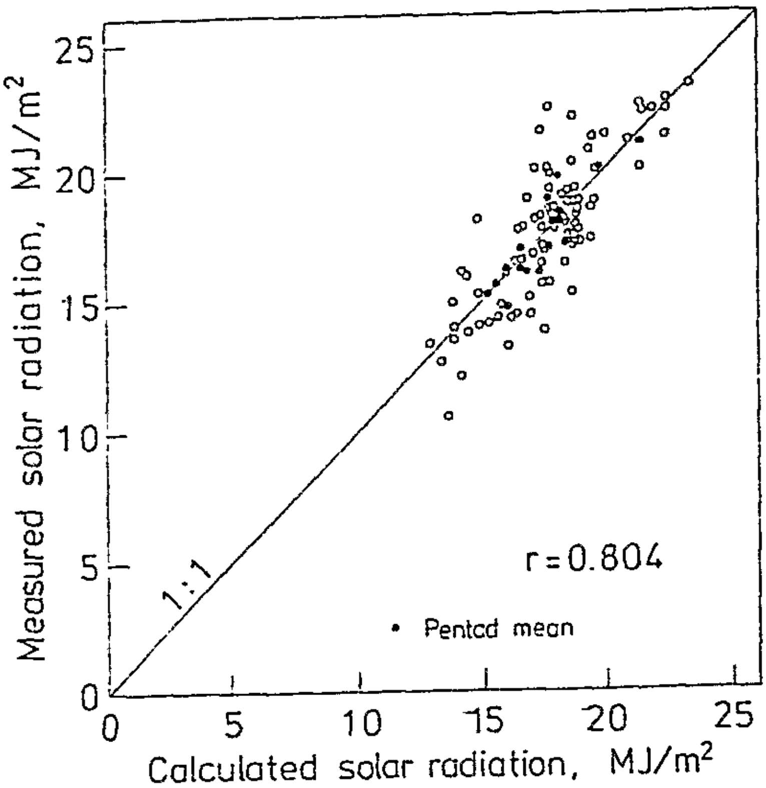


Fig.6. Comparison of actual values of solar radiation with values given by Eq.(7).

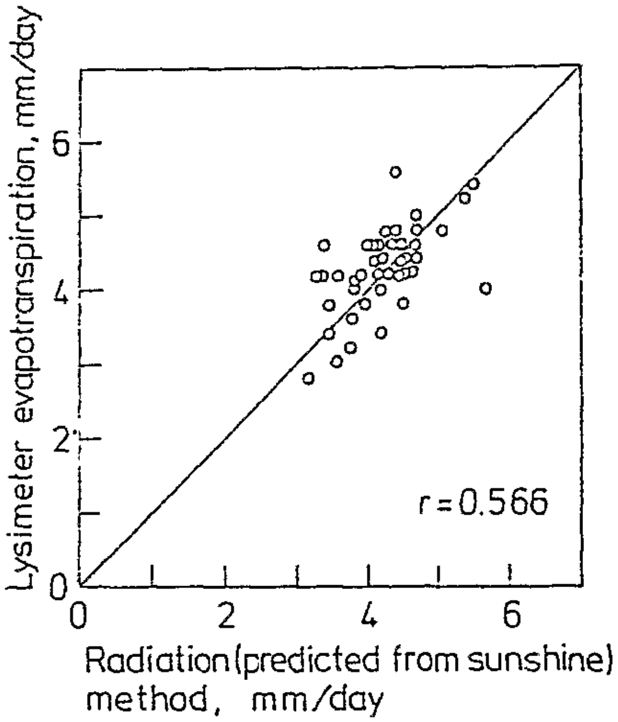


Fig.7. Comparison of lysimeter evapotranspiration with potential evapotranspiration estimated from radiation method using predicted solar radiation.

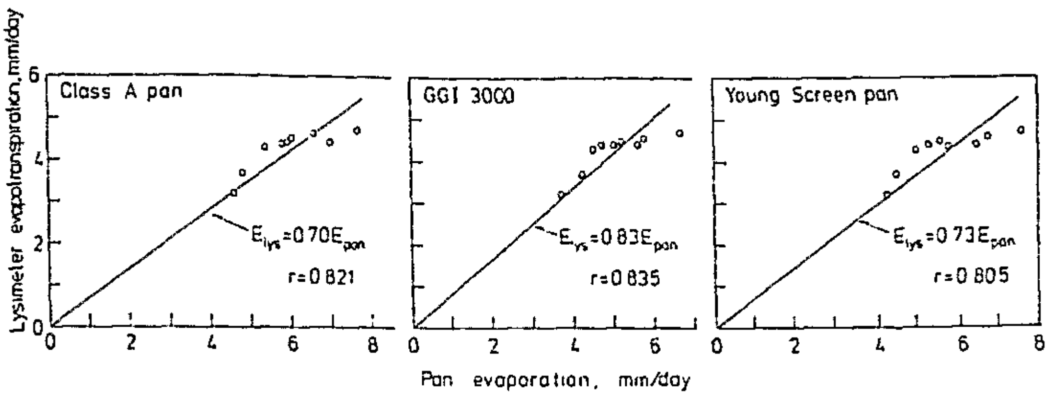


Fig. 8. Comparison of lysimeter evapotranspiration with pan evaporation.

Notes; Class A pan (Diameter 120.7cm, Depth 25cm)
GGI 3000 (Diameter 61.8cm, Depth 60cm)
Young screen (Diameter 90.0cm, Depth 60cm)

Table 1. Pan coefficient $K_p$ for class A pan for different ground cover and levels of mean relative humidity and mean daily wind velocity (from Doorenbos and Pruitt, 1975).

| Class A Pan | Case A<br>Pan surrounded by short green crop | | | | Case B 1/<br>Pan surrounded by dry-fallow land | | | |
|---|---|---|---|---|---|---|---|---|
| RH mean % | | low<br>< 40 | medium<br>40-70 | high<br>> 70 | | low<br>< 40 | medium<br>40-70 | high<br>> 70 |
| Wind<br>m/s | Upwind distance of green crop<br>m | | | | Upwind distance of dry fallow<br>m | | | |
| Light<br>< 2 | 0 | .55 | .65 | .75 | 0 | .7 | .8 | .85 |
| | 10 | .65 | .75 | .85 | 10 | .6 | .7 | .8 |
| | 100 | .7 | .8 | .85 | 100 | .55 | .65 | .75 |
| | 1 000 | .75 | .85 | .85 | 1 000 | .5 | .6 | .7 |
| Moderate<br>2 - 5 | 0 | .5 | .6 | .65 | 0 | .65 | .75 | .8 |
| | 10 | .6 | .7 | .75 | 10 | .55 | .65 | .7 |
| | 100 | .65 | .75 | .8 | 100 | .5 | .6 | .65 |
| | 1 000 | .7 | .8 | .8 | 1 000 | .45 | .55 | .6 |
| Strong<br>5 - 8 | 0 | .45 | .5 | .60 | 0 | .6 | .65 | .7 |
| | 10 | .55 | .6 | .65 | 10 | .5 | .55 | .65 |
| | 100 | .6 | .65 | .7 | 100 | .45 | .5 | .5 |
| | 1 000 | .65 | .7 | .75 | 1 000 | .4 | .45 | .55 |
| Very strong<br>> 8 | 0 | .4 | .45 | .5 | 0 | .5 | .6 | .65 |
| | 10 | .45 | .55 | .6 | 10 | .45 | .5 | .55 |
| | 100 | .5 | .6 | .65 | 100 | .4 | .45 | .5 |
| | 1 000 | .55 | .6 | .65 | 1 000 | .35 | .4 | .45 |

Table 2. Values of $K_1$ and $K_2$ in Eq.(19) for different $n/N$, daytime wind speed and minimum relative humidity (from Doorenboth and Pruitt, 1975)

| $n/N$ | Daytime wind (m/s) | Minimum relative humidity < 20 | 20 ∿ 50 | 50 < |
|---|---|---|---|---|
| 0.3∿0.6 | 0∿2 | $K_1$=-1.60 $K_2$=1.40 | $K_1$=-1.70 $K_2$=1.25 | $K_1$=-1.65 $K_2$=0.98 |
| | 2∿5 | $K_1$=-1.80 $K_2$=1.28 | $K_1$=-1.85 $K_2$=1.15 | $K_1$=-1.55 $K_2$=0.88 |
| | 5 < | $K_1$=-2.00 $K_2$=1.15 | $K_1$=-2.00 $K_2$=1.05 | $K_1$=-1.45 $K_2$=0.80 |
| 0.6∿0.8 | 0∿2 | $K_1$=-1.80 $K_2$=1.73 | $K_1$=-2.10 $K_2$=1.52 | $K_1$=-1.70 $K_2$=1.16 |
| | 2∿5 | $K_1$=-2.05 $K_2$=1.55 | $K_1$=-2.15 $K_2$=1.38 | $K_1$=-1.75 $K_2$=1.06 |
| | 5 < | $K_1$=-2.30 $K_2$=1.35 | $K_1$=-2.20 $K_2$=1.20 | $K_1$=-1.80 $K_2$=0.97 |
| 0.8 < | 0∿2 | $K_1$=-2.00 $K_2$=2.06 | $K_1$=-2.55 $K_2$=1.82 | $K_1$=-1.70 $K_2$=1.31 |
| | 2∿5 | $K_1$=-2.30 $K_2$=1.82 | $K_1$=-2.50 $K_2$=1.61 | $K_1$=-1.95 $K_2$=1.22 |
| | 5 < | $K_1$=-2.60 $K_2$=1.55 | $K_1$=-2.40 $K_2$=1.37 | $K_1$=-2.15 $K_2$=1.14 |

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# APPENDIX 1

## Summary of CPAC results

ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION FROM CLIMATIC DATA

LOCATION:CPAC S 15.36' W 42.30'

Initial date: 1982-06-05

| DATE | Data | | | | | | | | | Potential evapotranspiration (mm/day) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind | Temp | Hum | SVD | Sun | Rad (Obs) | Rad* (Cal) | Net (Obs) | Net* (Cal) | Obs Ep | Penman (Net) | Penman (Net*) | P-T model (Net) | P-T model (Net*) | Rad.model (Rad) | Rad.model (Rad*) | Cnuff | alfa | R-coeff |
| | m/s | C | % | mb | | MJ/m2 | MJ/m2 | MJ/m2 | MJ/m2 | | | | | | | | | | |
| 1 | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | |
| 5 | 1.0 | 18.7 | 65 | 7.55 | 0.79 | 14.50 | 17.04 | 4.06 | 7.73 | 5.80 | 2.53 | 3.35 | 1.74 | 2.77 | 3.46 | 4.07 | 1.38 | 4.20 | 1.41 |
| Mean | 1.0 | 18.7 | 65 | 7.55 | 0.79 | 14.50 | 17.04 | 4.06 | 7.73 | 5.80 | 2.53 | 3.35 | 1.74 | 2.77 | 3.46 | 4.07 | 1.38 | 4.20 | 1.41 |
| 6 | 2.1 | 19.8 | 65 | 8.08 | 0.90 | 19.20 | 18.44 | 8.07 | 8.28 | 4.00 | 4.36 | 4.19 | 3.23 | 3.02 | 4.67 | 4.48 | 2.57 | 1.07 | 0.86 |
| 7 | 0.1 | 19.3 | 63 | 8.28 | 0.94 | 18.24 | 18.91 | 8.91 | 8.29 | 3.60 | 3.28 | 3.18 | 3.22 | 3.08 | 4.40 | 4.56 | 2.56 | 1.41 | 0.69 |
| 8 | 1.4 | 19.5 | 66 | 7.78 | 0.91 | 18.67 | 18.56 | 8.77 | 8.33 | 3.20 | 3.88 | 3.75 | 3.18 | 3.02 | 4.52 | 4.49 | 2.53 | 1.27 | 0.68 |
| 9 | 2.0 | 21.4 | 64 | 9.17 | 0.91 | 17.47 | 18.56 | 8.78 | 8.44 | 3.80 | 4.46 | 4.36 | 3.28 | 3.16 | 4.36 | 4.63 | 2.61 | 1.15 | 0.58 |
| 10 | 1.3 | 21.0 | 60 | 9.95 | 0.88 | 18.04 | 17.16 | 9.09 | 7.76 | 2.60 | 4.27 | 3.88 | 3.38 | 2.89 | 4.47 | 4.25 | 2.60 | 0.97 | 0.49 |
| Mean | 1.4 | 20.2 | 64 | 8.64 | 0.89 | 18.32 | 18.32 | 8.80 | 8.22 | 3.44 | 4.05 | 3.86 | 3.26 | 3.02 | 4.48 | 4.48 | 2.59 | 1.33 | 0.64 |
| 11 | 2.3 | 21.0 | 71 | 7.21 | 0.91 | 19.02 | 18.56 | 9.34 | 8.71 | 2.60 | 4.37 | 4.19 | 3.47 | 3.24 | 4.71 | 4.60 | 2.76 | 0.94 | 0.46 |
| 12 | 1.2 | 20.4 | 64 | 8.63 | 0.85 | 22.38 | 17.06 | 11.01 | 8.10 | 2.40 | 4.00 | 3.72 | 4.35 | 2.98 | 5.49 | 4.38 | 3.45 | 0.70 | 0.37 |
| 13 | 1.8 | 21.5 | 65 | 8.97 | 0.75 | 16.35 | 16.46 | 7.52 | 7.78 | 2.40 | 3.93 | 4.00 | 2.02 | 2.91 | 4.80 | 4.11 | 2.24 | 1.07 | 0.49 |
| 14 | 1.7 | 22.3 | 78 | 8.88 | 0.87 | 18.50 | 18.09 | 8.46 | 8.65 | - | 3.97 | 4.03 | 3.21 | 3.20 | 4.60 | 4.57 | 2.55 | - | - |
| 15 | 1.8 | 20.9 | 69 | 7.66 | 0.93 | 19.07 | 18.79 | 8.79 | 8.69 | - | 4.07 | 4.04 | 3.26 | 3.23 | 4.72 | 4.65 | 2.59 | - | - |
| Mean | 1.8 | 21.2 | 68 | 8.11 | 0.86 | 19.06 | 17.95 | 9.10 | 8.39 | 2.47 | 4.23 | 4.00 | 3.42 | 3.13 | 4.74 | 4.46 | 2.72 | 0.90 | 0.44 |
| 16 | 2.1 | 19.3 | 70 | 6.71 | 0.95 | 18.35 | 19.14 | 7.44 | 8.67 | - | 3.65 | 4.00 | 2.69 | 3.14 | 4.42 | 4.62 | 2.14 | - | - |
| 17 | 2.7 | 20.2 | 62 | 8.99 | 0.76 | 17.70 | 16.69 | 6.07 | 7.63 | - | 4.32 | 4.54 | 2.52 | 2.88 | 4.35 | 4.00 | 2.08 | - | - |
| 18 | 2.6 | 19.2 | 66 | 7.56 | 0.93 | 18.99 | 18.79 | 9.40 | 8.38 | - | 4.67 | 4.38 | 3.39 | 3.02 | 4.57 | 4.52 | 2.69 | - | - |
| 19 | 1.0 | 19.6 | 69 | 7.07 | 0.94 | 17.16 | 18.91 | 8.16 | 8.58 | 2.80 | 3.48 | 3.52 | 2.97 | 3.12 | 4.16 | 4.58 | 2.35 | 1.19 | 0.57 |
| 20 | 0.2 | 18.4 | 65 | 7.48 | 0.89 | 18.12 | 18.32 | 8.77 | 8.11 | 3.00 | 3.20 | 3.01 | 3.12 | 2.89 | 4.30 | 4.35 | 2.48 | 1.21 | 0.59 |
| Mean | 1.7 | 19.3 | 66 | 7.55 | 0.89 | 18.00 | 18.37 | 8.13 | 8.27 | 2.90 | 3.05 | 3.09 | 2.94 | 2.99 | 4.36 | 4.43 | 2.33 | 1.20 | 0.50 |
| 21 | 0.1 | 18.8 | 65 | 7.59 | 0.85 | 16.43 | 17.74 | 8.47 | 7.96 | 3.20 | 3.88 | 2.94 | 3.04 | 2.86 | 3.93 | 4.24 | 2.41 | 1.33 | 0.60 |
| 22 | 0.9 | 19.5 | 63 | 8.38 | 0.94 | 17.88 | 18.91 | 8.90 | 8.31 | 3.60 | 3.77 | 3.58 | 3.26 | 3.02 | 4.31 | 4.57 | 2.59 | 1.39 | 0.70 |
| 23 | 0.9 | 20.0 | 66 | 7.95 | 0.82 | 16.07 | 17.39 | 8.59 | 7.99 | 3.40 | 3.60 | 3.42 | 3.14 | 2.92 | 4.11 | 4.24 | 2.49 | 1.36 | 0.69 |
| 24 | 0.9 | 21.1 | 66 | 8.51 | 0.61 | 13.77 | 14.70 | 6.31 | 7.18 | 3.60 | 3.08 | 3.26 | 2.35 | 2.68 | 3.42 | 3.65 | 1.86 | 1.93 | 0.88 |
| 25 | 1.0 | 20.5 | 64 | 8.60 | 0.76 | 17.79 | 16.69 | 8.61 | 7.73 | 3.40 | 3.76 | 3.58 | 3.18 | 2.85 | 4.37 | 4.10 | 2.52 | 1.35 | 0.65 |
| Mean | 0.8 | 20.0 | 65 | 8.22 | 0.79 | 16.53 | 17.09 | 8.19 | 7.84 | 3.44 | 3.44 | 3.34 | 2.99 | 2.86 | 4.03 | 4.16 | 2.38 | 1.47 | 0.72 |
| 26 | 1.2 | 20.7 | 67 | 8.85 | 0.85 | 15.57 | 17.74 | 7.58 | 8.22 | 3.70 | 3.47 | 3.66 | 2.88 | 3.04 | 3.84 | 4.38 | 2.23 | 1.66 | 0.81 |
| 27 | 1.4 | 22.4 | 61 | 10.56 | 1.00 | 17.29 | 19.73 | 8.86 | 8.79 | 4.50 | 4.33 | 4.31 | 3.36 | 3.34 | 4.30 | 4.99 | 2.67 | 1.69 | 0.86 |
| 28 | 1.4 | 20.4 | 59 | 9.82 | 0.88 | 17.76 | 18.21 | 7.65 | 7.99 | 4.00 | 3.91 | 4.01 | 2.82 | 2.94 | 4.36 | 4.47 | 2.24 | 2.15 | 0.92 |
| 29 | 1.2 | 20.8 | 61 | 9.58 | 0.57 | 13.47 | 14.12 | 5.51 | 6.81 | 4.00 | 3.18 | 3.40 | 2.04 | 2.52 | 3.33 | 3.49 | 1.62 | 2.96 | 1.21 |
| 30 | 2.0 | 24.4 | 64 | 11.00 | 0.94 | 17.73 | 18.91 | 7.71 | 8.93 | 4.80 | 4.37 | 4.75 | 3.01 | 3.49 | 4.62 | 4.92 | 2.39 | 2.01 | 0.87 |
| Mean | 1.4 | 21.7 | 62 | 9.88 | 0.85 | 16.36 | 17.74 | 7.46 | 8.15 | 4.52 | 3.84 | 4.04 | 2.81 | 3.07 | 4.18 | 4.45 | 2.23 | 2.09 | 0.94 |
| Month | 1.3 | 20.2 | 65 | 8.31 | 0.85 | 17.14 | 17.75 | 7.79 | 8.18 | 3.76 | 3.66 | 3.75 | 2.86 | 2.97 | 4.20 | 4.34 | 2.27 | 1.87 | 0.79 |

ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION FROM CLIMATIC DATA

LOCATION :CPAC S 15.36' W 42.30'

JUL 1982

| DATE | Wind | Temp | Hum | SVD | Sun | Rad (Obs) | Rad* (Cal) | Net (Obs) | Net* (Cal) | Obs Ep | Penman (Net) | Penman (Net*) | P-T model (Net) | P-T model (Net*) | Rad.model (Rad) | Rad.model (Rad*) | Eq(l) | alfa | R-coeff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m/s | C | % | mb | | MJ/m2 | MJ/m2 | MJ/m2 | MJ/m2 | | | | | | | | | | |
| 1 | 1.8 | 19.2 | 67 | 7.34 | 0.93 | 17.62 | 18.79 | 7.45 | 8.42 | 4.40 | 3.64 | 3.92 | 2.69 | 3.06 | 4.24 | 4.52 | 2.13 | 2.06 | 0.87 |
| 2 | 2.9 | 19.9 | 68 | 9.29 | 0.93 | 17.62 | 18.79 | 7.46 | 8.18 | 4.20 | 4.72 | 4.92 | 2.72 | 2.99 | 4.29 | 4.58 | 2.16 | 1.94 | 0.82 |
| 3 | 2.4 | 18.6 | 69 | 6.64 | 0.85 | 13.81 | 17.74 | 4.42 | 8.10 | 4.00 | 2.93 | 3.98 | 1.50 | 2.09 | 3.29 | 4.23 | 1.25 | 3.19 | 1.02 |
| 4 | 1.9 | 19.4 | 71 | 6.53 | 0.86 | 19.26 | 17.97 | 9.16 | 8.33 | 4.20 | 4.01 | 3.77 | 3.32 | 3.02 | 4.65 | 4.34 | 2.63 | 1.59 | 0.76 |
| 5 | 2.1 | 19.9 | 64 | 8.36 | 0.93 | 20.23 | 18.79 | 6.43 | 8.36 | 4.60 | 3.77 | 4.27 | 2.42 | 3.05 | 4.93 | 4.58 | 1.97 | 2.39 | 0.78 |
| Mean | 2.2 | 19.4 | 66 | 7.63 | 0.90 | 17.71 | 18.42 | 7.82 | 8.20 | 4.20 | 3.81 | 4.17 | 2.55 | 3.00 | 4.20 | 4.45 | 2.07 | 2.24 | 0.85 |
| 6 | 1.6 | 18.1 | 59 | 8.51 | 0.96 | 18.36 | 18.91 | 7.14 | 8.02 | 3.80 | 3.71 | 3.96 | 2.53 | 2.84 | 4.34 | 4.47 | 2.01 | 1.89 | 0.74 |
| 7 | 1.8 | 18.7 | 60 | 8.62 | 0.93 | 17.20 | 18.79 | 7.51 | 8.07 | 4.20 | 3.45 | 3.61 | 2.69 | 2.89 | 4.18 | 4.48 | 2.13 | 1.97 | 0.86 |
| 8 | 1.5 | 18.8 | 59 | 8.09 | 0.94 | 17.63 | 19.03 | 7.62 | 8.11 | - | 3.84 | 3.98 | 2.73 | 2.91 | 4.22 | 4.55 | 2.17 | - | - |
| 9 | 1.2 | 18.9 | 63 | 8.80 | 0.93 | 17.83 | 18.79 | 7.84 | 8.22 | - | 3.57 | 3.68 | 2.82 | 2.95 | 4.27 | 4.50 | 2.23 | - | - |
| 10 | 1.1 | 18.7 | 61 | 8.41 | 0.84 | 15.61 | 17.62 | 8.35 | 7.76 | - | 3.72 | 3.55 | 2.99 | 2.70 | 3.72 | 4.21 | 2.37 | - | - |
| Mean | 1.3 | 18.6 | 60 | 8.50 | 0.91 | 17.33 | 18.63 | 7.69 | 8.04 | 4.00 | 3.66 | 3.76 | 2.75 | 2.87 | 4.13 | 4.44 | 2.10 | 1.93 | 0.80 |
| 11 | 1.1 | 20.2 | 61 | 9.23 | 0.85 | 18.46 | 17.74 | 8.08 | 7.92 | - | 3.96 | 3.70 | 3.23 | 2.91 | 4.52 | 4.34 | 2.56 | - | - |
| 12 | 1.6 | 19.4 | 65 | 7.88 | 0.85 | 19.92 | 17.74 | 8.21 | 8.01 | - | 3.86 | 3.88 | 2.97 | 2.98 | 4.01 | 4.28 | 2.36 | - | - |
| 13 | 2.1 | 17.5 | 64 | 7.20 | 0.82 | 17.05 | 17.39 | 7.44 | 7.71 | - | 3.81 | 3.80 | 2.61 | 2.70 | 4.17 | 4.06 | 2.07 | - | - |
| 14 | 2.1 | 18.2 | 66 | 7.10 | 0.57 | 12.03 | 14.12 | 4.42 | 6.80 | - | 2.92 | 3.50 | 1.57 | 2.41 | 2.05 | 3.34 | 1.24 | - | - |
| 15 | 2.4 | 19.8 | 63 | 8.54 | 0.40 | 13.30 | 12.95 | 5.60 | 6.43 | 2.00 | 3.71 | 3.93 | 2.07 | 2.35 | 3.25 | 3.15 | 1.64 | 1.70 | 0.72 |
| Mean | 1.9 | 19.0 | 64 | 7.99 | 0.71 | 16.33 | 15.99 | 6.91 | 7.37 | 2.00 | 3.65 | 3.70 | 2.49 | 2.65 | 3.92 | 3.84 | 1.98 | 1.70 | 0.72 |
| 16 | 2.5 | 19.5 | 71 | 6.57 | 0.56 | 16.24 | 14.80 | 6.55 | 6.97 | 3.80 | 3.56 | 3.66 | 2.38 | 2.53 | 3.93 | 3.39 | 1.89 | 2.01 | 0.81 |
| 17 | 2.0 | 18.9 | 64 | 7.06 | 0.80 | 16.76 | 17.16 | 8.00 | 7.75 | 3.40 | 4.05 | 3.95 | 2.90 | 2.70 | 4.01 | 4.11 | 2.30 | 1.40 | 0.71 |
| 18 | 1.2 | 19.1 | 62 | 8.40 | 0.67 | 14.20 | 15.41 | 6.72 | 7.14 | 3.60 | 3.38 | 3.42 | 2.42 | 2.57 | 3.43 | 3.70 | 1.92 | 1.87 | 0.88 |
| 19 | 1.7 | 18.3 | 63 | 7.70 | 0.66 | - | 15.29 | 6.34 | 7.00 | 3.60 | 3.39 | - | 2.25 | - | - | 3.62 | 1.79 | 2.01 | - |
| 20 | 2.5 | 19.2 | 59 | 9.12 | 0.94 | - | 19.03 | 8.60 | 8.14 | 4.00 | 4.70 | - | 3.10 | - | - | 4.50 | 2.46 | 1.62 | - |
| Mean | 2.0 | 19.0 | 64 | 7.95 | 0.72 | 15.76 | 16.10 | 7.26 | 7.42 | 3.60 | 3.81 | 3.60 | 2.61 | 2.63 | 3.79 | 3.80 | 2.07 | 1.80 | 0.80 |
| 21 | 2.9 | 18.5 | 60 | 8.52 | 0.85 | 16.39 | 17.06 | 8.51 | 7.70 | 4.60 | 4.80 | 4.67 | 3.84 | 2.77 | 3.90 | 4.25 | 2.41 | 1.91 | 0.99 |
| 22 | 3.4 | 17.6 | 59 | 8.25 | 0.95 | 19.97 | 19.14 | 8.11 | 8.05 | 4.00 | 5.03 | 5.02 | 2.85 | 2.83 | 4.67 | 4.40 | 2.26 | 2.12 | 0.86 |
| 23 | 2.9 | 17.1 | 61 | 7.60 | 0.81 | 20.13 | 17.27 | 8.75 | 7.54 | 4.20 | 4.74 | 4.40 | 3.84 | 2.62 | 4.67 | 4.01 | 2.42 | 1.74 | 0.76 |
| 24 | 3.3 | 18.1 | 61 | 8.10 | 0.75 | 20.14 | 16.46 | 9.53 | 7.36 | 4.60 | 5.29 | 4.60 | 3.30 | 2.61 | 4.76 | 3.89 | 2.60 | 1.72 | 0.81 |
| 25 | 3.3 | 18.4 | 61 | 8.25 | 0.86 | 22.00 | 17.97 | 9.94 | 7.84 | 4.00 | 5.44 | 4.05 | 3.54 | 2.79 | 5.24 | 4.27 | 2.81 | 1.71 | 0.77 |
| Mean | 3.2 | 17.9 | 60 | 8.14 | 0.85 | 19.74 | 17.74 | 8.97 | 7.71 | 4.60 | 5.00 | 4.72 | 3.17 | 2.73 | 4.65 | 4.10 | 2.51 | 1.84 | 0.84 |
| 26 | 3.4 | 17.1 | 60 | 7.80 | 0.87 | 17.23 | 18.09 | 7.70 | 7.75 | 4.80 | 4.82 | 4.81 | 2.71 | 2.78 | 4.80 | 4.20 | 2.15 | 2.23 | 1.01 |
| 27 | 2.5 | 17.3 | 64 | 7.11 | 0.84 | 18.84 | 17.62 | 8.90 | 7.77 | 4.40 | 4.43 | 4.09 | 3.14 | 2.71 | 4.20 | 4.10 | 2.49 | 1.77 | 0.80 |
| 28 | 2.2 | 17.8 | 65 | 7.13 | 0.91 | 21.38 | 18.56 | 11.21 | 8.14 | 3.70 | 4.89 | 4.03 | 3.95 | 2.87 | 5.00 | 4.36 | 3.13 | 1.10 | 0.62 |
| 29 | 1.1 | 17.5 | 66 | 6.80 | 0.66 | 13.23 | 15.29 | 6.20 | 7.12 | 4.10 | 2.88 | 3.12 | 2.20 | 2.50 | 3.09 | 3.57 | 1.75 | 2.35 | 1.11 |
| 30 | 2.0 | 18.4 | 60 | 8.46 | 0.90 | 18.37 | 18.44 | 9.19 | 7.94 | 4.20 | 4.51 | 4.16 | 3.27 | 2.83 | 4.36 | 4.30 | 2.60 | 1.62 | 0.81 |
| 31 | 2.1 | 20.7 | 59 | 10.01 | 0.57 | 13.95 | 14.12 | 5.95 | 6.74 | 4.20 | 3.09 | 4.12 | 2.20 | 2.49 | 3.44 | 3.40 | 1.75 | 2.40 | 1.03 |
| Mean | 2.2 | 18.1 | 62 | 7.88 | 0.79 | 17.02 | 17.07 | 8.23 | 7.50 | 4.23 | 4.26 | 4.06 | 2.91 | 2.60 | 4.02 | 4.02 | 2.31 | 1.93 | 0.91 |
| Month | 2.1 | 18.7 | 63 | 8.02 | 0.81 | 17.31 | 17.33 | 7.60 | 7.73 | 3.93 | 4.04 | 4.03 | 2.75 | 2.76 | 4.13 | 4.13 | 2.10 | 1.91 | 0.82 |

ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION FROM CLIMATIC DATA

LOCATION :CPAC S 15.36' W 42.30'

AUG 1982

| DATE | Wind | Temp | Hum | SVD | Sun | Rad (Obs) | Rad* (Cal) | Net (Obs) | Net* (Cal) | Obs Ep | Penman (Net) | Penman (Net*) | P-T model (Net) | P-T model (Net*) | Rad.model (Rad) | Rad.model (Rad*) | Eaull | alfa | R-coeff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m/s | C | % | mb | | MJ/m2 | MJ/m2 | MJ/m2 | MJ/m2 | | | | | | | | | | |
| 1 | 1.6 | 22.2 | 57 | 11.51 | 0.72 | 15.11 | 16.11 | 7.57 | 7.40 | 4.20 | 4.24 | 4.19 | 2.07 | 2.00 | 3.01 | 4.06 | 2.27 | 1.05 | 0.93 |
| 2 | 1.4 | 22.7 | 61 | 10.76 | 0.76 | 10.39 | 16.57 | 10.79 | 7.77 | 4.40 | 4.94 | 4.03 | 4.11 | 2.96 | 4.60 | 4.21 | 3.27 | 1.35 | 0.79 |
| 3 | 0.9 | 20.6 | 60 | 7.76 | 0.46 | 10.50 | 12.72 | 5.31 | 6.53 | 4.60 | 2.61 | 2.97 | 1.96 | 2.41 | 2.61 | 3.13 | 1.56 | 2.95 | 1.40 |
| 4 | 1.4 | 20.0 | 67 | 0.10 | 0.04 | 17.12 | 17.62 | 9.33 | 0.19 | 5.00 | 4.10 | 3.77 | 3.46 | 3.03 | 4.23 | 4.35 | 2.74 | 1.07 | 0.99 |
| 5 | 2.7 | 20.3 | 63 | 0.01 | 0.43 | 12.72 | 12.37 | 5.34 | 6.27 | 4.20 | 3.02 | 4.10 | 1.96 | 2.31 | 3.12 | 3.03 | 1.56 | 2.70 | 1.13 |
| Mean | 1.6 | 21.3 | 63 | 9.39 | 0.64 | 14.70 | 15.00 | 7.67 | 7.23 | 4.40 | 3.94 | 3.01 | 2.07 | 2.70 | 3.69 | 3.76 | 2.20 | 2.13 | 1.06 |
| 6 | 2.7 | 19.0 | 69 | 6.01 | 0.63 | 14.41 | 14.94 | 6.63 | 7.20 | 4.20 | 3.73 | 3.90 | 2.39 | 2.59 | 3.46 | 3.50 | 1.09 | 2.22 | 1.02 |
| 7 | 1.9 | 18.8 | 66 | 7.30 | 0.46 | 14.90 | 12.72 | 6.93 | 6.30 | 4.20 | 3.56 | 3.41 | 2.49 | 2.29 | 3.56 | 3.04 | 1.97 | 2.13 | 0.99 |
| 8 | 1.9 | 20.0 | 56 | 10.29 | 0.70 | 21.16 | 15.07 | 11.07 | 7.13 | 4.60 | 5.34 | 4.19 | 4.05 | 2.61 | 5.16 | 3.07 | 3.21 | 1.43 | 0.75 |
| 9 | 1.6 | 19.5 | 49 | 11.56 | 0.04 | 20.00 | 17.62 | 11.22 | 7.30 | 4.40 | 5.42 | 4.29 | 4.07 | 2.65 | 5.03 | 4.26 | 3.23 | 1.36 | 0.73 |
| 10 | 2.3 | 22.2 | 49 | 13.65 | 0.63 | 14.30 | 14.94 | 0.60 | 6.72 | 4.40 | 5.53 | 4.95 | 3.29 | 2.54 | 3.63 | 3.77 | 2.61 | 1.69 | 1.02 |
| Mean | 2.1 | 19.9 | 50 | 9.93 | 0.65 | 17.13 | 15.22 | 0.91 | 6.95 | 4.36 | 4.72 | 4.15 | 3.26 | 2.54 | 4.17 | 3.71 | 2.50 | 1.77 | 0.90 |
| 11 | 1.9 | 21.6 | 50 | 10.03 | 0.70 | 17.07 | 16.92 | 0.01 | 7.65 | 4.60 | 4.73 | 4.30 | 3.31 | 2.07 | 4.27 | 4.23 | 2.62 | 1.75 | 0.90 |
| 12 | 3.6 | 19.6 | 62 | 0.66 | 0.94 | 21.21 | 10.91 | 10.15 | 0.20 | 4.00 | 5.75 | 5.21 | 3.69 | 3.01 | 5.14 | 4.50 | 2.93 | 1.64 | 0.70 |
| 13 | - | 19.3 | 66 | 7.61 | 0.90 | 13.96 | 19.49 | - | 0.62 | 4.00 | - | | - | 3.12 | 3.37 | 4.70 | - | | - |
| 14 | - | 19.2 | 60 | 0.90 | 0.97 | - | 19.30 | - | 0.29 | 4.60 | - | | - | - | | 4.66 | | - | - |
| 15 | - | 20.1 | 53 | 11.05 | 0.00 | - | 10.21 | - | 7.69 | 4.90 | - | | - | - | - | 4.45 | - | - | - |
| Mean | 2.0 | 20.0 | 60 | 9.41 | 0.91 | 17.41 | 10.50 | 9.40 | 0.11 | 4.74 | 5.24 | 4.00 | 3.50 | 3.00 | 4.26 | 4.53 | 2.70 | 1.70 | 0.04 |
| 16 | - | 22.0 | 51 | 12.95 | 0.50 | 4.20 | 14.26 | 2.97 | 6.59 | 4.30 | - | - | 1.12 | 2.49 | 1.06 | 3.50 | 0.89 | 4.03 | 3.42 |
| 17 | - | 20.9 | 52 | 11.06 | 0.02 | 4.21 | 17.39 | 2.00 | 7.47 | 4.40 | | - | 1.07 | 2.77 | 1.04 | 4.30 | 0.05 | 5.19 | 3.55 |
| 18 | - | 19.4 | 51 | 11.04 | 0.62 | 10.09 | 14.02 | 11.09 | 6.61 | 4.60 | | - | 4.31 | 2.40 | 4.56 | 3.50 | 3.42 | 1.35 | 0.05 |
| 19 | - | 20.0 | 62 | | - | 13.02 | 6.76 | 7.45 | | 4.60 | 2.16 | - | 2.73 | - | 3.37 | 1.65 | 2.16 | 2.03 | 1.10 |
| 20 | - | 21.5 | 64 | 9.23 | 0.49 | 10.12 | 13.07 | 10.95 | 6.60 | 4.00 | - | | 4.10 | 2.47 | 4.53 | 3.26 | 3.26 | 1.23 | 0.74 |
| Mean | - | 20.8 | 56 | 11.27 | 0.62 | 11.05 | 13.26 | 7.23 | 6.02 | 4.34 | 2.16 | - | 2.67 | 2.53 | 2.91 | 3.20 | 2.12 | 2.93 | 1.93 |
| 21 | - | 20.0 | 60 | 7.06 | 0.31 | 23.41 | 10.73 | 15.30 | 5.06 | 3.20 | - | | 5.70 | 2.17 | 5.70 | 2.65 | 4.52 | 0.71 | 0.46 |
| 22 | - | 18.0 | 70 | 6.51 | 0.21 | 15.01 | 9.45 | 7.74 | 5.37 | 3.00 | - | - | 2.70 | 1.93 | 3.59 | 2.26 | 2.20 | 1.36 | 0.70 |
| 23 | - | 21.1 | 51 | 12.26 | 0.50 | 14.15 | 13.30 | 6.09 | 6.27 | 3.20 | - | - | 2.57 | 2.33 | 3.51 | 3.30 | 2.04 | 1.57 | 0.77 |
| 24 | - | 20.0 | 50 | 10.31 | 0.54 | 16.01 | 13.77 | 0.42 | 6.61 | 3.00 | - | - | 3.12 | 2.45 | 3.96 | 3.40 | 2.40 | 1.53 | 0.01 |
| 25 | - | 21.2 | 61 | 9.02 | 0.43 | 16.00 | 12.37 | 0.59 | 6.27 | 3.00 | - | - | 3.20 | 2.34 | 3.90 | 3.07 | 2.54 | 1.10 | 0.63 |
| Mean | - | 20.5 | 62 | 9.35 | 0.40 | 16.92 | 11.93 | 9.40 | 6.00 | 3.24 | - | | 3.47 | 2.24 | 4.16 | 2.94 | 2.76 | 1.27 | 0.67 |
| 26 | - | 21.9 | 55 | 11.02 | 0.40 | 14.13 | 11.90 | 7.12 | 6.01 | 3.40 | - | | 2.60 | 2.26 | 3.55 | 2.99 | 2.13 | 1.60 | 0.00 |
| 27 | 1.0 | 22.3 | 57 | 12.92 | 0.63 | 17.14 | 14.94 | 0.16 | 6.05 | 5.60 | 4.10 | 3.70 | 3.09 | 2.60 | 4.33 | 3.70 | 2.46 | 2.20 | 1.09 |
| 28 | 0.2 | 22.6 | 40 | 14.26 | 0.09 | 22.47 | 10.32 | 11.99 | 7.66 | 5.20 | 4.01 | 3.50 | 4.57 | 2.92 | 5.70 | 4.65 | 3.62 | 1.43 | 0.77 |
| 29 | 0.9 | 22.6 | 50 | 13.71 | 0.95 | 22.69 | 19.14 | 11.67 | 0.01 | 4.00 | 5.25 | 4.14 | 4.44 | 3.05 | 5.76 | 4.06 | 3.53 | 1.13 | 0.50 |
| 30 | 0.7 | 22.5 | 52 | 13.16 | 0.91 | 22.35 | 18.56 | 11.57 | 7.95 | 5.40 | 4.99 | 3.90 | 4.41 | 3.03 | 5.67 | 4.71 | 3.50 | 1.54 | 0.00 |
| 31 | 1.0 | 21.6 | 56 | 11.35 | 0.09 | 22.25 | 18.32 | 13.37 | 0.00 | 5.90 | 5.54 | 3.94 | 5.02 | 3.00 | 5.57 | 4.50 | 3.90 | 1.40 | 0.09 |
| Mean | 0.0 | 22.3 | 52 | 12.07 | 0.70 | 20.17 | 16.06 | 10.65 | 7.41 | 4.92 | 4.95 | 3.05 | 4.04 | 2.01 | 5.10 | 4.26 | 3.20 | 1.50 | 0.02 |
| Month | 1.0 | 20.0 | 50 | 10.37 | 0.67 | 16.30 | 15.15 | 0.09 | 7.10 | 4.35 | 4.20 | 4.15 | 3.30 | 2.64 | 4.05 | 3.74 | 2.62 | 1.90 | 1.04 |

ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION FROM CLIMATIC DATA

LOCATION :CPAC S 15.36' W 47.30'

SEP 1982

| DATE | Data: Wind m/s | Temp C | Hum % | SVD mb | Sun | Rad (Obs) MJ/m2 | Rad* (Cal) MJ/m2 | Net (Obs) MJ/m2 | Net* (Cal) MJ/m2 | Obs Ep | Potential evapotranspiration [mm/day]: Penman (Net) | Penman (Net*) | P T model (Net) | P T model (Net*) | Rad.model (Rad) | Rad.model (Rad*) | Equil | alfa | R-coeff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.9 | 22.2 | 55 | 12.04 | 0.76 | 21.27 | 16.57 | 12.35 | 7.46 | 3.40 | 5.25 | 3.70 | 4.60 | 2.82 | 5.37 | 4.10 | 3.71 | 0.92 | 0.53 |
| 2 | 1.7 | 23.7 | 59 | 12.01 | 0.73 | 18.77 | 16.22 | 9.06 | 7.66 | 3.60 | 5.04 | 4.36 | 3.81 | 2.96 | 4.04 | 4.18 | 3.03 | 1.19 | 0.62 |
| 3 | 1.7 | 22.1 | 50 | 13.30 | 0.53 | 16.55 | 13.65 | 9.26 | 6.39 | 3.60 | 5.14 | 4.20 | 3.50 | 2.41 | 4.17 | 3.44 | 2.70 | 1.30 | 0.73 |
| 4 | 1.2 | 21.4 | 51 | 12.49 | 0.64 | 17.92 | 15.05 | 8.51 | 6.79 | 2.80 | 4.41 | 3.90 | 3.10 | 2.54 | 4.47 | 3.75 | 2.53 | 1.11 | 0.53 |
| 5 | 0.7 | 21.6 | 52 | 12.30 | 0.40 | 14.70 | 12.95 | 7.50 | 6.22 | 2.40 | 3.69 | 3.31 | 2.01 | 2.33 | 3.70 | 3.24 | 2.23 | 1.07 | 0.55 |
| Mean | 1.2 | 22.2 | 53 | 12.44 | 0.63 | 17.86 | 14.89 | 9.50 | 6.90 | 3.16 | 4.71 | 3.93 | 3.60 | 2.67 | 4.51 | 3.76 | 2.86 | 1.12 | 0.59 |
| 6 | 1.2 | 22.6 | 47 | 14.53 | 0.83 | 19.94 | 17.51 | 9.30 | 7.30 | 2.00 | 4.90 | 4.32 | 3.54 | 2.81 | 5.06 | 4.44 | 2.81 | 0.71 | 0.33 |
| 7 | 1.9 | 22.7 | 56 | 12.14 | 0.64 | 19.17 | 15.05 | 8.17 | 7.07 | 2.20 | 4.73 | 4.40 | 3.12 | 2.70 | 4.87 | 3.83 | 2.47 | 0.89 | 0.30 |
| 8 | 1.1 | 21.9 | 51 | 12.87 | 0.88 | 22.27 | 18.21 | 9.54 | 7.73 | 2.60 | 4.60 | 4.14 | 3.60 | 2.91 | 5.60 | 4.57 | 2.85 | 0.91 | 0.39 |
| 9 | 1.8 | 21.8 | 42 | 15.15 | 0.94 | 23.17 | 18.91 | 9.12 | 7.41 | 1.60 | 4.78 | 4.27 | 3.43 | 2.79 | 5.81 | 4.74 | 2.72 | 0.59 | 0.23 |
| 10 | 0.5 | 23.1 | 41 | 16.67 | 0.88 | 21.12 | 18.21 | 8.84 | 7.26 | 1.40 | 4.35 | 3.87 | 3.39 | 2.78 | 5.40 | 4.66 | 2.69 | 0.52 | 0.22 |
| Mean | 1.1 | 22.4 | 47 | 14.27 | 0.83 | 21.13 | 17.50 | 8.99 | 7.37 | 1.96 | 4.69 | 4.20 | 3.42 | 2.80 | 5.35 | 4.45 | 2.71 | 0.72 | 0.31 |
| 11 | 0.5 | 21.0 | 49 | 13.32 | 0.40 | 15.29 | 11.98 | 6.00 | 5.84 | 1.40 | 3.10 | 3.16 | 2.26 | 2.20 | 3.84 | 2.99 | 1.79 | 0.78 | 0.31 |
| 12 | 0.8 | 21.3 | 58 | 10.64 | 0.63 | 15.22 | 14.94 | 6.26 | 7.01 | 1.20 | 3.19 | 3.41 | 2.34 | 2.62 | 3.79 | 3.72 | 1.86 | 0.65 | 0.27 |
| 13 | 1.0 | 23.9 | 60 | 11.06 | 0.55 | 18.10 | 13.89 | 8.35 | 6.93 | 1.40 | 4.06 | 3.62 | 3.24 | 2.69 | 4.60 | 3.59 | 2.57 | 0.54 | 0.25 |
| 14 | 1.9 | 21.7 | 78 | 7.79 | 0.03 | 8.93 | 7.11 | 3.00 | 4.64 | - | 2.42 | 2.09 | 1.16 | 1.74 | 2.24 | 1.78 | 0.92 | - | - |

# APPENDIX 2

A BASIC program for calculating the potential evapotranspiration from climatic data by

T. Sakuratani

```
10 LPRINT "ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION FROM CLIMATIC DATA"
20 LPRINT
30 'EPO = Potential evapotranspiration from Penman based on observed net radiation (mm/day)
40 'EPC = Potential evapotranspiration from Penman based on sunshine duration (mm/day)
50 'EPTO= Potential evapotranspiration from Prestley-Taylor based on observed net radiation (mm/day)
60 'EPTC= Potential evapotranspiration from Prestley-Taylor based on calculated net radiation (mm/day)
70 'ERO = Potential evapotranspiration from radiation method based on observed solar radiation (mm/day)
80 'ERC = Potential evapotranspiration from radiation method based on sunshine duration (mm/day)
90 'R0 = Extraterrestrial radiation (MJ/M2)
100 'RS = Short-wave radiation (MJ/M2)
110 'POSSN= Possible duration of sunshine (hr)
120 'N' = Duration of sunshine (hr)
130 'RLN= Net long wave radiation (MJ/M2)
140 'RN =Net radiation (MJ/M2)
150 'TD = Air temperature (C)
160 'HUM= Relative humidity (%)
170 'U  = Wind speed (m/s)
180 I1=0:I2=0:I3=0:I4=0:I5=0:I6=0:I7=0:I8=0:I9=0:I10=0:I11=0:I12=0:I13=0:I14=0:I15=0:I16=0:I17=0:I18=0:I19=0
190 II=0
200 PU=0
210 PTD=0
220 PHUM=0
230 PVD=0
240 PSUN=0
250 PRS=0
260 PRSC=0
270 PRN=0
280 PRNC=0
290 PEOBS=0
300 PEOP=0
310 PEPC=0
320 PEPTO=0
330 PEPTC=0
340 PERO=0
350 PERC=0
360 PEOUT=0
370 PALFA=0
380 PRCOEFF=0
390 J1=0:J2=0:J3=0:J4=0:J5=0:J6=0:J7=0:J8=0:J9=0:J10=0:J11=0:J12=0:J13=0:J14=0:J15=0:J16=0:J17=0:J18=0:J19=0
400 SP1=0:SP2=0:SP3=0:SP4=0:SP5=0:SP6=0:SP7=0:SP8=0:SP9=0:SP10=0:SP11=0:SP12=0:SP13=0:SP14=0:SP15=0:SP16=0:SP17=0:SP18=0:SP19=0:Z=0
410 II=0
420 INPUT "From key or File or Free, K/F/FR";C$
430 IF C$="F" GOTO 600
440 IF C$="FR" GOTO 450
450 INPUT "Do you input Observed evapotranspiration, Y/N";U$
460 INPUT "Do you input wind, Y/N";V$
470 INPUT "Do you input relative humidity, Y/N";W$
480 INPUT "Do you input net radiation, Y/N";X$
490 INPUT "Do you input solar radiation, Y/N";Y$
500 INPUT "Do you input duration of sunshine, Y/N";Z$
510 INPUT "Atomosperic pressure";P
520 INPUT "LOCATION";STIT$
530 INPUT "LATITUDE,  N or S,  Deg.Min";LA$,LAT
540 INPUT "LONGITUDE,  E or W,  Deg.Min";LO$,LON
550 INPUT "DATE,  0000 00-00";DAT$
560 DATE$=DAT$
570 IF C$="FR" GOTO 800
580 GOTO 640
590 IDAY=DAY:GOTO 690
600 INPUT "Atomosperic pressure";P
610 OPEN "EPAC" FOR INPUT AS #1:'''''''''''''''' FILE NAME ''''''''''''''''
620 INPUT #1,STIT$,LA$,LAT,LO$,LON,DAT$
630 DATE$=DAT$
640 DM$=MID$(DAT$,9)
650 DAY=VAL(DM$)
```

```
660 YEAR=VAL(MID$(DATE$,1,4))
670 LY=YEAR/4-FIX(YEAR/4)
680 IF LY<.01 THEN LY=1, ELSE LY=0
690 IF DAY=1 GOTO 960
700 LPRINT "LOCATION:" SITE$;
710 LPRINT USING "                    &&";LA$;
720 LPRINT USING "##.##";LAT;
730 LPRINT "'";
740 LPRINT USING "  &&";LO$;
750 LPRINT USING "##.##";LON;
760 LPRINT "'"
770 LPRINT
780 LPRINT "Initial date:  " DAT$
790 LPRINT
800 LPRINT SPC(31);"Data";SPC(32);"Potential evapotranspiration [mm/day]"
810 LPRINT "
820 LPRINT " DATE";" Wind ";" Temp";"  Hum";"  SVD";"  Sun";"  Rad  ";" Rad*";" Net";"  Net*";" Obs Fe ";" Penman ";"    P-T model";" Rad.model ";" Fcull";" alfa";" R-coeff"
830 LPRINT SPACE$(37);"(Obs) (Cal) (Obs) (Cal)       (Net)(Net*) (Net)(Net*) (Rad)(Rad*)"
840  LPRINT "         m/s      C      %      mb        MJ/m2 MJ/m2 MJ/m2 MJ/m2";"
850 LPRINT
860 IF C$="FR" GOTO 1150
870 FOR I=1 TO DAY-1
880 IF I=6 THEN LPRINT:LPRINT:LPRINT
890 IF I=11 THEN LPRINT:LPRINT:LPRINT
900 IF I=16 THEN LPRINT:LPRINT:LPRINT
910 IF I=21 THEN LPRINT:LPRINT:LPRINT
920 IF I=26 THEN LPRINT:LPRINT:LPRINT
930 LPRINT USING " ##  ";I
940 NEXT I
950 IF C$="K" GOTO 970
960 IF C$="F" THEN INPUT #1,IDATE,IDAY,EOBS,U,HUM,TD,RN,RS,N:GOTO 1290
970 J=-1
980 JJ=-1
990 J=J+1
1000 IDATE=DATE+J
1010 JJ=JJ+1
1020 IDAY=DAY+JJ
1030 IF IDATE=32 THEN PRINT "FEB":DAY=1:JJ=0:GOTO 590
1040 IF IDATE=60+LY THEN PRINT "MAR":DAY=1:JJ=0:GOTO 590
1050 IF IDATE=91+LY THEN PRINT "APR":DAY=1:JJ=0:GOTO 590
1060 IF IDATE=121+LY THEN PRINT "MAY":DAY=1:JJ=0:GOTO 590
1070 IF IDATE=152+LY THEN PRINT "JUN":DAY=1:JJ=0:GOTO 590
1080 IF IDATE=182+LY THEN PRINT "JUL":DAY=1:JJ=0:GOTO 590
1090 IF IDATE=213+LY THEN PRINT "AUG":DAY=1:JJ=0:GOTO 590
1100 IF IDATE=244+LY THEN PRINT "SEP":DAY=1:JJ=0:GOTO 590
1110 IF IDATE=274+LY THEN PRINT "OCT":DAY=1:JJ=0:GOTO 590
1120 IF IDATE=305+LY THEN PRINT "NOV":DAY=1:JJ=0:GOTO 590
1130 IF IDATE=335+LY THEN PRINT "DEC":DAY=1:JJ=0:GOTO 590
1140 PRINT IDAY
1150 IF U$="Y" THEN INPUT "Observed evapotranspiration (mm/day) =";EOBS
1160 IF U$="N" THEN EOBS=0
1170 IF V$="Y" THEN INPUT "Wind (m/s) =";U
1180 IF V$="N" THEN U=0
1190 IF W$="Y" THEN INPUT "Relative humidity (%) =";HUM
1200 IF W$="N" THEN HUM=0
1210 INPUT "Air temperature=";TD
1220 IF X$="Y" THEN INPUT "Net radiation (MJ/M2) =";RN
1230 IF X$="N" THEN RN=0
1240 IF Y$="Y" THEN INPUT "Solar radiation (MJ/M2) =";RS
1250 IF Y$="N" THEN RS=0
1260 IF Z$="Y" THEN INPUT "Sunshine duration (hr) =";N
1270 IF Z$="N" THEN N=0
1280 IF C$="FR" GOTO 1410
1290 IF IDATE<=31 THEN M$="JAN":MN=31
1300 IF IDATE<=59+LY THEN IF IDATE>31 THEN M$="FEB":MN=28+LY
```

```
1310 IF IDATE<=90+LY THEN IF IDATE>59+LY THEN M$="MAR":MN=31
1320 IF IDATE<=120+LY THEN IF IDATE>90+LY THEN M$="APR":MN=30
1330 IF IDATE<=151+LY THEN IF IDATE>120+LY THEN M$="MAY":MN=31
1340 IF IDATE<=181+LY THEN IF IDATE>151+LY THEN M$="JUN":MN=30
1350 IF IDATE<=212+LY THEN IF IDATE>181+LY THEN M$="JUL":MN=31
1360 IF IDATE<=243+LY THEN IF IDATE>212+LY THEN M$="AUG":MN=31
1370 IF IDATE<=273+LY THEN IF IDATE>243+LY THEN M$="SEP":MN=30
1380 IF IDATE<=304+LY THEN IF IDATE>273+LY THEN M$="OCT":MN=31
1390 IF IDATE<=334+LY THEN IF IDATE>304+LY THEN M$="NOV":MN=30
1400 IF IDATE<=365+LY THEN IF IDATE>334+LY THEN M$="DEC":MN=31
1410 DIST=1+.033*COS(6.28*DATE/365)
1420 DECL=.409*SIN(6.28*(284+DATE)/365)
1430 LATI=(LAT-FIX(LAT))*100/60+FIX(LAT)
1440 IF LA$="S" THEN LATI=-LATI
1450 LATI=LATI*3.14/180
1460 T=-TAN(LATI)*TAN(DECL)
1470 IF T<-1 GOTO 1500
1480 IF T>1 GOTO 1520
1490 GOTO 1530
1500 T=-1
1510 GOTO 1530
1520 T=1
1530 TT=SQR(1-T^2)/ABS(T)
1540 IF T<0 GOTO 1570
1550 CA=ATN(TT)
1560 GOTO 1580
1570 CA=3.1416-ATN(TT)
1580 POSSN=24*CA/3.14
1590 X1=SIN(LATI)*SIN(DECL)*CA
1600 X2=COS(LATI)*COS(DECL)*SQR(1-T^2)
1610 R0=(24/3.1415)*4.97*DIST*(X1+X2)
1620 '      !!  !! +++++++++++++++ CHANGEABLE COEFFICIENT +++++++++++++
1630 RSC=(.25+.40*(N/POSSN))*R0
1640 SUN=N/POSSN
1650 PHUM=HUM
1660 L=2.49-.00214*TD
1670 G=.001*P/(.622*L)
1680 AIR=TD
1690 GOSUB 3010
1700 ES1=ES
1710 AIR=AIR+.1
1720 GOSUB 3010
1730 ES2=ES
1740 D=10!*(ES2-ES1)
1750 A=D/(D+G)
1760 B=G/(D+G)
1770 IF U=0 GOTO 1800
1780 '   !!  !!! +++++++++++++++ CHANGEABLE COEFFICIENT +++++++++++++
1790 FU=.27+.233*U
1800 IF HUM=0 GOTO 1960
1810 IF N=0 GOTO 1950
1820 HUM=HUM/100!
1830 VD=ES1-HUM*ES1
1840 RLN1=4.9E-09*(273+TD)^4
1850 '       !! !!!         +++++++++++++ CHANGEABLE COEFFICIENT +++++++++++
1860 RLN2=.34-4.400001E-02*SQR(HUM*ES1)
1870 '        !  !      +++++++++++++++++++++++++++++++++++++++++++++++++++++++
1880 RLN3=.1+.9*(N/POSSN)
1890 RLN=RLN1*RLN2*RLN3
1900 '       '!  !!  ++++++++++++++ CHANGEABLE COEFFICIENT ++++++++++++++
1910 RSC=(.25+.40*(N/POSSN))*R0
1920 '          !!      +++++++++++++ CHANGEABLE COEFFICIENT ++++++++++++++
1930 RNC=(1-.25)*RSC-RLN
1940 IF U=0 GOTO 1960
1950 EPO=A*(RN/L)+B*FU*VD
1960 IF RN=0 GOTO 2040
```

```
1970 EQUI=A*(RN/L)
1980 IF EQUI=0 THEN ALFA=0:GOTO 2010
1990 ALFA=LOBS/EQUI
2000 '      !!!!     ++++++++++++++++ CHANGEABLE COEFFICIENT +++++++++++++
2010 EPTO=1.26*EQUI
2020 IF RS=0 THEN RCOEFF=0:GOTO 2040
2030 RCOEFF=EOBS/(A*(RS/L))
2040 IF RS=0 GOTO 2130
2050 '       !!      +++++++++++++++++ CHANGEABLE COEFFICIENT ++++++++++++
2060 ERO=.04*A*(RS/L)
2070 IF U=0 GOTO 2110
2080 IF N=0 GOTO 2030
2090 EPC=A*(RNC/L)+B*(U*VD)
2100 '      !!!!  ++++++++++++++++++ CHANGEABLE COEFFICIENT ++++++++++++
2110 EPTC=1.26*A*(RNC/L)
2120 '       !!   !! ++++++++++++++++++++ CHANGEABLE COEFFICIENT++++++++++++++++
2130 RSC=(.25+.40*(N/POSSN))*RO
2140 '       !!          +++++++++++++++ CHANGEABLE COEFFICIENT +++++++++++++
2150 ERC=.04*A*(RSC/L)
2160 IF C$<"ER" THEN LPRINT SPC(5)::GOTO 2240
2170 IF IDAY=1 GOTO 2800
2180 IF IDAY=6 THEN GOSUB 3140
2190 IF IDAY=11 THEN GOSUB 3140
2200 IF IDAY=16 THEN GOSUB 3140
2210 IF IDAY=21 THEN GOSUB 3140
2220 IF IDAY=26 THEN GOSUB 3140
2230 LPRINT USING " ##  ":IDAY;
2240 IF U=0 THEN LPRINT "    -    "::I1=I1+1 ELSE LPRINT USING " ##.#  ":U;
2250 IF TD=0 THEN LPRINT "    -    "::I2=I2+1 ELSE LPRINT USING " ##.#  ":TD;
2260 IF PHUM=0 THEN LPRINT "    -   "::I3=I3+1 ELSE  LPRINT USING "  ##  ":PHUM;
2270 IF VD=0 THEN LPRINT "    -   "::I4=I4+1 ELSE LPRINT USING "##.## ":VD;
2280 IF SUN=0 THEN LPRINT "    -    "::I5=I5+1 ELSE LPRINT USING "##.## ":SUN;
2290 IF RS=0 THEN LPRINT "    -   "::I6=I6+1 ELSE LPRINT USING "##.## ":RS;
2300 IF RSC=0 THEN LPRINT "    -   "::I7=I7+1 ELSE LPRINT USING "##.## ":RSC;
2310 IF RN=0 THEN LPRINT "    -   "::I8=I8+1 ELSE LPRINT USING "##.## ":RN;
2320 IF RNC=0 THEN LPRINT "    -    "::I9=I9+1 ELSE LPRINT USING "##.## ":RNC;
2330 IF LOBS=0 THEN LPRINT "    -   "::I10=I10+1 ELSE LPRINT USING "##.## ":LOBS;
2340 IF EPO=0 THEN LPRINT "    -   "::I11=I11+1 ELSE LPRINT USING "##.## ":EPO;
2350 IF EPC=0 THEN LPRINT "    -   "::I12=I12+1 ELSE LPRINT USING "##.## ":EPC;
2360 IF EPTO=0 THEN LPRINT "    -   "::I13=I13+1 ELSE LPRINT USING "##.## ":EPTO;
2370 IF EPTC=0 THEN LPRINT "    -   "::I14=I14+1 ELSE LPRINT USING "##.## ":EPTC;
2380 IF ERO=0 THEN LPRINT "    -   "::I15=I15+1 ELSE LPRINT USING "##.## ":ERO;
2390 IF ERC=0 THEN LPRINT "    -   "::I16=I16+1 ELSE LPRINT USING "##.## ":ERC;
2400 IF EQUI=0 THEN LPRINT "    -   "::I17=I17+1 ELSE LPRINT USING "##.## ":EQUI;
2410 IF ALFA=0 THEN LPRINT "    -   "::I18=I18+1 ELSE LPRINT USING "##.## ":ALFA;
2420 IF RCOEFF=0 THEN LPRINT "    -   "::I19=I19+1 ELSE LPRINT USING "##.## ":RCOEFF
2430 IF C$="ER" GOTO 1150
2440 II=II+1
2450 PU=PU+U
2460 PTD=PTD+TD
2470 PPHUM=PPHUM+PHUM
2480 PVD=PVD+VD
2490 PSUN=PSUN+SUN
2500 PRS=PRS+RS
2510 PRSC=PRSC+RSC
2520 PRN=PRN+RN
2530 PRNC=PRNC+RNC
2540 PEOBS=PEOBS+LOBS
2550 PEPO=PEPO+EPO
2560 PEPC=PEPC+EPC
2570 PEPTO=PEPTO+EPTO
2580 PEPTC=PEPTC+EPTC
2590 PERO=PERO+ERO
2600 PERC=PERC+ERC
2610 PEQUI=PEQUI+EQUI
2620 PALFA=PALFA+ALFA
```

```
2630 PRCOEFF=PRCOEFF+RCOEFF
2640 U=0:TD=0:PHUM=0:VD=0:SUN=0:RS=0:RSC=0:RN=0:RNC=0:LOBS=0:LPO=0:EPC=0:EP10=0:EPIC=0:ERO=0:ERC=0:FOUT=0:ALFA=0:RCOEFF=0
2650 IF IDATE=31 THEN GOSUB 3120
2660 IF IDATE=59+LY THEN GOSUB 3120
2670 IF IDATE=90+LY THEN GOSUB 3120
2680 IF IDATE=120+LY THEN GOSUB 3120
2690 IF IDATE=151+LY THEN GOSUB 3120
2700 IF IDATE=181+LY THEN GOSUB 3120
2710 IF IDATE=212+LY THEN GOSUB 3120
2720 IF IDATE=243+LY THEN GOSUB 3120
2730 IF IDATE=273+LY THEN GOSUB 3120
2740 IF IDATE=304+LY THEN GOSUB 3120
2750 IF IDATE=334+LY THEN GOSUB 3120
2760 IF IDATE=365+LY THEN GOSUB 3120
2770 IF C$="F" GOTO 960
2780 IF C$="K" GOTO 990
2790 LPRINT:LPRINT:LPRINT
2800 LPRINT "ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION FROM CLIMATIC DATA"
2810 LPRINT
2820 LPRINT "LOCATION  :"SITE$;
2830 LPRINT USING "                     &&";LA$;
2840 LPRINT USING "##.##";LA;
2850 LPRINT "'";
2860 LPRINT USING "  &&";LO$;
2870 LPRINT USING "##.##";LON;
2880 LPRINT "'"
2890 LPRINT
2900 LPRINT M$;
2910 LPRINT USING "    &  &";DATE
2920 LPRINT
2930 LPRINT SPC(31);"Data";SPC(32);"Potential evapotranspiration [mm/day]"
2940 LPRINT "      |-- - -- - --- - - - ------       - -----     | |-- - --  -- -- ----------- -------- -- ----- -|"
2950 LPRINT " DATE";" Wind ";"  Temp";"   Hum";"   SVD";"   Sun";"   Rad  ";" Rad+";" Net";"   Net+";" Obs Ep ";" Penman ";"    P-T model";"  Rad.model ";" Fault";"  alfa";" R-coeff"
2960 LPRINT SPACE$(37);"(Obs) (Cal) (Obs) (Cal)        (Net)(Net+) (Net)(Net+) (Rad)(Rad+)"
2970 LPRINT "        m/s     C     %     mb        MJ/m2 MJ/m2 MJ/m2 MJ/m2";"        |      ---|  |---- ---|  |-  -- --|
2980 LPRINT
2990 GOTO 2230
3000 END
3010 TA=AIR+273.16
3020 X1=373.16/TA
3030 X2=.4343*LOG(X1)
3040 X3=10!^(11.344*(1!-1!/X1))
3050 X4=10!^(3.49149*(1!-X1))
3060 X5=.4343*LOG(1013.25)
3070 X6=-7.90298*(X1-1!)+5.02808*X2
3080 X7=1.3816E-07*(X3-1!)-8.1328E-03*(X4-1!)-X5
3090 X=X6-X7
3100 ES=10!^X
3110 RETURN
3120 ML=1
3130 GOTO 3150
3140 MF=0
3150 LPRINT:LPRINT "Mean ";
3160 IF II-I1=0 THEN LPRINT "   -   "; ELSE P1=PU/(II-I1):LPRINT USING " ##.#  ";P1;:J1=J1+1:SP1=SP1+P1
3170 IF II-I2=0 THEN LPRINT "   -   "; ELSE P2=PTD/(II-I2):LPRINT USING " ##.#  ";P2;:J2=J2+1:SP2=SP2+P2
3180 IF II-I3=0 THEN LPRINT "   -  "; ELSE P3=PPHUM/(II-I3):LPRINT USING "  ##  ";P3;:J3=J3+1:SP3=SP3+P3
3190 IF II-I4=0 THEN LPRINT "   -  "; ELSE P4=PVD/(II-I4):LPRINT USING "##.## ";P4;:J4=J4+1:SP4=SP4+P4
3200 IF II-I5=0 THEN LPRINT "   -  "; ELSE P5=PSUN/(II-I5):LPRINT USING "##.## ";P5;:J5=J5+1:SP5=SP5+P5
3210 IF II-I6=0 THEN LPRINT "   -  "; ELSE P6=PRS/(II-I6):LPRINT USING "##.## ";P6;:J6=J6+1:SP6=SP6+P6
3220 IF II-I7=0 THEN LPRINT "   -  "; ELSE P7=PRSC/(II-I7):LPRINT USING "##.## ";P7;:J7=J7+1:SP7=SP7+P7
3230 IF II-I8=0 THEN LPRINT "   -  "; ELSE P8=PRN/(II-I8):LPRINT USING "##.## ";P8;:J8=J8+1:SP8=SP8+P8
3240 IF II-I9=0 THEN LPRINT "      "; ELSE P9=PRNC/(II-I9):LPRINT USING "##.## ";P9;:J9=J9+1:SP9=SP9+P9
3250 IF II-I10=0 THEN LPRINT "   -   "; ELSE P10=PEOBS/(II-I10):LPRINT USING "##.## ";P10;:J10=J10+1:SP10=SP10+P10
3260 IF II-I11=0 THEN LPRINT "   -   "; ELSE P11=PEPO/(II-I11):LPRINT USING "##.## ";P11;:J11=J11+1:SP11=SP11+P11
3270 IF II-I12=0 THEN LPRINT "   -   "; ELSE P12=PEPC/(II-I12):LPRINT USING "##.## ";P12;:J12=J12+1:SP12=SP12+P12
```

```
3280 IF I1-I13=0 THEN LPRINT "   -   "; ELSE P13=PEP10/(I1-I13):LPRINT USING "##.## ";P13;:J13=J13+1:SP13=SP13+P13
3290 IF I1-I14=0 THEN LPRINT "   -   "; ELSE P14=PEPTC/(I1-I14):LPRINT USING "##.## ";P14;:J14=J14+1:SP14=SP14+P14
3300 IF I1-I15=0 THEN LPRINT "   -   "; ELSE P15=PLRO/(I1-I15):LPRINT USING "##.## ";P15;:J15=J15+1:SP15=SP15+P15
3310 IF I1-I16=0 THEN LPRINT "   -   "; ELSE P16=PLRC/(I1-I16):LPRINT USING "##.## ";P16;:J16=J16+1:SP16=SP16+P16
3320 IF I1-I17=0 THEN LPRINT "   -   "; ELSE P17=PLQUI/(I1-I17):LPRINT USING "##.## ";P17;:J17=J17+1:SP17=SP17+P17
3330 IF I1-I18=0 THEN LPRINT "   -   "; ELSE P18=PALFA/(I1-I18):LPRINT USING "##.## ";P18;:J18=J18+1:SP18=SP18+P18
3340 IF I1-I19=0 THEN LPRINT "   -   "; ELSE P19=PRCOLIT/(I1-I19):LPRINT USING "##.## ";P19:J19=J19+1:SP19=SP19+P19
3350 I1=0:I2=0:I3=0:I4=0:I5=0:I6=0:I7=0:I8=0:I9=0:I10=0:I11=0:I12=0:I13=0:I14=0:I15=0:I16=0:I17=0:I18=0:I19=0
3360 LPRINT
3370 PD=0:P1D=0:PPHOM=0:PVD=0;PSUN=0:PRS=0:PRSC=0:PRN=0:PRNC=0:PLOBS=0:PLPO=0:PLPC=0:PEP10=0:PEPTC=0:PLRO=0:PLRC=0:PLQUI=0:PALFA=0:P
RCOLIT=0
3380 I1=0
3390 IF ME=0 GOTO 3710
3400 IF MC=1 GOTO 3410
3410 LPRINT "Month";
3420 IF J1=0 THEN LPRINT "   -    "; ELSE LPRINT USING " ##.#  ";SP1/J1;
3430 IF J2=0 THEN LPRINT "   -    "; ELSE LPRINT USING " ##.#  ";SP2/J2;
3440 IF J3=0 THEN LPRINT "   -   "; ELSE LPRINT USING "  ##  ";SP3/J3;
3450 IF J4=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP4/J4;
3460 IF J5=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP5/J5;
3470 IF J6=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP6/J6;
3480 IF J7=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP7/J7;
3490 IF J8=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP8/J8;
3500 IF J9=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP9/J9;
3510 IF J10=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP10/J10;
3520 IF J11=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP11/J11;
3530 IF J12=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP12/J12;
3540 IF J13=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP13/J13;
3550 IF J14=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP14/J14;
3560 IF J15=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP15/J15;
3570 IF J16=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP16/J16;
3580 IF J17=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP17/J17;
3590 IF J18=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP18/J18;
3600 IF J19=0 THEN LPRINT "   -   "; ELSE LPRINT USING "##.## ";SP19/J19;
3610 SP1=0:SP2=0:SP3=0:SP4=0:SP5=0:SP6=0:SP7=0:SP8=0:SP9=0:SP10=0:SP11=0:SP12=0:SP13=0:SP14=0:SP15=0:SP16=0:SP17=0:SP18=0:SP19=0
3620 J1=0:J2=0:J3=0:J4=0:J5=0:J6=0:J7=0:J8=0:J9=0:J10=0:J11=0:J12=0:J13=0:J14=0:J15=0:J16=0:J17=0:J18=0:J19=0
3630 IF MN=28 GOTO 3670
3640 IF MN=29 GOTO 3680
3650 IF MN=30 GOTO 3690
3660 IF MN=31 GOTO 3700
3670 LPRINT
3680 LPRINT
3690 LPRINT
3700 LPRINT:LPRINT:LPRINT:LPRINT:LPRINT
3710 RETURN
```

Measurement of Leaf Temperature of Wheat in the Field

Tetsuo Sakuratani and Ariovaldo Luchiari Jr.

## 1. Introduction

An effort has been made to sence plant water stress from airplanes or satellites using infrared imaging of the vegetated area. Water stress is inferred from leaf temperature. In order to obtain a fundamental relationship between leaf temperature and environmental conditions such as soil moisture, solar radiation and humidity, the measurements of leaf temperature of wheat were made in the field.

Since the measurements are still being conducted, this report is described mainly about the measurement method.

## 2. Method

The apparatus shown in Fig. 1 consists principally of copper-constantan thermocouples, a low-noise amplifier and a six-channel automatic recorder of 10 m V in maximum scale. Thin copper-constantan thermocouples of 0.1 mm in diameter and of 15 cm in length were connected to Cu-Co wires of 0.65 mm in diameter having cold junctions. The temperature of the cold junctions was maintained at 0°C in a ice jar. The tips of 0.1 mm thermocouples were affixed on the surface of the leaves with small gum tape. Leaf temperatures were measured at 1st leaf (upper leaf), 2nd leaf, and 3rd leaf, using two individuals. The electric signals corresponding leaf temperature were recorded continuously through the low noise amplifier on the recorder.

## 3. Results

Fig. 2 shows an example of the diurnal couse of averaged leaf temperature before irrigation (A) and after irrigation (B). Before the irrigation, leaf temperature, is 2 ∿ 4°C lower than air temperature, while after the irrigation the one is 4 ∿ 5°C lower than air temperature. This indicated that before the irrigation the wheat leaves are under water stress.

## 4. Some Remarks for Further Studies

It is necessary to continue the measurements during growing season and to analyze the data to obtain the relation between leaf temperature of wheat and environmental conditions.

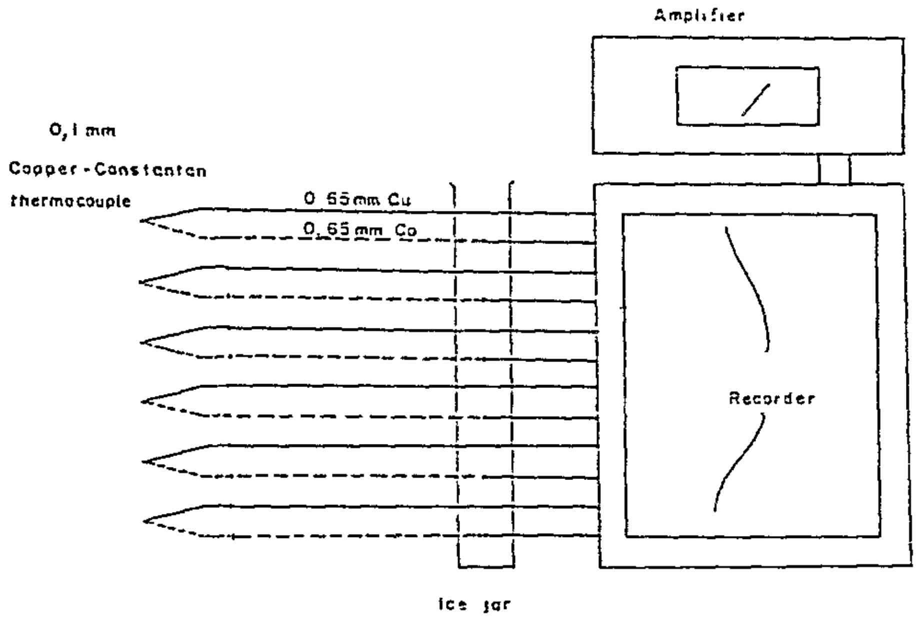


Fig. 1. Experimental setup for measuring leaf temperature.

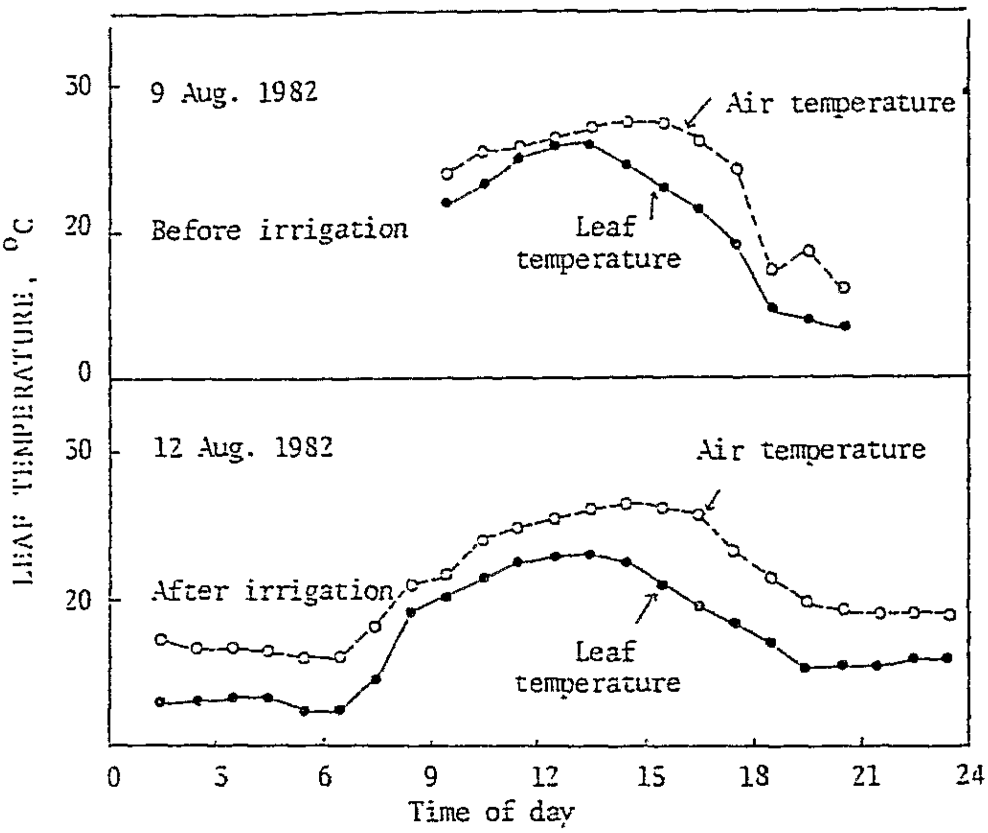


Fig. 2. Diurnal course of leaf temperature of wheat

# X-ray fluorescence spectrometry of the Cerrado soils

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# X-ray Fluorescence Spectrometry of "Cerrado Soils"

Tadao Ando

One of the major constraints to limit agricultural production in the Cerrado region is reported to be in the soils[1,2); low fertility status, Al-toxicity, low water retention capacity and so on. In order to establish a productive, stable and efficient agricultural systems in this region, it is indispensable to manage properly the soils on the basis of the information of the soil properties.

The soil survey is now intensively undertaken in the Cerrado region. Although soil surveys attempt to provide facts about many different soil properties, not all of which are closely related to soil management for agricultural production. Further, each soil map unit may include only one kind of soil as defined by the classification system but most frequently includes many different kinds of soil[3).

Soil management practice, however, is site-specific. Even in the Cerrado region where Dark Red Latosol and Red Yellow Latosol are dominant soil types[2,4), the soil properties may be different from place to place. Moreover, more than 50 million ha of the Cerrado region including various soil types is estimated to be developed as farmland[5). Therefore, a great number of soil samples should be analized for better land use and better soil management.

X-ray fluorescence spectrometry is a rapid and reliable method to determine quantitatively chemical composition of soils. By using X-ray fluorescence spectrometer, we can obtain the following informations on soils;

a) Elemental composition of soils

Elemental composition of soil varies from soil to soil and is a kind of fingerprints of the soil. The informations on elemental composition of soils will be very useful for soil classification.

b) Amount of nutrient reserves

The concentrations of the available P, exchangeable K, Ca, Mg and some trace elements are reported to be very low in the Cerrado soils[2). Even though the availability of these nutrients were very low, we can expect some nutrient supply from the soils by increasing the availability through use of mycorrhiza or low-nutrient tolerant crops or other methods, if the soils contain nutrients as a potential source. But if not, we must apply these nutrients as fertilizers.

From the data of X-ray fluorescence spectrometry of soils, we can estimate potential ability of nutrient supply of soils.

c) Presence of toxic or valuable elements

If we find high concentration of toxic elements such as heavey metals or valuable elements in the land where is planned to be cultivated, we had better change the land use. Qualitative analysis of soils by X-ray fluorescence spectrometry can rapidly offer the information on the presence of toxic or valuable elements.

The objective of this research is to estimate the elemental composition and the amount of nutrient reserves of the Cerrado soils by applying X-ray fluorescence spectrometry. In this report, the following subjects were briefly described and discussed.

I. Features of X-ray fluoresecence spectrometry.

II. Comparison of elemental composition between some Cerrado soils and some Japanese soils.

III. Elemental composition of the Cerrado soils.

IV. Estimation of nutrient reserves and nutrient availability of some Cerrado soils.

## I. Features of X-ray fluorescence spectrometry

X-ray fluorescence analysis is a sort of physical analysis and may be said to be a kin to spectroscopic analysis. While the object of X-ray diffraction analysis is crystals that compose a substance, the object of X-ray fluorescence analysis is elements present in the substance.

When a certain element in the sample is irradiated and excited with the high-energy X-rays generated from the X-ray tube, it emits fluorescent X-rays having the wavelength inherent to the element and intensity proportional to the content of the element.

For example, by use of a LiF single crystal, the X-ray intensity is measured with a $2\theta$ value corresponding to the target element under the conditions that the Bragg's Law may always be satisfied.

Bragg's Law; $n\lambda = 2d \cdot \sin \theta$

which gives the relationship among the wavelength ($\lambda$), the spacing of the diffracting crystal (2d) and the angle (θ) through which the radiation is diffracted.

The following are main features of X-ray fluorescence spectrometry;

1) Generally X-ray spectra are little affected by the state of a substance whether the sample is solid, powder, or liquid, or whether it is crystalline or non-crystalline.

2) Non-destructive analysis. This method practically does not cause any change or loss of the element. Furthermore, since the same sample can be measured repeatedly, reliable results can be obtained.

3) Based theoretically on the difference in the atomic number, this analytical method can easily analyze elements belonging to the same group, such as Zr-Hf and Nb-Ta, which are quite difficult to analyze by chemical analysis.

4) Spectral lines are simple and stable as compared with those by emission spectroscopy, leading to ease in analysis and improved accuracy.

5) Measurement time is very short, requiring only 10 to 80 seconds per elements. In the advanced instruments, quantitative analysis of samples is automatically run.

6) In a standard X-ray fluorescence spectrometer, all the elements from atomic number 9 (F) to 92 (U) can be quantitatively analyzed.

7) Sample preparation is also easy. For the soil samples, dried soils are glinded and pelletised or fused with borax etc.

Figure 1 and 2 are examples of quailitative analysis of soil samples. These soils were collected from $A_1$ horizon of Organic soil (CPAC) and Humic gley soil (Univ. of Goiás). Figure 1 shows that Organic soil (CPAC) is extraordinarily rich in Nb, Y, Pb and Cu, but poor in Ba, Sr, Rb, Zn, Fe and Mn. Figure 2 shows that Humic gley soil (Univ. of Goiás) contains higher amount of Ba, Zr, Fe and Mn. There are some unidentified elements in both soils, which are usually not found in soils.

An element concentration and X-ray intensity of soil samples are generally well correlated. The correlation between K concentration and X-ray intensity of 15 soil samples is shown in Fig. 3. The K concentration was determined by a flamephotometer after the soil samples were fused with $Na_2CO_3$ and then dissolved into dilute $HC\ell$ solutions. By using this kind of correlation equation, an element concentration of samples is calculated from X-ray intensity of samples.

## II. Comparison of elemental composition between some Cerrado soils and some Japanese soils.

### 1. Introduction

In about 2 million $Km^2$ of the Cerrado region, Red Yellow Latosol (LV) and Dark Red Latosol (LE) occupies 24.2% and 18.7% of this region, respectively[4]. These soils are usually very low in exchangeable bases, available phosphorus, cation exchange capacity and high in Aℓ saturation[2].

In order to characterize these two soils further, the elemental composition were analysed by X-ray fluorescence spectrometer and compared with those of some representative Japanese soils.

### 2. Materials and methods

The two types of the Cerrado soils were collected from the surface horizons of CPAC field (Table 1). Twenty seven soil samples were collected from 19 points of noncultivated area of Chugoku-district in Japan. These samples cover almost all major soil types found in the upland area of Japan.

The samples were air dried and screened through a 2mm sieve. Thus prepared soil samples were dried at 100°C overnight and glinded by a vibration mill for 3 minutes. About 4g of the soil powder were then pelletised under the pressure of 300 $kg/cm^2$. X-ray fluorescence spectrometry for these samples were carried out by Toshiba AFV-777. The analytical conditions are shown in Table 2.

### 3. Results and discussion

Since intensity of X-ray emitted from each element in a soil sample is essentially proportional to the element concentration in the sample, the results are reported on a X-ray intensity basis. The higher X-ray intensity means the higher element concentration. In order to make the results visible, two related elements are shown in a figure.

The intensities of X-ray emitted from Si and Aℓ in soil samples are shown in Fig. 4. Compared with Japanese soils, the Cerrado soils contain higher amount of Aℓ and lower amount of Si. Among the Cerrado soils, LV showed higher Aℓ and lower Si concentration than LE. There is high negative correlation between Si and Aℓ content in soils.

Figures 5 shows the intensity of X-ray emitted from Fe and Ti in soil samples. Both of Fe and Ti contents are high in the Cerrado soils compared with Japanese soils. Among the Cerrado soils, LV contained higher amount of Ti than LE.

The intensities of X-ray emitted from Rb or K, Ca or Mg, and Ba or Sr are shown in Fig. 6, 7, and 8, respectively. The concentrations of alkaline and alkaline earth metals are vey low in the Cerrado soils compared with Japanese soils, though some Japanese soils showed low Ca concentration.

Zr concentration in the Cerrado soils is high, especially in LV, but we could not find much differnce in P concentration between the Cerrado and Japanese soils (Fig. 9).

Trace elements such as Mn, Zn and Cu are also low in the Cerrado soils, but there are not much difference in Ni concentration (Figs. 10 and 11).

Figure 12 shows the summarized data in % or ppm concentration of dry soil. Japanese soils contain 11 to 29% of Si and the average Si content is about 19%. On the other hand, the Cerrado soils contain 7 to 20% of Si and the mean value is 10%. Figure 12 shows that the Cerrado soils contain low amount of Si and higher amount of Aℓ and Fe as main component of the soils than Japanese soils do.

The concentration of K, Ca, Mg, Sr and Ba in the Cerrado soils are very low indicating that the Cerrado soils are strongly weathered. As we cannot expect much supply of K, Ca and Mg from these soils, we need to apply continuously these nutrients as fertilizers.

Phosphorus status is similar in both soil groups as far as total P is concerned. The trace elements such as Mn, Zn, and Cu are very low in the Cerrado soils indicating that these trace elements deficiency become a serious problem in the Cerrado area with increasing agricultural production.

The analysis was done for only limited number of soil samples in both area. Therefore these data may not be representative value. In order to characterize generally the elemental composition of the Cerrado soils, more soil samples from different places and from different soil types should be analysed.

4. Sammary

In order to characterize the elemental composition of the Cerrado soil, seven samples of Dark Red Latosol (LE) and Red Yellow Latosol (LA) from CPAC field were analysed by X-ray fluorescence spectrometer (Toshiba AFV-777) and were compared with 27 Japanese soils including major soil types in Japanese

upland area.

Compared with most of Japanese soils, both of LE and LV contained more Aℓ, Fe, Ti and Zr, but much less K, Ca, Mg, Sr and Ba. The trace elements such as Mn, Cu, and Zn were also very low in the Cerrado soils. P and Ni concentrations were similar in both soil groups. Low concentration of K, Ca, Mg, and trace elements in these Cerrado soils indicate that these nutrients deficiency will become serious limiting factors of crop production in these soils, unless nutrients are properly supplied to the field.

## III. Elemental composition of the Cerrado soils

This research have been done in collaboration with Madeira, Jamil and Fukuhara, but have not been completed yet.

### 1. Introduction

Agricultural development is going on in the vast area of the Cerrado region, but there is limited information available on the soil property and fertility status of most of the soils. Partially because this area is as huge as 2 million $Km^2$ and the soil classes are not so simple as expected. The distribution of main soil classes in the Cerrado region has been figured out by CPAC researchers (Appendix 1).

Lopes and Cox[1)] assayed the fertility status of a large number of the surface soils collected from 600,000 $Km^2$ area in central Brasil. This survey clarified the general conditions of the Cerrado soils; low levels of effective CEC and extractable Ca, Mg, P and Zn, and high levels of Fe and Aℓ saturation. But they did not try to relate these data with soil classes, vegetation, topography or other parameters.

In the Cerrado region, dry spell is one of the serious problems in the crop production during rainy season. This problem can be partially overcomed by the amendment of subsoils[6)]. This fact indicates that properties of the subsoils also should be taken into consideration. However, there is little informations available on properties of the subsoils in the Cerrado region.

The objecties of this research are to study (1) elemental composition of the surface soils and subsoils in the Cerrado region, and (2) the relationships between elemental composition of the soils and fertility status of the soils.

## 2. Materials and methods

Soil samples were collected mainly from Goiás state and Brasília-DF. Sampling sites were selected to cover the major soil classes in the area. Figure 13 shows the location of the sampling sites. General description of each sampling sites and soils is shown in Appendix 2.

The samples were air dried, screened through a 2 mm sieve and treated as described earlier for X-ray fluorescence spectrometry. The analytical conditions are shown in Table 3. The chemical analysis has not been completed yet.

## 3. Results and discussion

Among the soil samples collected from 30 sampling sites, 64 soil samples from 15 sites (No. 1 ∿ 15) were analysed by X-ray fluorescence spectrometer. Tables 4 and 5 show the X-ray intensity measured. Among these 20 elements, the concentration of Si, Fe, Aℓ, Ti, K, Ca, Mg, P, Zn and Mn was estimated by using the calibration curves in Table 3. The results are shown in Table 6.

A skeleton of soil is usually composed of oxides of Si, Fe, Aℓ and Ti. Under intensive soil formation processes, these composition is completely altered and the soil formation processes are reflected in the elemental composition of each horizon. As shown in Table 6, the concentration of skeleton elements (Si, Fe, Aℓ and Ti) is very similar through horizons in most of the Cerrado soils. However, the elemental composition itself is location specific. Even in the soils which belong to the same class and locate under the similar climatic and topographic conditions as the points J-1 and J-12, the elemental composition varies greatly place to place. It does not always relate to soil class.

On the other hand, there are big difference in the elemental composition among the horizons of the points J-2 and J-8. In these points, different parent materials mixed in layers possibly by erosion. And the differences in parent materials are still maintained in the composition of skeleton elements. These facts indicate that the composition of skeleton elements was mainly determined by the parent materials and was not much affected by other soil formation factors. If this is true, most of the Cerrado soils might not been under intensive soil formation processes, even though they were very old soils.

Figure 14 shows the composition of skeleton element of the surface soils. In each soil class, the composition is not always similar. But the elemental composition was found among different soil classes; J-11 (Plinthiic Yellow Latosol), J-12 ∿ 13 (Red Yellow Latosol), J-14 (Dark Red Latosol) and J-15 (Low Humic Gley). In these soils, not only skeleton elements but also other elements are similarly contained (Tables 4, 5 and 6). Since these soils located in the close vicinity, the parent materials may be the same.

In the present soil classification system, soil color is an important factor to classify soils. Although soil color is easily determined and a convenient parameter, it sometimes changes drastically by soil moisture content and by changes in some chemical conditions of soils. To what extent soil color is related to soil fertility status? The darkness of soil color is closely related to the content of the humic materials which contain C, N and P. But other soils color is not related to soil fertility status. On the other hand, the chemical composition of soils is much more stable than soil color and closely related to clay mineral composition and texture which affect much behavior of nutrients in the soil[7]. Therefore, elemental composition of soil skeleton can become an important indicator of soil property. If we find the close relation between elemental composition of soil skeleton and some soil properties (cation exchange capacities, P-fixing capacity, nutrient contents etc.), this will be a useful tool to classify soils. This point is presently under intensive investigations.

Concentration of such nutrients as K, Ca, Mg, P, Zn and Mn in the soils varied in various degrees (Table 6). Although these nutrients tend to accumulate in the surface horizon, the variation within horizons is much smaller than that among the sampling sites. The soils in CPAC field contained generally very low amount of these nutrients, but some other Cerrado soils contained relatively high amount of these nutrients.

Concentration of total K in the soils is generally very low, but high in the soils of the points 8, 9, 10 in the vicinity of Goiânia. Total Ca concentration was high in the points 5 and 9, but all the soils in CPAC contained trace amount of Ca. Total Mg concentration was especially high in the point 9 and especially low in the point 3 (Quartz sandy soil). Total P concentration was high in the points 7, 4, and 5, but very low in the CPAC soils except the surface horizon of the organic soil. Concentration of total Zn and Mn were especially low in the soils of CPAC.

After the soil analysis was completed, the relationships among elements, total and available nutrients, and other soil properties will be thoroughly discussed.

4. Summary

In order to study (1) elemental composition of the surface soils and subsoils in the Cerrado region, and (2) the relationships between elemental composition and fertility status of the soils, sample were collected mainly from Goiás state and Brasília DF. Among the soil samples collected from 30 sampling sites where cover major soil classes in the region, 64 soil samples from 15 sites were analysed by X-ray fluorescence spectrometer.

The concentration of skeleton elements (Si, Fe, Aℓ and Ti) is very similar through horizons in most of the Cerrado soils. However, the elemental composition itself is location specific and does not always related to soil class. The analytical results indicate that the composition of skeleton elements was mainly determined by the parent materials. Most of the Cerrado soils might not been under intensive soil formation processes. The possibility to classify soils by elemental composition of soils was also briefly discussed.

Although K, Ca, Mg, P, Zn and Mn tend to accumulate in the surface horizon, the variation within horizons is much smaller than that among the sampling sites. The soils in CPAC field contained generally very low amount of these nutrients, but some other Cerrado soils contained relatively high amount of these nutrients.

## IV. Estimation of nutrient reserves and nutrient availability of some Cerrado soils

This research is under way in collaboration with Morethson, Castelo, Madeira and Jamil.

1. Introduction

The concentrations of the available P, exchangeable K, Ca, Mg and some trace elements are reported to be very low in the Cerrado soils[2,3]. Even though the availability of these nutrients were very low, we can expect some nutrient supply from the soils by increasing the availability through use of mycorhiza or low-nutrient tolerant crops or other methods, if the soils contain nutrients as a potential source. But if not, we must apply these nutrients as fertilizers. From the data of X-ray fluorescence spectrometry of soils, we can estimate potential ability of nutrient supply of soils.

The amount of available nutrients in soils is supposed to be related to the total nutrient content of the soils. If we can find the relationships between total nutrient content and available nutrient content, we can estimate availability of a certain nutrient by applying X-ray fluorescence spectrometry to soils. Since X-ray fluorescence spectrometry is rapid and reliable method to determine total amount of most of nutrient in soils, these informations will be helpful in planning land use, land modification, selection of crops, fertilizer application and other soil managements.

In this research, the amount of nutrient reserves and nutrient availability of some Cerrado soils are estimated by X-ray fluorescence spectrometry, chemical analysis and pot experiments.

## 2. Materials and methods

Seven kinds of top soil samples (0-20cm depth) were collected from CPAC field in a virgin area. They are 2 types of Red Yellow Latosol (medium and clayey), 2 types of Dark Red Latosol (medium and clayey), Quartz sandy soil, Organic soil and Low humic gley soil. Soil samples were air dried and passed through a 2 mm sieve. Plastic pots were filled with 3.0 kg of the air dry soil (2.5 kg for Organic soil). All pots received the nutrient shown in Table 7 and 8. Phosphorus and lime ($CaCO_3$ or $MgCO_3$) were applied as powder and thoroughly mixed with soil. The amount of $CaCO_3$ or $MgCO_3$ which correct soil $_pH$ (1:2, 5 $H_2O$) to around 6, 0 were applied. All other nutrients were applied in solution.

Wheat (cv. BH 1145) or soybean (cv. IAC-2) were seeded and thined to 10 or 5 plants per pot 4 days after emergence, respectively. One day after emergence, rhizobium japonicum was inoculated to soybean. Before inoculating rhizobium, minerals in the medium were removed by centrifugation. All the pots were placed in a glass house and irrigated twice a day to maintain soil moisture conditions at field capacity. All the treatments were duplicated. Analytical methods for soils and plants will be reported later.

## 3. Results and discussion

Severe Ca deficiency sympton appeared in both plants on the pots of -Ca treatment, except Humic Gley soil, 7 days after emergence. Moderately severe Mg and P deficiency symptoms appeared in wheat on the pots of -Mg and -P treatment 10 days after emergence, respectively.

All the analytical data will be reported and discussed after completion of the experiments.

4. Summary


ACKNOWLEDGEMENT

I am most grateful to Drs. Elmar Wagner, Edson Lobato, Morethson Resende and J. Madeira Netto, senior staffs of CPAC; and Dr. T. Ogata, head of the Japanese consultant team at CPAC, for giving me a chance to do a research work at CPAC and also for their nice orientation and encouragement.

I would like to express my most sincere thanks to Drs. Luiz J.C.B. Carvalho and Jamil Macêdo, CPAC researchers; and Dr. M. Fukuhara, Japanese consultant at CPAC; Miss Nair S. Hayashida, Mr. Fernado Filho, Mr. M. Habu and many other CPAC and JICA staffs, who worked and discussed with me and helped me all the time during 2 months of my stay at CPAC.


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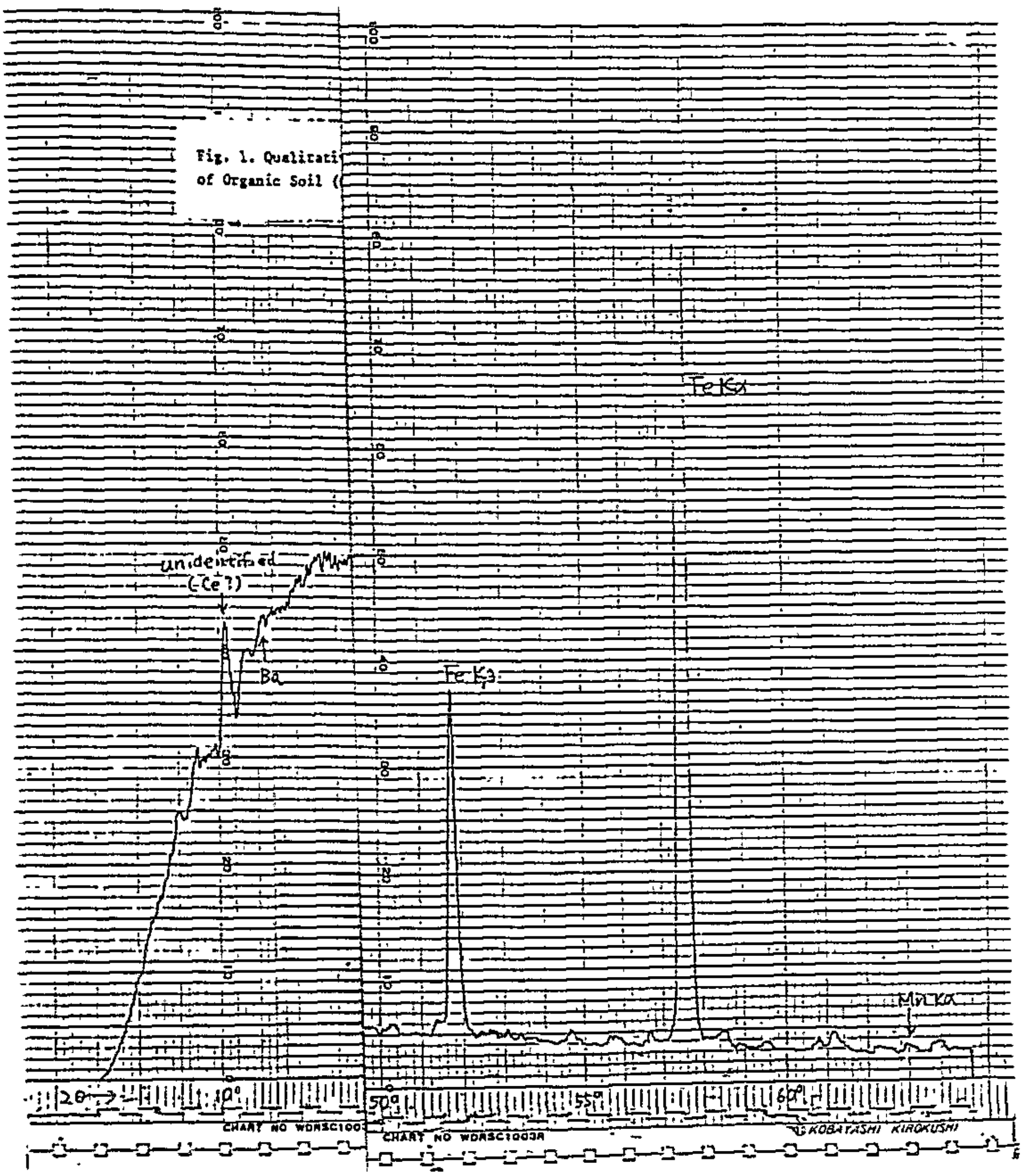
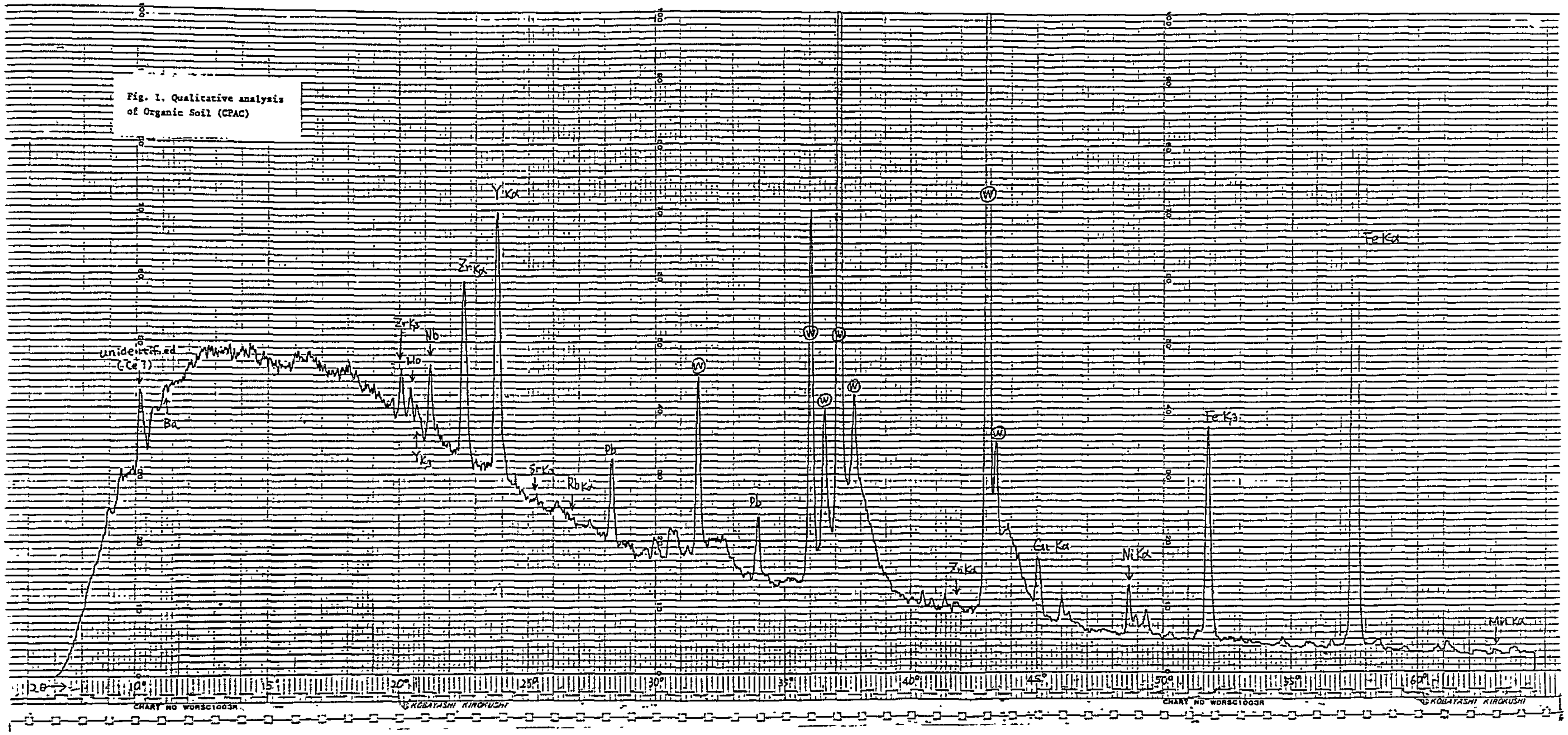


Fig. 1. Qualitati
of Organic Soil (
unidentified
(Ce?)
Ba
Fe Kβ
Fe Kα
Mn Kα
CHART NO WDRSC1003R
KOBAYASHI KIROKUSHI

Fig. 1. Qualitative analysis of Organic Soil (CPAC)



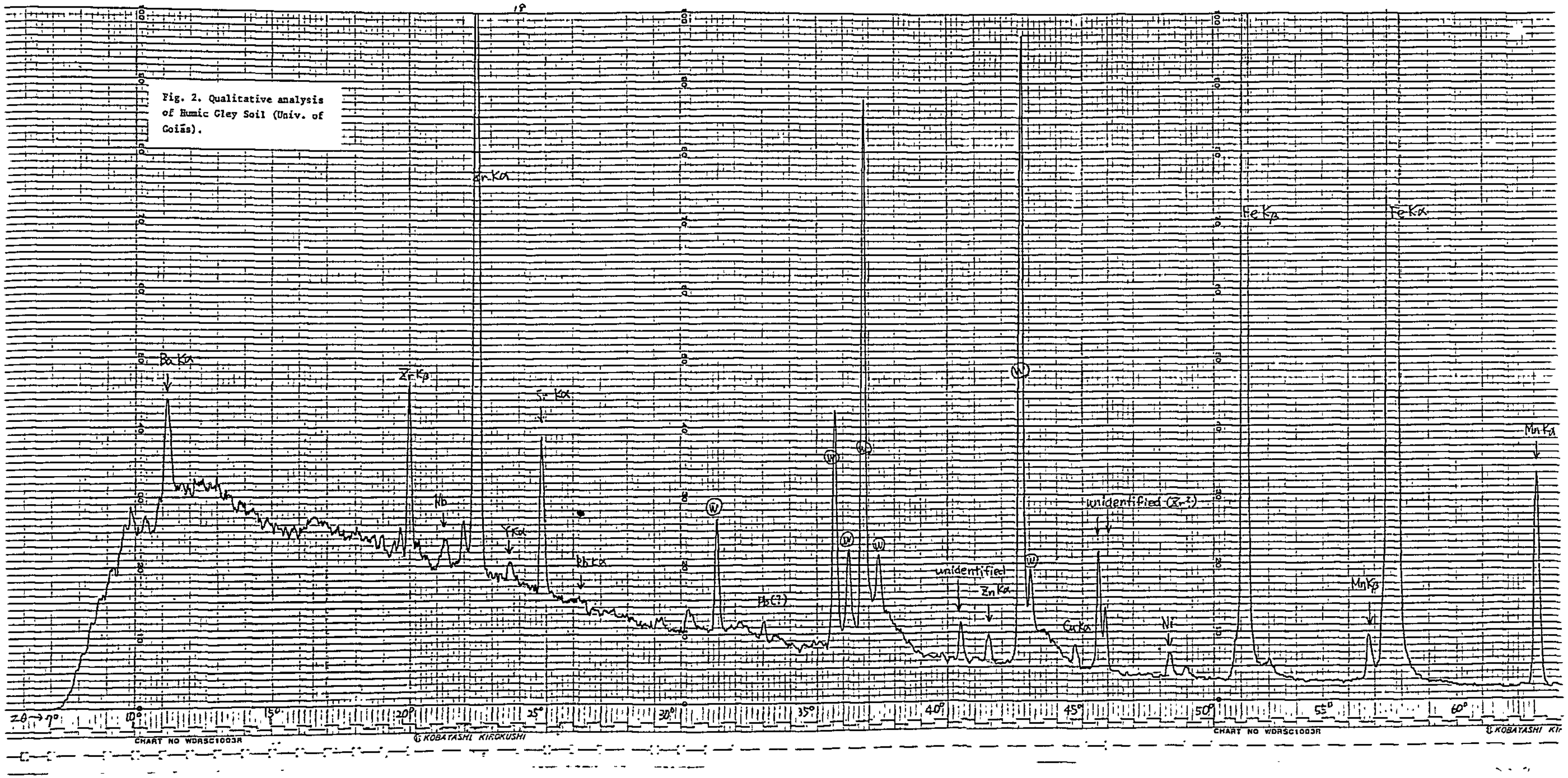



Fig. 2. Qualitative analysis of Humic Gley Soil (Univ. of Goiás).

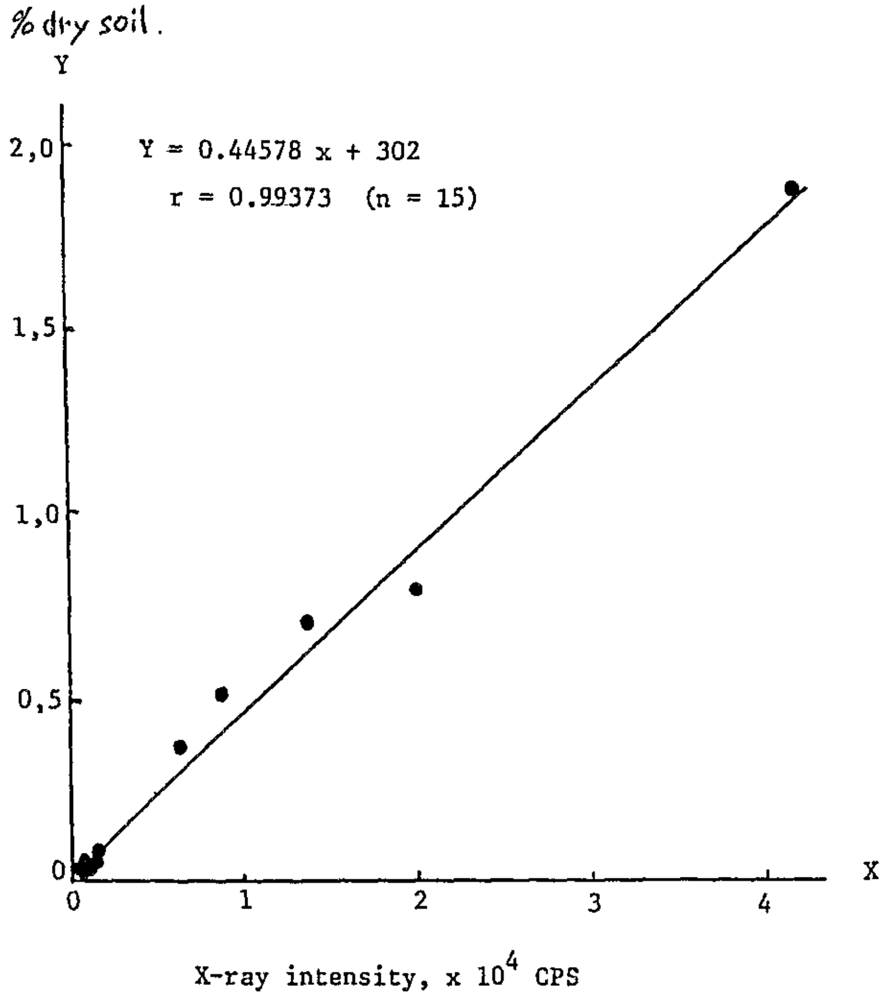



Fig. 3. Correlation between K concentration and X-ray intensity of dried soils.

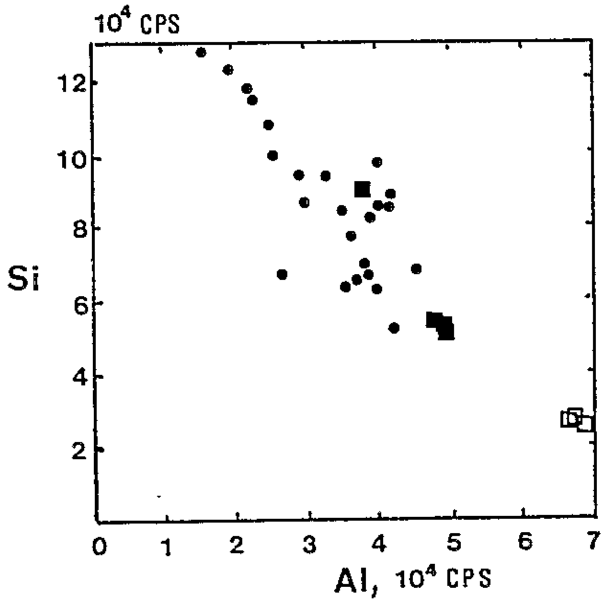



Fig. 4. Intensity of X-ray emitted from Si and Al in Japanese soils (●), LE (■) and LV (□).

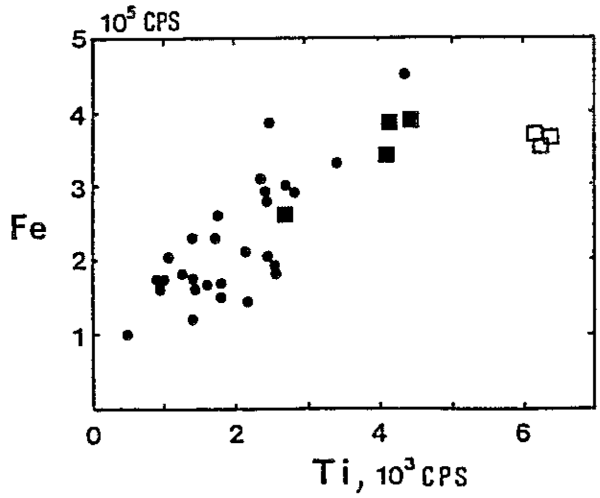



Fig. 5. Intensity of X-ray emitted from Fe and Ti in Japanese soils (●), LE (■) and LV (□).

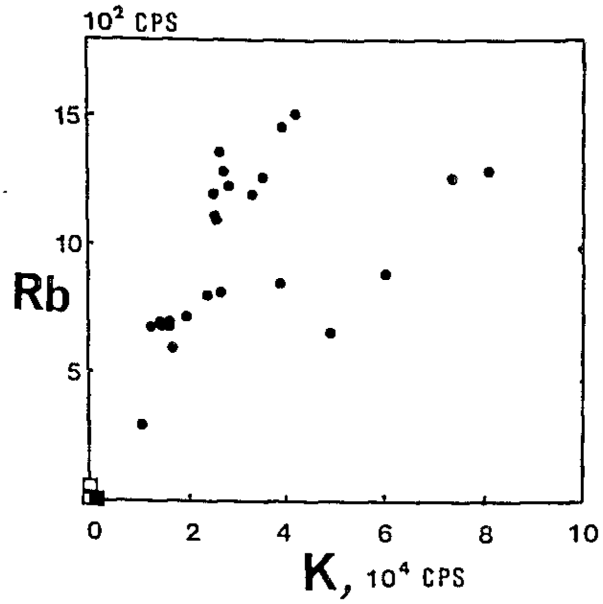



Fig. 6. Intensity of X-ray emitted from Rb and K in Japanese soils (●), LE (■) and LV (□).

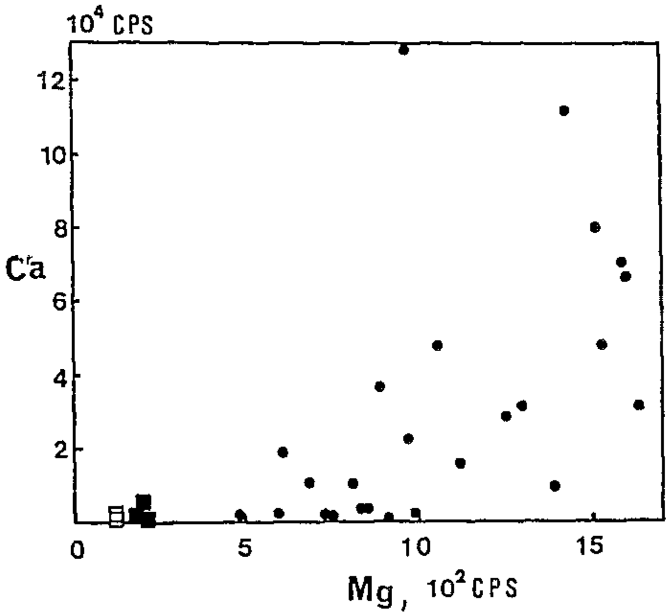



Fig. 7. Intensity of X-ray emitted from Ca and Mg in Japanese soils (●), LE (■) and LV (□).

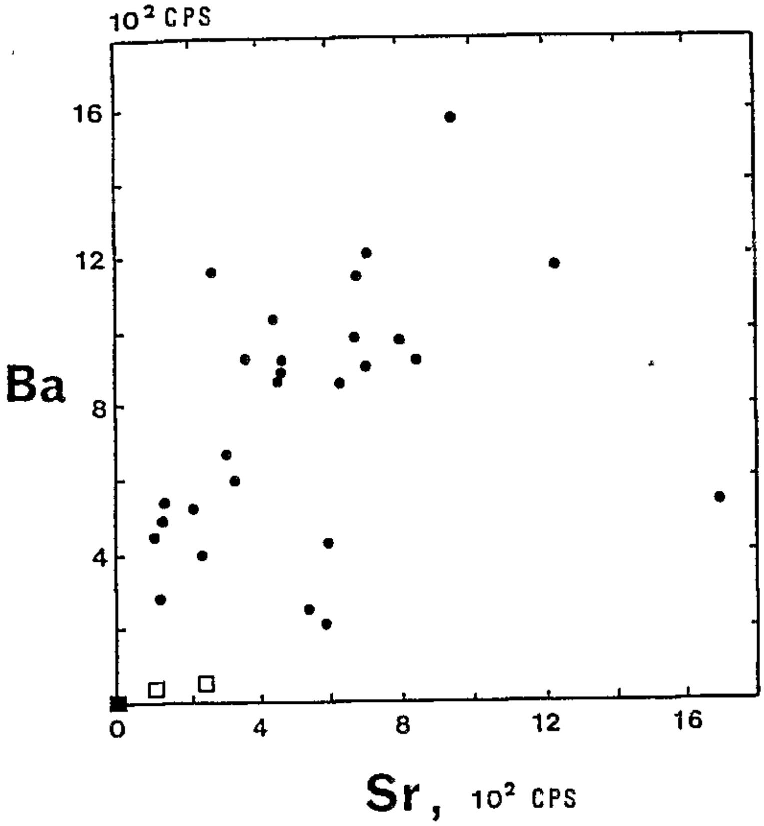



Fig. 8. Intensity of X-ray emitted from Ba and Sr in Japanese soils (•), LE (■) and LV (□).

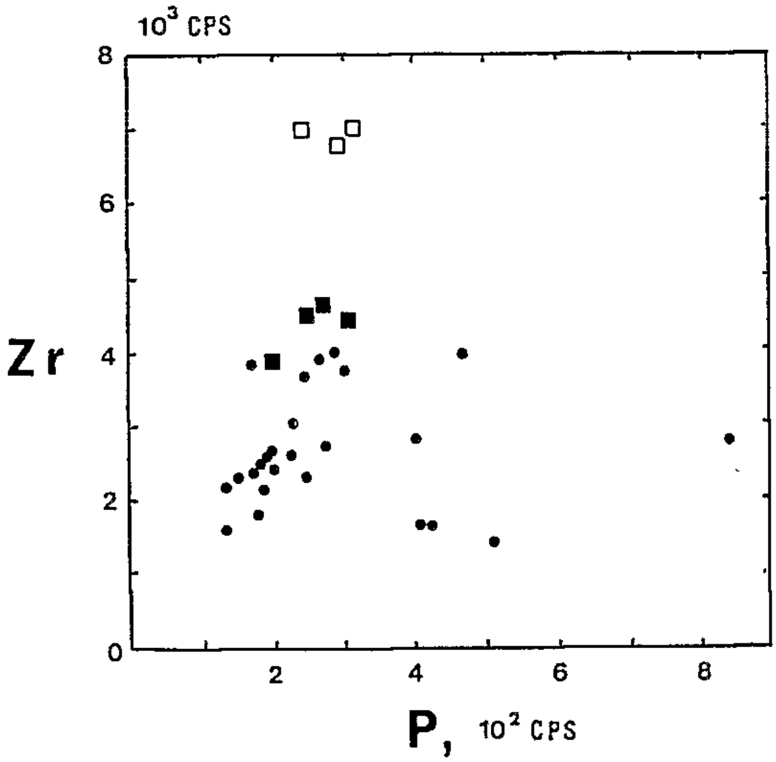



Fig. 9. Intensity of X-ray emitted from Zn and P in Japanese soils (•), LE (■) and LV (□).

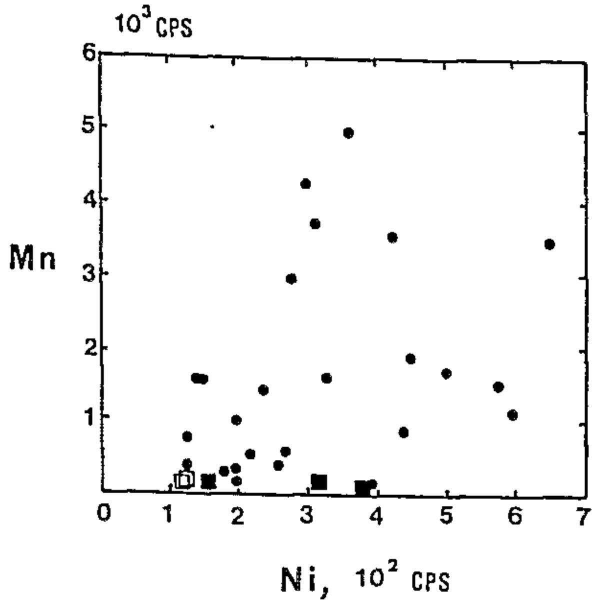



Fig. 10. Intensity of X-ray emitted from Mn and Ni in Japanese soils (•), LE (■) and LV (□).

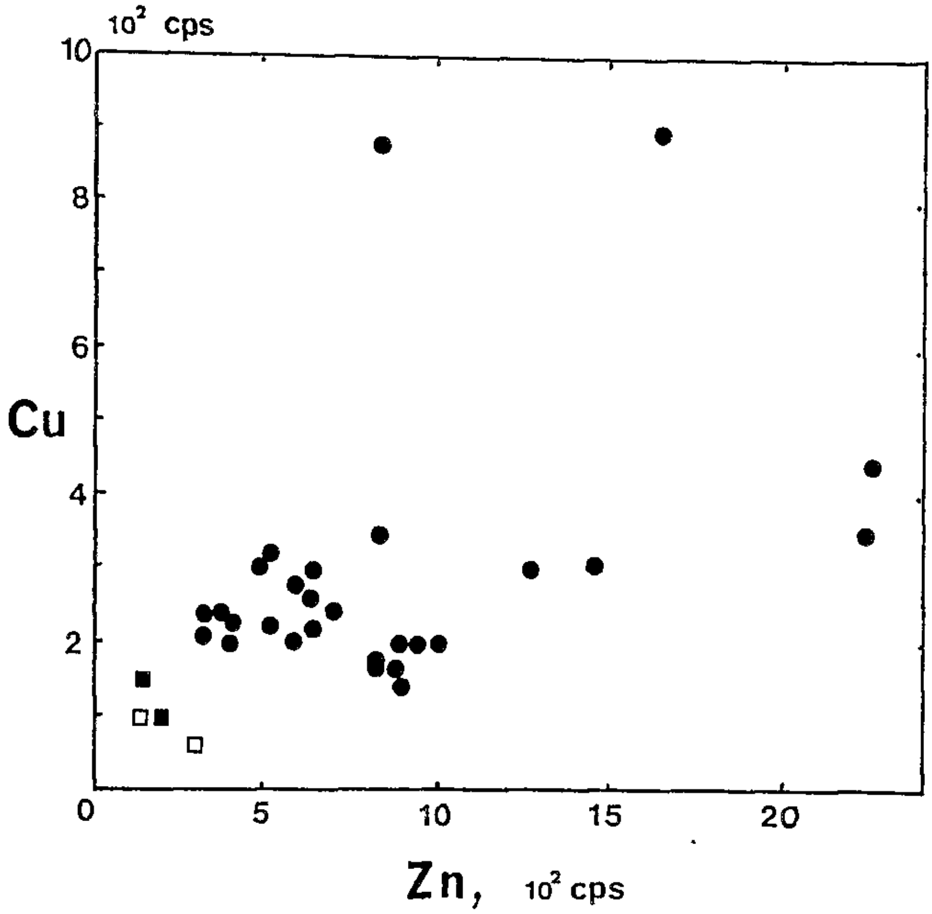



Fig. 11. Intensity of X-ray emitted from Cu and Zn in Japanese soils (•) and LE (■) and LV (□).

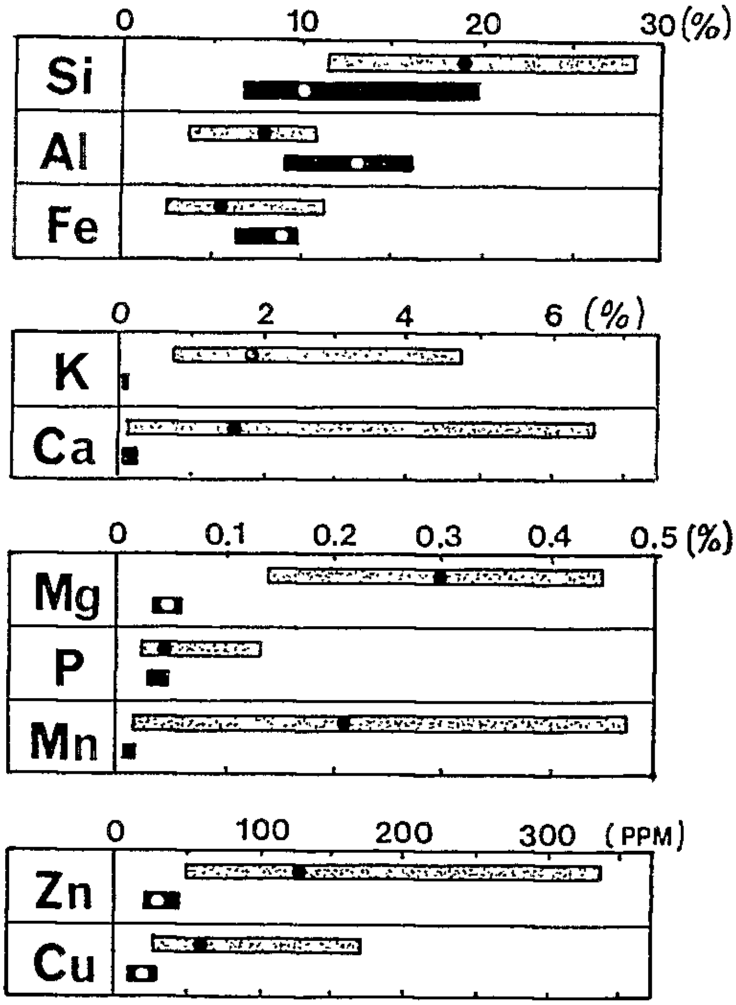



Fig. 12. Elemental concentration in some Japanese soils ( ) and some Cerrado soils ( ) Average concentration of each element is shown by a black circle (Japanese soils) and a open circle (Cerrado soils).

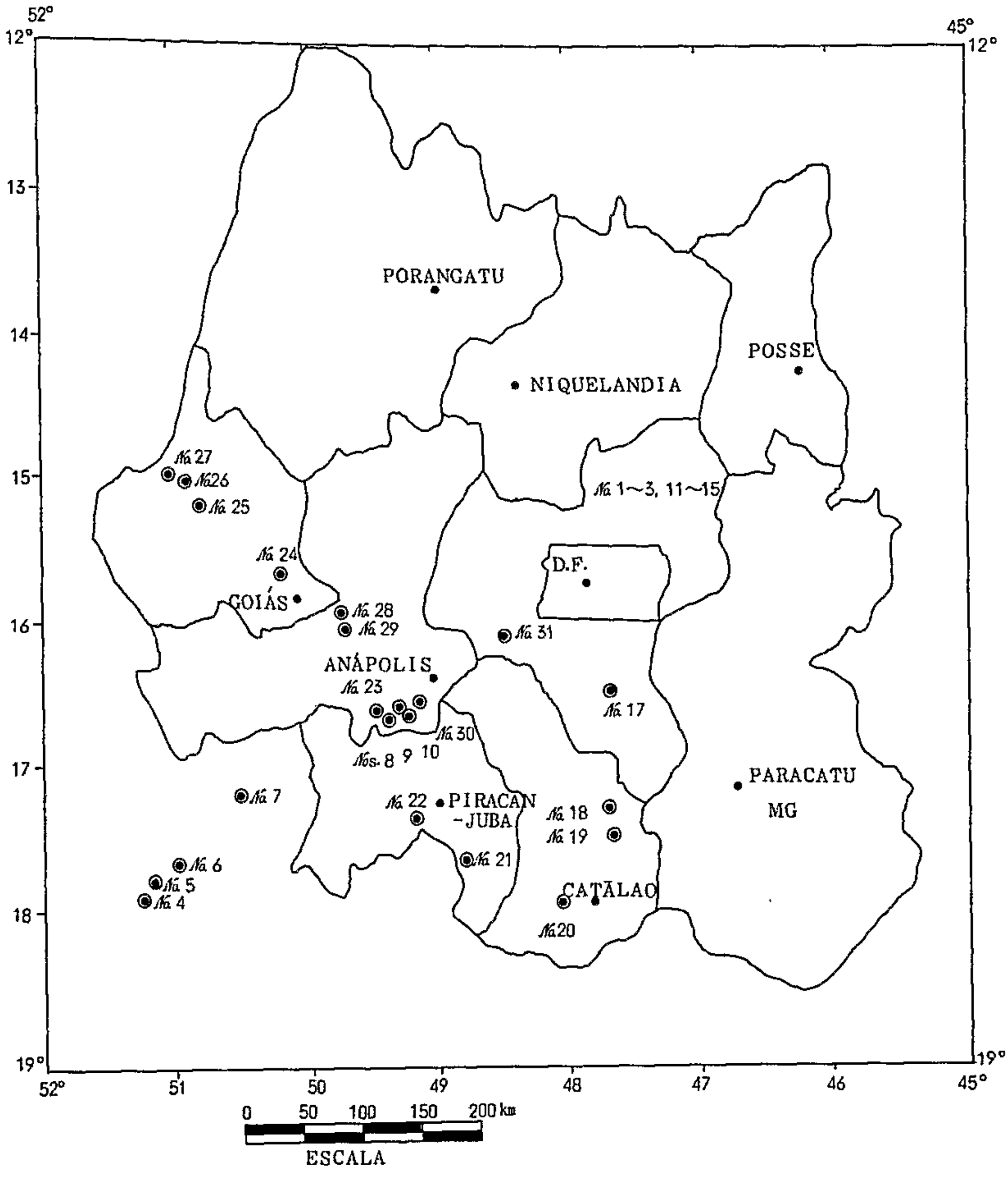



Fig.13 Location of soil sampling sites.

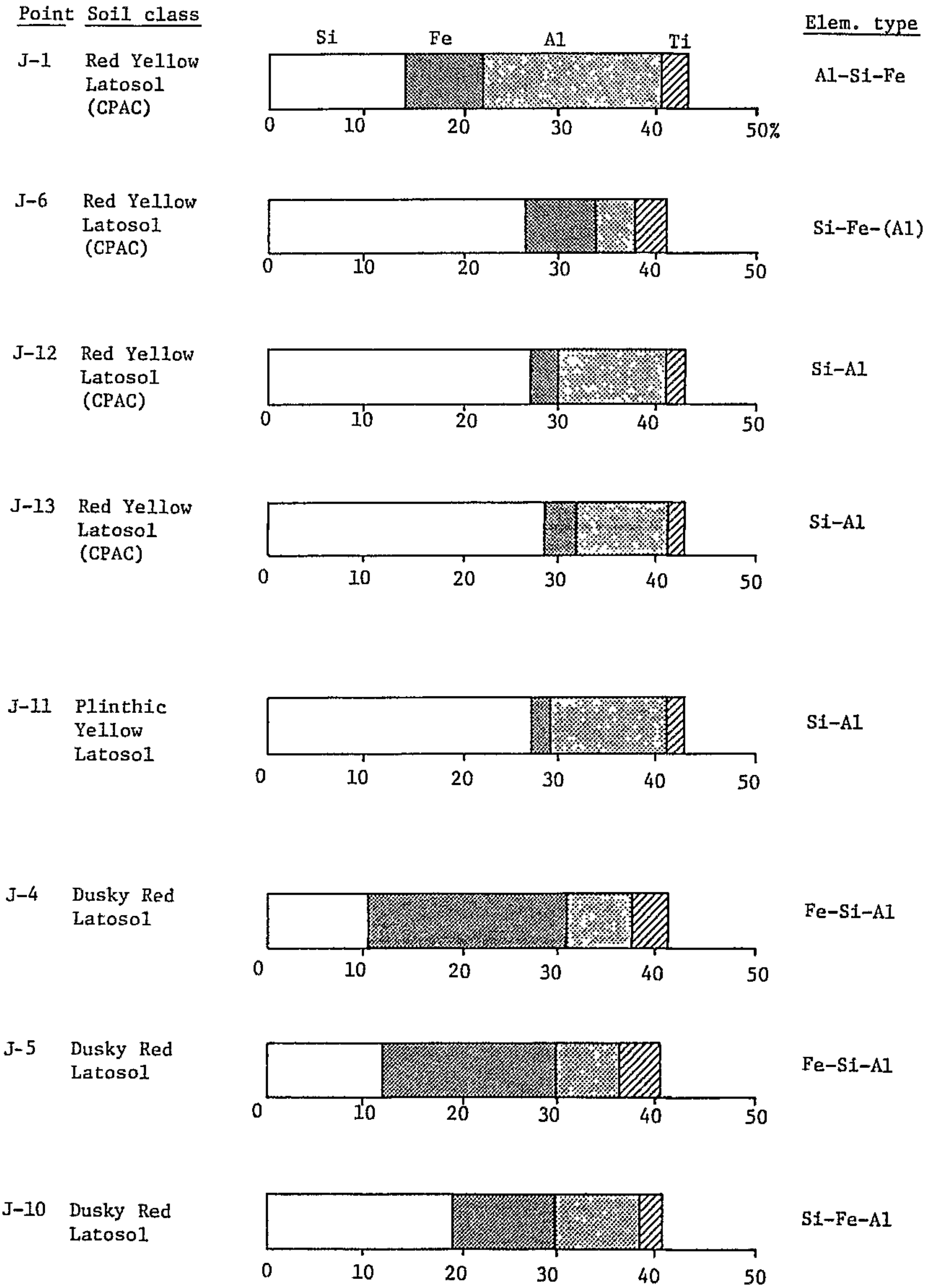



Fig.14a. Elemental composition of soil skeleton

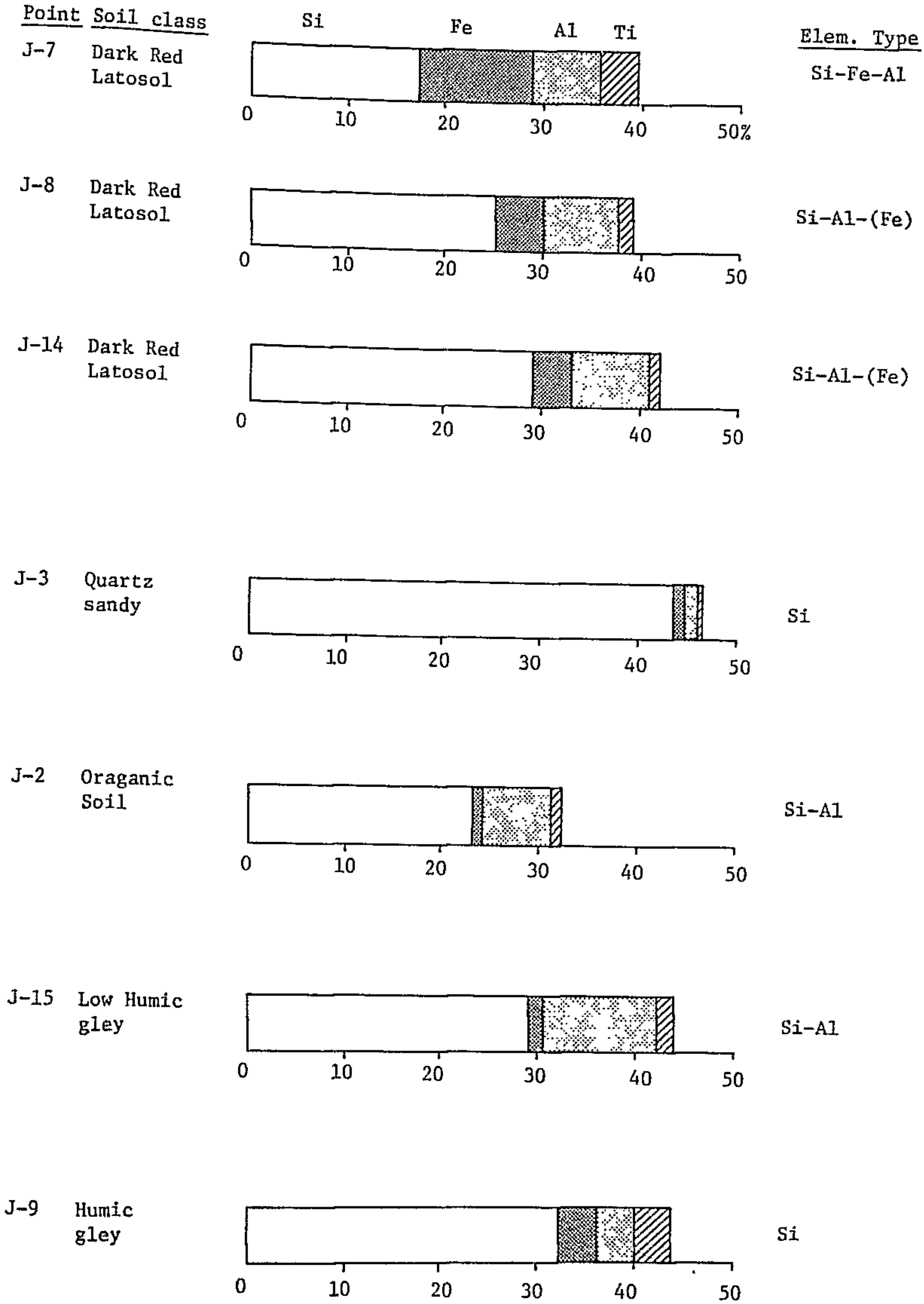



Fig. 14b. Elemental composition of soil skeleton

Table 1 Cerrado soil samples

| No. | Soil type | Horizon cm | pH ($H_2O$) |
|---|---|---|---|
| 1 | LE | 0 ∿ 10 | 5.19 |
| 2 | " | 10 ∿ 20 | 4.61 |
| 3 | LE | 0 ∿ 10 | 4.05 |
| 4 | " | 10 ∿ 20 | 4.38 |
| 5 | LV | 0 ∿ 10 | 4.85 |
| 6 | " | 10 ∿ 20 | 4.50 |
| 7 | " | 25 ∿ | 4.65 |

Table 2 Analytical conditions for X-ray fluorescence spectrometry (Toshiba AFV-777)

| Element | X-ray | Crystal | Detector | Time |
|---|---|---|---|---|
| Aℓ | Cr | EDDT | PC | 10 sec. |
| Si | Cr | EDDT | PC | 10 |
| Fe | W | LiF | SC | 10 |
| K | Cr | LiF | PC | 10 |
| Ca | Cr | LiF | PC | 10 |
| Mg | Cr | ADP | PC | 20 |
| P | Cr | Ge 111 | PC | 20 |
| Mn | W | LiF | SC | 10 |
| Zn | W | LiF | SC | 10 |
| Cu | W | LiF | SC | 10 |

Table 3 Analytical conditions for X-ray fluorescence spectrometry

| Element | Incident X-ray | | | 2θ | Detector | PHA | | Slit | Crystal | Calibration ($Y = A + BX + CX^2$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tube | KV | mA | | | Base | Window | | | A | B | C | R |
| Fe | W | 25 | 20 | 57,510 | SC | 200 | 400 | F | LiF | 0.52762 | 0.00920 | 0.00001 | 0.998 |
| Mn | W | 50 | 40 | 62,960 | SC | 150 | 500 | C | LiF | 69.07324 | 27.84427 | -0.07708 | 0.983 |
| Ti | W | 50 | 40 | 86,120 | SC | 200 | 400 | F | LiF | 0.25080 | 0.03713 | -0.00010 | 0.947 |
| Ca | Cr | 40 | 35 | 113,200 | PC | 250 | 300 | F | LiF | -0.00279 | 0.00030 | 0.00000 | 0.999 |
| K | Cr | 40 | 35 | 136,800 | PC | 200 | 300 | F | LiF | 0.02500 | 0.00005 | -0.00000 | 0.994 |
| S | Cr | 40 | 35 | 110,675 | PC | 200 | 250 | C | Ge-111 | | | | |
| P | Cr | 40 | 35 | 140,848 | PC | 200 | 200 | C | Ge-111 | 17.34840 | 6.60998 | 0.02575 | 0.999 |
| Si | Cr | 40 | 35 | 107,980 | PC | 150 | 250 | F | EDDT | 6.35004 | 0.31200 | -0.00065 | 0.973 |
| Aℓ | Cr | 40 | 35 | 142,504 | PC | 150 | 250 | F | EDDT | 1.09379 | -0.00011 | 0.00003 | 0.998 |
| Mg | Cr | 40 | 35 | 136,820 | PC | 250 | 250 | C | ADP | -135.53711 | 1.71840 | 0.00023 | 0.994 |
| Ba | W | 50 | 40 | Scan | SC | 200 | Integral | F | LiF | | | | |
| Zr | " | " | " | " | " | " | " | " | " | | | | |
| Sr | " | " | " | " | " | " | " | " | " | | | | |
| Rb | " | " | " | " | " | " | " | " | " | | | | |
| Zn | " | " | " | " | " | " | " | " | " | -10.53091 | 28.09166 | -2.06502 | 0.992 |
| Cu | " | " | " | " | " | " | " | " | " | | | | |
| Ni | " | " | " | " | " | " | " | " | " | | | | |
| Y | " | " | " | " | " | " | " | " | " | | | | |
| Nb | " | " | " | " | " | " | " | " | " | | | | |
| Mo | " | " | " | " | " | " | " | " | " | | | | |

## Table 4 X-ray Spectrometry (Intensity)

| Soil sample | | | | Fe | Mn | Ri | | Ca | K | S | P | Si | Aℓ | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | x $10^3$ | x $10^3$ | x $10^3$ | | x $10^2$ | x $10^3$ | x 10 | x $10^2$ | x $10^3$ | x $10^2$ | x 1 |
| J-1 | Red Yellow Latosol (CPAC) | $A_1$ | 0∿ 15 | 482 | 4.9 | 60 | | 91 | 8 | 297 | 41 | 26 | 792 | 205 |
| | | $A_3$ | 15∿ 40 | 484 | 4.7 | 59 | | 10 | 8 | 241 | 30 | 26 | 808 | 197 |
| | | $B_1$ | 40∿ 70 | 490 | 5.3 | 62 | | 8 | 7 | 204 | 29 | 22 | 823 | 224 |
| | | $B_{21}$ | 70∿140 | 490 | 4.9 | 63 | | 7 | 7 | 182 | 26 | 25 | 830 | 207 |
| | | $B_{22}$ | 140∿230 | 503 | 4.9 | 62 | | 8 | 7 | 168 | 23 | 25 | 825 | 206 |
| | | $B_3CA$ | 230∿250$^+$ | 500 | 5.3 | 62 | | 7 | 7 | 143 | 22 | 27 | 822 | 207 |
| J-2 | Organic Soil (CPAC) | $A_1$ | 0∿ 50 | 33 | 3.9 | 14 | | 60 | 16 | 547 | 190 | 61 | 463 | 231 |
| | | C | 50∿ 55 | 46 | 2.2 | 29 | | 12 | 86 | 145 | 24 | 98 | 670 | 593 |
| | | IIA | 55∿ 70 | 40 | 3.7 | 20 | | 11 | 29 | 412 | 44 | 55 | 454 | 283 |
| | | IIC | 70∿ 90$^+$ | 31 | 2.1 | 36 | | 22 | 29 | 148 | 9 | 105 | 687 | 426 |
| J-3 | Quartz Sandy (CPAC) | $A_1$ | 0∿ 20 | 25 | 2.9 | 5 | | 10 | 3 | 154 | 15 | 208 | 137 | 109 |
| | | $A_3$ | 20∿ 60 | 20 | 2.7 | 5 | | 7 | 2 | 78 | 9 | 216 | 131 | 99 |
| | | $C_1$ | 60∿100 | 13 | 2.1 | 8 | | 7 | 3 | 89 | 11 | 185 | 243 | 104 |
| | | $C_2$ | 100∿130$^+$ | 27 | 3.5 | 6 | | 7 | 2 | 58 | 7 | 212 | 159 | 106 |
| J-4 | Dusky Red Latosol (Rio Verde) | $A_1$ | 0∿ 20 | 945 | 54.1 | 237 | | 75 | 8 | 264 | 162 | 13 | 460 | 476 |
| | | $A_3$ | 20∿ 40 | 946 | 55.2 | 238 | | 110 | 8 | 294 | 169 | 13 | 457 | 442 |
| | | $B_1$ | 40∿ 80 | 953 | 51.1 | 241 | | 66 | 7 | 214 | 126 | 12 | 469 | 469 |
| | | $B_2$ | 80∿140 | 961 | 48.0 | 247 | | 63 | 6 | 181 | 114 | 11 | 477 | 454 |
| J-5 | Dusky Red Latosol (Rio Verde) | $A_1$ | 0∿ 20 | 870 | 56.1 | 213 | | 2,010 | 12 | 599 | 162 | 18 | 443 | 454 |
| | | $A_3$ | 20∿ 40 | 891 | 58.7 | 223 | | 572 | 8 | 440 | 141 | 18 | 468 | 415 |
| | | $B_1$ | 40∿ 90 | 899 | 52.1 | 226 | | 349 | 6 | 274 | 119 | 16 | 479 | 391 |
| | | $B_2$ | 90∿150 | 912 | 46.2 | 232 | | 145 | 5 | 184 | 101 | 15 | 487 | 390 |
| J-6 | Red Yellow Latosol | $A_1$ | 0∿ 20 | 456 | 13.2 | 93 | | 134 | 6 | 230 | 64 | 75 | 342 | 261 |
| | | $A_2$ | 20∿ 35 | 439 | 9.8 | 89 | | 32 | 5 | 162 | 46 | 82 | 340 | 226 |
| | | $B_1$ | 35∿ 85 | 510 | 9.7 | 117 | | 27 | 5 | 155 | 46 | 62 | 403 | 252 |
| | | $IIB_2$ | 85∿140 | 532 | 11.4 | 125 | | 26 | 5 | 129 | 46 | 58 | 420 | 239 |

| Soil sample | | | | Fe | Mn | Ti | | Ca | K | S | P | Si | Aℓ | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | x $10^3$ | x $10^3$ | x $10^3$ | | x $10^2$ | x $10^3$ | x 10 | x $10^2$ | x $10^2$ | x $10^2$ | x 1 |
| J-7 | Dark Red Latosol | $A_1$ | 0∿ 20 | 652 | 91.6 | 160 | | 202 | 16 | 458 | 213 | 38 | 447 | 377 |
| | | $A_3$ | 20∿ 40 | 713 | 30.9 | 158 | | 44 | 5 | 254 | 133 | 35 | 448 | 249 |
| | | $B_1$ | 40∿ 90 | 703 | 25.0 | 161 | | 32 | 4 | 198 | 86 | 36 | 459 | 236 |
| | | $B_2$ | 90∿140$^+$ | 724 | 22.6 | 165 | | 20 | 4 | 160 | 68 | 31 | 473 | 239 |
| J-8 | Dark Red Latosol (Goiania) | $A_1$ | 0∿ 20 | 330 | 15.6 | 25 | | 208 | 155 | 286 | 58 | 71 | 477 | 576 |
| | | $A_3$ | 20∿ 30 | 363 | 15.6 | 26 | | 145 | 150 | 266 | 54 | 66 | 518 | 515 |
| | | $B_1$ | 30∿ 60 | 408 | 12.4 | 29 | | 44 | 166 | 172 | 37 | 56 | 574 | 503 |
| | | $B_{21}$ | 60∿100 | 434 | 11.6 | 30 | | 43 | 174 | 145 | 33 | 55 | 589 | 488 |
| | | II$B_{22}$ | 100∿185 | 511 | 11.8 | 32 | | 27 | 184 | 110 | 40 | 44 | 614 | 489 |
| | | IIC | 185∿230 | 477 | 37.2 | 32 | | 28 | 199 | 104 | 40 | 45 | 625 | 486 |
| J-9 | Humic Gley (Univ. Goias) | $A_1$ | 0∿ 20 | 263 | 98.5 | 100 | | 781 | 88 | 431 | 132 | 105 | 314 | 779 |
| | | $Cg_1$ | 20∿ 50 | 303 | 21.2 | 70 | | 405 | 51 | 174 | 43 | 85 | 467 | 781 |
| | | $Cg_2$ | 50∿ 80 | 229 | 27.3 | 73 | | 596 | 61 | 139 | 40 | 74 | 515 | 1,060 |
| | | $Cg_3$ | 80∿ 90 | 223 | 31.4 | 91 | | 894 | 129 | 138 | 48 | 92 | 445 | 1,450 |
| J-10 | Dusky Red Latosol (Goiania) | $A_1$ | 2∿ 20 | 593 | 28.5 | 58 | | 229 | 97 | 268 | 48 | 45 | 527 | 386 |
| | | $A_3$ | 10∿ 40 | 542 | 36.3 | 62 | | 109 | 84 | 316 | 50 | 56 | 482 | 371 |
| | | $B_1$ | 40∿100 | 622 | 28.7 | 54 | | 52 | 93 | 169 | 41 | 38 | 563 | 407 |
| | | $B_2$ | 100∿150 | 634 | 26.2 | 52 | | 38 | 100 | 143 | 36 | 40 | 582 | 412 |
| J-11 | Plinthic Yellow Latosol (CPAC) | $A_1$ | 0∿ 15 | 123 | 3.0 | 38 | | 41 | 14 | 205 | 27 | 79 | 631 | 301 |
| | | $A_3$ | 15∿ 30 | 53 | 2.7 | 39 | | 22 | 13 | 160 | 14 | 83 | 674 | 329 |
| | | $B_1$ | 30∿ 60 | 52 | 2.6 | 40 | | 16 | 14 | 144 | 14 | 70 | 703 | 296 |
| | | $B_2$ | 60∿100$^+$ | 58 | 2.6 | 41 | | 12 | 14 | 125 | 11 | 78 | 730 | 280 |
| J-12 | Red Yellow Latosol (CPAC) | $A_1$ | 0∿ 15 | 188 | 3.2 | 35 | | 38 | 14 | 203 | 26 | 78 | 606 | 286 |
| | | $A_3$ | 15∿ 30 | 161 | 3.0 | 37 | | 19 | 12 | 188 | 22 | 77 | 646 | 301 |
| | | $B_1$ | 30∿ 60 | 155 | 2.9 | 40 | | 16 | 12 | 144 | 17 | 65 | 690 | 323 |
| | | $B_2$ | 60∿120$^+$ | 131 | 2.7 | 41 | | 15 | 11 | 130 | 15 | 74 | 709 | 288 |

| Soil sample | | | | Fe | Mn | Ti | | Ca | K | S | P | Si | Aℓ | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | $\times 10^3$ | $\times 10^3$ | $\times 10^3$ | | $\times 10^2$ | $\times 10^3$ | $\times 10$ | $\times 10^2$ | $\times 10^2$ | $\times 10^2$ | $\times 1$ |
| J-13 | Red Yellow | $A_1$ | 0∿ 15 | 229 | 3.8 | 31 | | 60 | 19 | 215 | 34 | 84 | 550 | 319 |
| | Latosol | $A_3$ | 15∿ 25 | 202 | 3.2 | 31 | | 20 | 20 | 182 | 24 | 84 | 572 | 315 |
| | (CPAC) | $B_1$ | 25∿ 70 | 206 | 2.9 | 33 | | 15 | 24 | 144 | 20 | 71 | 604 | 345 |
| | | $B_2$ | 70∿120 | 163 | 2.7 | 38 | | 13 | 15 | 128 | 16 | 75 | 679 | 323 |
| J-14 | Dark Red | $A_1$ | 0∿ 20 | 263 | 5.6 | 26 | | 66 | 22 | 203 | 38 | 89 | 490 | 322 |
| | Latosol | $A_3$ | 20∿ 30 | 269 | 4.4 | 28 | | 26 | 22 | 177 | 30 | 88 | 504 | 321 |
| | (CPAC) | $B_1$ | 30∿ 70 | 289 | 3.9 | 29 | | 20 | 25 | 140 | 27 | 74 | 530 | 368 |
| | | $B_2$ | 70∿110$^+$ | 292 | 3.4 | 29 | | 19 | 26 | 132 | 23 | 84 | 539 | 392 |
| J-15 | Low Humic | $A_1$ | 0∿ 20 | 104 | 2.9 | 36 | | 21 | 12 | 204 | 21 | 87 | 610 | 288 |
| | Gley | $A_3$ | 20∿ 30 | 50 | 2.7 | 37 | | 16 | 11 | 155 | 14 | 88 | 657 | 332 |
| | (CPAC) | $C_1$ | 30∿ 60 | 38 | 2.6 | 43 | | 13 | 11 | 126 | 14 | 72 | 711 | 356 |
| | | $C_2$ | 60∿120$^+$ | 46 | 2.5 | 43 | | 11 | 10 | 114 | 12 | 85 | 698 | 353 |

Table 5 X-ray Spectrometry (Intensity)

| Soil sample | | | | Ba | Zr | Sr | Rb | Zn | Cu | Ni | | Y | Nb | Mo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | K | K | K | K | K | K | K | | | | |
| J-1 | Red Yellow Latosol (CPAC) | $A_1$ | 0∼ 15 | 1.5 | 65.0 | 1.3 | 1.0 | 1.6 | 0.8 | 1.3 | | 3.0 | 5.2 | |
| | | $A_3$ | 15∼ 40 | 2.0 | 65.0 | 1.2 | 0.5 | 1.5 | 0.2 | 1.5 | | 3.4 | 5.0 | |
| | | $B_1$ | 40∼ 70 | 3.0 | 66.6 | 2.2 | 0.9 | 1.0 | 0.5 | 1.5 | | 3.5 | 4.8 | |
| | | $B_{21}$ | 70∼140 | 1.5 | 67.1 | 1.8 | 0.5 | 1.4 | 1.0 | 1.3 | | 3.2 | 5.6 | |
| | | $B_{22}$ | 140∼230 | 0.6 | 68.7 | 1.5 | 0.8 | 1.2 | 0.3 | 1.5 | | 3.8 | 5.9 | |
| | | $B_3$CA | 230∼250$^+$ | 3.0 | 67.0 | 1.6 | 0.2 | 1.3 | 0.5 | 1.4 | | 4.2 | 4.8 | |
| J-2 | Organic Soil (CPAC) | A | 0∼ 50 | 1.5 | 27.0 | 0.5 | 0.5 | 1.4 | 7.2 | 6.8 | | 35.5 | 11.5 | 4.5 |
| | | C | 50∼ 55 | 4.1 | 50.2 | 4.0 | 2.0 | 1.3 | 8.1 | 3.0 | | 8.6 | 4.5 | 1.0 |
| | | IIA | 55∼ 70 | 1.8 | 33.7 | 1.0 | 1.9 | 1.8 | 12.1 | 9.8 | | 59.0 | 18.0 | 6.1 |
| | | IIC | 70∼ 90$^+$ | 2.7 | 69.8 | 2.1 | 1.6 | 1.4 | 11.5 | 2.3 | | 5.4 | 4.2 | 1.1 |
| J-3 | Quartz Sandy (CPAC) | $A_1$ | 0∼ 20 | 3.1 | 16.2 | 1.1 | 0.9 | 0.2 | 1.1 | 1.0 | | | 2.3 | |
| | | $A_3$ | 20∼ 60 | 2.3 | 18.7 | 1.8 | 0.3 | 0.5 | 0.5 | 0.9 | | | 2.0 | |
| | | $C_1$ | 60∼100 | 0.5 | 19.3 | 1.0 | 0.6 | 0.5 | 0.5 | 0.4 | | | 1.5 | |
| | | $C_2$ | 100∼130$^+$ | 1.5 | 23.0 | 0.6 | 0.8 | 0.6 | 1.1 | 11.0 | | 2.0 | 2.0 | |
| J-4 | Dusky Red Latosol (Rio Verde) | $A_1$ | 0∼ 20 | 3.0 | 40.8 | 4.3 | 0.3 | 2.0 | 1.8 | 4.0 | | 1.5 | 10.0 | |
| | | $A_3$ | 20∼ 40 | 3.8 | 40.3 | 4.7 | 0.4 | 1.7 | 1.8 | 4.0 | | 1.2 | 9.6 | |
| | | $B_1$ | 40∼ 80 | 4.8 | 32.5 | 4.0 | 0.5 | 1.8 | 1.8 | 3.9 | | | 9.2 | |
| | | $B_2$ | 80∼140 | 3.5 | 32.8 | 4.1 | 0.6 | 1.5 | 1.8 | 3.6 | | 1.2 | 10.1 | |
| J-5 | Dusky Red Latosol (Rio Verde) | $A_1$ | 0∼ 20 | 5.4 | 40.8 | 5.9 | 0.4 | 1.9 | 1.4 | 3.9 | | 1.1 | 11.3 | |
| | | $A_3$ | 20∼ 40 | 4.1 | 37.0 | 5.4 | 0.4 | 1.8 | 1.5 | 4.4 | | 1.0 | 10.8 | |
| | | $B_1$ | 40∼ 90 | 6.2 | 41.6 | 5.3 | 0.4 | 1.3 | 1.5 | 4.0 | | 1.8 | 11.4 | |
| | | $B_2$ | 90∼150 | 5.1 | 41.2 | 4.0 | 0.3 | 1.5 | 1.5 | 3.5 | | 0.8 | 11.0 | |
| J-6 | Red Yellow Latosol | $A_1$ | 0∼ 20 | 1.5 | 50.4 | 2.1 | 0.6 | 0.8 | 1.7 | 1.9 | | 1.1 | 6.0 | |
| | | $A_2$ | 20∼ 35 | 1.0 | 53.6 | 1.5 | 0.9 | 1.5 | 1.6 | 2.0 | | | 6.2 | |
| | | $B_1$ | 35∼ 85 | 1.8 | 55.7 | 1.3 | 1.1 | 0.9 | 1.6 | 2.8 | | | 6.6 | |
| | | II$B_2$ | 85∼140 | 1.2 | 55.0 | 2.0 | 1.0 | 0.7 | 2.1 | 2.7 | | | 6.7 | |

| Soil sample | | | Ba | Zr | Sr | Rb | Zn | Cu | Ni | | Y | Nb | Mo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | K | K | K | K | K | K | K | | | | |
| J-7 | Dark Red Latosol | $A_1$ 0~20 | 2.0 | 43.0 | 0.4 | 0.7 | 2.2 | 3.1 | 2.1 | | 1.3 | 3.3 | |
| | | $A_3$ 20~40 | 1.7 | 38.0 | 0.9 | 0.3 | 1.9 | 3.0 | 1.5 | | 1.3 | 3.8 | |
| | | $B_1$ 40~90 | 0.7 | 36.5 | 1.3 | 0.6 | 0.8 | 3.1 | 1.7 | | 1.8 | 3.2 | |
| | | $B_2$ 90~140$^+$ | 2.2 | 38.8 | 1.5 | 0.6 | 1.1 | 3.2 | 2.1 | | 1.0 | 3.1 | |
| J-8 | Dark Red Latosol (Goiânia) | $A_1$ 0~20 | 7.0 | 23.0 | 2.2 | 2.0 | 2.5 | 1.4 | 1.4 | | | 2.0 | |
| | | $A_3$ 20~30 | 6.5 | 23.3 | 2.4 | 2.5 | 1.3 | 2.0 | 2.0 | | | 1.5 | |
| | | $B_1$ 30~60 | 5.3 | 24.3 | 2.3 | 4.0 | 1.2 | 1.8 | 1.8 | | | 2.5 | |
| | | $B_{21}$ 60~100 | 5.8 | 24.5 | 1.8 | 2.7 | 1.8 | 2.1 | 2.1 | | | 2.2 | |
| | | $IIB_{22}$ 100~185 | 6.5 | 26.1 | 2.7 | 3.6 | 1.0 | 2.1 | 2.1 | | | 1.9 | |
| | | IIC 185 230 | 6.2 | 24.8 | 2.7 | 2.6 | 1.5 | 2.3 | 2.3 | | | 2.3 | |
| J-9 | Humic Gley (Univ. Goiás) | $A_1$ 0~20 | 14.0 | 100.0 | 22.7 | 1.0 | 4.1 | 3.0 | 3.0 | | 2.5 | 4.3 | |
| | | $Cg_1$ 20~50 | 7.8 | 53.2 | 14.3 | 0.7 | 3.8 | 2.8 | 2.8 | | 2.0 | 3.6 | |
| | | $Cg_2$ 50~80 | 8.3 | 65.0 | 19.8 | 1.0 | 3.5 | 2.6 | 2.6 | | 1.6 | 2.8 | |
| | | $Cg_3$ 80~90 | 15.5 | 85.0 | 37.0 | 1.0 | 4.3 | 3.0 | 3.0 | | 2.5 | 4.2 | |
| J-10 | Dusky Red Latosol (Goiânia) | $A_1$ 2~20 | 2.4 | 29.5 | 1.5 | 1.9 | 3.1 | 2.7 | 2.7 | | 2.2 | 2.2 | |
| | | $A_3$ 10~40 | 3.0 | 27.0 | 0.6 | 1.9 | 2.5 | 2.4 | 2.4 | | 1.3 | 3.8 | |
| | | $B_1$ 40~100 | 2.5 | 31.5 | 0.7 | 1.6 | 2.1 | 2.6 | 2.6 | | 2.0 | 3.1 | |
| | | $B_2$ 100~150 | 2.7 | 32.5 | 1.1 | 0.9 | 2.1 | 3.0 | 3.0 | | 2.6 | 3.4 | |
| J-11 | Plinthic Yellow Latosol (CPAC) | $A_1$ 0~15 | 2.2 | 52.7 | 1.5 | 1.8 | 1.8 | 2.1 | 2.1 | | 4.2 | 3.6 | |
| | | $A_3$ 15~30 | 2.3 | 61.1 | 1.3 | 1.0 | 1.5 | 1.7 | 1.7 | | 4.7 | 3.8 | |
| | | $B_1$ 30~60 | 3.0 | 60.0 | 2.0 | 1.4 | 1.7 | 2.0 | 2.0 | | 4.9 | 3.5 | |
| | | $B_2$ 60~100$^+$ | 2.1 | 62.5 | 2.0 | 1.0 | 2.0 | 3.0 | 3.0 | | 4.3 | 4.0 | |
| J-12 | Red Yellow Latosol (CPAC) | $A_1$ 0~15 | 1.5 | 55.0 | 2.0 | 1.5 | 1.4 | 2.2 | 2.2 | | 2.6 | 3.6 | |
| | | $A_3$ 15~30 | 1.6 | 60.1 | 1.5 | 1.2 | 1.7 | 2.1 | 2.1 | | 4.8 | 4.5 | |
| | | $B_1$ 30~60 | 1.8 | 64.5 | 1.3 | 1.6 | 1.2 | 2.6 | 2.6 | | 3.4 | 4.2 | |
| | | $B_2$ 60~120$^+$ | 1.6 | 69.5 | 1.3 | 1.8 | 1.8 | 2.7 | 2.7 | | 5.2 | 4.1 | |

| Soil sample | | | | Ba | Zr | Ar | Rb | Zn | Cu | Ni | | Y | Nb | Mo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | K | K | K | K | K | K | K | | | | |
| J-13 | Red Yellow Latosol (CPAC) | $A_1$ | 0∿ 15 | 1.0 | 46.5 | 1.4 | 1.3 | 1.1 | 2.0 | 2.0 | | 3.9 | 2.5 | |
| | | $A_3$ | 15∿ 25 | 2.5 | 48.5 | 2.0 | 1.3 | 1.6 | 1.8 | 1.8 | | 3.5 | 3.5 | |
| | | $B_1$ | 25∿ 70 | 1.8 | 52.2 | 1.5 | 1.5 | 1.3 | 1.6 | 1.6 | | 3.7 | 4.1 | |
| | | $B_2$ | 70∿120$^+$ | 1.9 | 61.2 | 1.5 | 0.9 | 2.0 | 2.6 | 2.6 | | 5.0 | 4.6 | |
| J-14 | Dark Red Latosol (CPAC) | $A_1$ | 0∿ 20 | 2.4 | 40.1 | 1.0 | 1.5 | 1.2 | 1.7 | 1.7 | | 3.2 | 2.2 | |
| | | $A_3$ | 20∿ 30 | 1.5 | 39.3 | 1.8 | 1.4 | 1.2 | 1.5 | 1.5 | | 3.0 | 2.0 | |
| | | $B_1$ | 30∿ 70 | 1.8 | 41.1 | 1.3 | 0.5 | 1.1 | 1.5 | 1.5 | | 3.0 | 1.8 | |
| | | $B_2$ | 70∿110$^+$ | 1.8 | 39.5 | 1.1 | 1.2 | 1.4 | 1.1 | 1.1 | | 3.3 | 2.3 | |
| J-15 | Low Humic Gley (CPAC) | $A_1$ | 0∿ 20 | 1.8 | 60.5 | 1.0 | 1.0 | 1.5 | 1.5 | 1.5 | | 4.0 | 3.2 | |
| | | $A_3$ | 20∿ 30 | 2.0 | 66.6 | 2.0 | 1.2 | 1.5 | 3.0 | 3.0 | | 5.5 | 4.2 | |
| | | $C_1$ | 30∿ 60 | 0.5 | 85.0 | 1.5 | 1.0 | 1.6 | 4.0 | 4.0 | | 5.6 | 4.8 | |
| | | $C_2$ | 60∿120$^+$ | 2.2 | 83.0 | 1.9 | 1.2 | 1.6 | 3.9 | 3.9 | | 5.5 | 5.3 | |

Table 6 X-ray Spectrometry (Concentration)

| Soil sample | | | | Si | Fe | A | Ti | K | Ca | Mg | P | An | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | % | % | % | % | % | % | ppm | ppm | ppm | ppm |
| J-1 | Red Yellow Latosol (CPAC) | $A_1$ | 0∿ 15 | 14.0 | 7.9 | 18.6 | 0.13 | 0.050 | 0.025 | 226 | 332 | 29 | 66 |
| | | $A_3$ | 15∿ 40 | 14.0 | 7.9 | 19.3 | 2.10 | 0.048 | tr.* | 212 | 239 | 27 | 60 |
| | | $B_1$ | 40∿ 70 | 12.9 | 8.0 | 20.0 | 2.18 | 0.046 | tr. | 261 | 231 | 16 | 76 |
| | | $B_{21}$ | 70∿140 | 13.8 | 8.0 | 20.3 | 2.20 | 0.046 | tr. | 230 | 207 | 25 | 66 |
| | | $B_{22}$ | 140∿230 | 13.8 | 8.3 | 20.1 | 2.18 | 0.046 | tr. | 228 | 183 | 20 | 66 |
| | | $B_3CA$ | 230∿250+ | 14.3 | 8.3 | 20.0 | 2.18 | 0.046 | tr. | 230 | 175 | 23 | 76 |
| J-2 | Organic Soil (CPAC) | $A_1$ | 0∿ 50 | 23.0 | 0.9 | 7.1 | 0.75 | 0.082 | 0.015 | 274 | 2,203 | 25 | 38 |
| | | C | 50∿ 55 | 30.7 | 1.0 | 13.6 | 1.25 | 0.337 | tr. | 963 | 191 | 23 | tr. |
| | | IIA | 55∿ 70 | 21.6 | 0.9 | 6.8 | 0.95 | 0.128 | tr. | 369 | 358 | 33 | 33 |
| | | IIC | 70∿ 90+ | 32.0 | 0.8 | 14.3 | 0.46 | 0.130 | tr. | 638 | 79 | 25 | tr. |
| J-3 | Quartz Sandy (CPAC) | $A_1$ | 0∿ 20 | 43.3 | 0.8 | 1.6 | 0.43 | 0.030 | tr. | 55 | 122 | tr. | 11 |
| | | $A_3$ | 20∿ 60 | 43.6 | 0.7 | 1.6 | 0.43 | 0.027 | tr. | 37 | 79 | 3 | 5 |
| | | $C_1$ | 60∿100 | 42.0 | 0.7 | 2.7 | 0.54 | 0.031 | tr. | 46 | 93 | 3 | tr. |
| | | $C_2$ | 100∿130+ | 43.5 | 0.8 | 1.8 | 0.47 | 0.028 | tr. | 49 | 65 | 6 | 27 |
| J-4 | Dusky Red Latosol (Rio Verde) | $A_1$ | 0∿ 20 | 10.3 | 20.4 | 7.0 | 3.59 | 0.051 | 0.020 | 734 | 1,764 | 37 | 1,212 |
| | | $A_3$ | 20∿ 40 | 10.3 | 20.4 | 6.9 | 3.58 | 0.049 | 0.031 | 668 | 1,870 | 31 | 1,233 |
| | | $B_1$ | 40∿ 80 | 10.0 | 20.6 | 7.2 | 3.55 | 0.044 | 0.017 | 720 | 1,259 | 33 | 1,153 |
| | | $B_2$ | 80∿140 | 9.7 | 20.9 | 7.4 | 3.49 | 0.043 | 0.016 | 691 | 1,106 | 27 | 1,090 |
| J-5 | Dusky Red Latosol (Rio Verde) | $A_1$ | 0∿ 20 | 11.8 | 17.9 | 6.6 | 3.75 | 0.065 | 0.796 | 691 | 1,764 | 35 | 1,250 |
| | | $A_3$ | 20∿ 40 | 11.8 | 18.6 | 7.2 | 3.69 | 0.048 | 0.184 | 617 | 1,461 | 33 | 1,300 |
| | | $B_1$ | 40∿ 90 | 11.2 | 18.9 | 7.5 | 3.67 | 0.042 | 0.107 | 571 | 1,168 | 23 | 1,172 |
| | | $B_2$ | 90∿150 | 19.3 | 19.3 | 7.7 | 3.63 | 0.040 | 0.041 | 569 | 948 | 27 | 1,053 |
| J-6 | Red Yellow Latosol | $A_1$ | 0∿ 20 | 26.1 | 7.3 | 4.3 | 2.86 | 0.042 | 0.038 | 328 | 546 | 11 | 285 |
| | | $A_2$ | 20∿ 35 | 27.6 | 7.0 | 4.3 | 2.79 | 0.039 | tr. | 264 | 376 | 27 | 196 |
| | | $B_1$ | 35∿ 85 | 23.2 | 8.5 | 5.6 | 3.26 | 0.038 | tr. | 312 | 376 | 13 | 194 |
| | | $IIB_2$ | 85∿140 | 22.3 | 9.0 | 6.0 | 3.37 | 0.039 | tr. | 288 | 376 | 8 | 238 |

* tr. = <0.01

| Soil sample | | | | Si | Fe | Aℓ | Ti | K | Ca | Mg | P | Zn | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | % | % | % | % | % | % | ppm | ppm | ppm | ppm |
| J-7 | Dark Red Latosol | $A_1$ | 0∿ 15 | 17.3 | 11.8 | 6.7 | 3.70 | 0.081 | 0.059 | 544 | 2,593 | 41 | 1,835 |
| | | $A_3$ | 20∿ 40 | 16.5 | 13.4 | 6.7 | 3.69 | 0.038 | 0.010 | 306 | 1,351 | 35 | 718 |
| | | $B_1$ | 40∿ 90 | 16.8 | 13.2 | 7.0 | 3.71 | 0.036 | tr. | 283 | 776 | 11 | 579 |
| | | $B_2$ | 90∿140$^+$ | 15.4 | 13.7 | 7.3 | 3.73 | 0.035 | tr. | 288 | 586 | 18 | 521 |
| J-8 | Dark Red Latosol (Goiânia) | $A_1$ | 0∿ 20 | 25.3 | 4.9 | 7.4 | 1.12 | 0.590 | 0.061 | 929 | 487 | 47 | 347 |
| | | $A_3$ | 20∿ 30 | 24.1 | 5.5 | 8.6 | 1.15 | 0.571 | 0.041 | 809 | 449 | 23 | 347 |
| | | $B_1$ | 30∿ 60 | 21.8 | 6.4 | 10.3 | 1.25 | 0.629 | 0.010 | 786 | 297 | 20 | 264 |
| | | $B_{21}$ | 60∿100 | 21.6 | 6.9 | 10.8 | 1.28 | 0.658 | 0.010 | 757 | 264 | 33 | 244 |
| | | $IIB_{22}$ | 100∿185 | 18.5 | 8.5 | 11.6 | 1.34 | 0.694 | tr. | 759 | 323 | 16 | 249 |
| | | IIC | 185∿230 | 19.1 | 7.8 | 12.0 | 1.34 | 0.746 | tr. | 753 | 323 | 27 | 860 |
| J-9 | Humic Gley (Univ. Goiás) | A | 0∿ 20 | 32.0 | 3.8 | 3.8 | 2.99 | 0.053 | 0.260 | 1,340 | 1,339 | 70 | 1,926 |
| | | $Cg_1$ | 20∿ 50 | 28.2 | 4.5 | 7.2 | 2.37 | 0.210 | 0.126 | 1,344 | 349 | 66 | 487 |
| | | $Cg_2$ | 50∿ 80 | 25.9 | 3.3 | 8.5 | 2.44 | 0.246 | 0.192 | 1,940 | 323 | 62 | 634 |
| | | $Cg_3$ | 80∿ 90 | 29.6 | 2.6 | 6.6 | 2.82 | 0.495 | 0.303 | 2,831 | 394 | 72 | 729 |
| J-10 | Dusky Red Latosol (Goiania) | $A_1$ | 2∿ 20 | 19.1 | 10.4 | 8.8 | 2.08 | 0.378 | 0.068 | 561 | 394 | 57 | 662 |
| | | $A_3$ | 10∿ 40 | 21.8 | 9.2 | 7.6 | 2.18 | 0.330 | 0.030 | 533 | 412 | 47 | 840 |
| | | $B_1$ | 40∿100 | 17.3 | 11.1 | 9.9 | 1.97 | 0.363 | 0.013 | 601 | 332 | 39 | 667 |
| | | $B_2$ | 100∿150 | 17.8 | 11.4 | 10.5 | 1.92 | 0.390 | tr. | 611 | 289 | 39 | 608 |
| J-11 | Plinthic Yellow Latosol (CPAC) | $A_1$ | 0∿ 15 | 27.0 | 1.8 | 12.2 | 1.52 | 0.072 | tr. | 402 | 215 | 33 | 14 |
| | | $A_3$ | 15∿ 30 | 27.8 | 1.1 | 13.8 | 1.55 | 0.068 | tr. | 454 | 115 | 27 | 6 |
| | | $B_1$ | 30∿ 60 | 25.0 | 1.0 | 14.9 | 1.58 | 0.071 | tr. | 393 | 115 | 31 | 3 |
| | | $B_2$ | 60∿100$^+$ | 26.8 | 1.1 | 16.0 | 1.61 | 0.072 | tr. | 363 | 93 | 37 | 3 |
| J-12 | Red Yellow Latosol (CPAC) | $A_1$ | 0∿ 15 | 26.8 | 2.7 | 11.3 | 1.43 | 0.073 | tr. | 374 | 207 | 25 | 19 |
| | | $A_3$ | 15∿ 30 | 26.6 | 2.3 | 12.7 | 1.49 | 0.064 | tr. | 402 | 175 | 31 | 14 |
| | | $B_1$ | 30∿ 60 | 23.9 | 2.3 | 14.4 | 1.58 | 0.065 | tr. | 443 | 137 | 20 | 11 |
| | | $B_2$ | 60∿120$^+$ | 25.9 | 2.0 | 15.1 | 1.61 | 0.062 | tr. | 378 | 122 | 33 | 6 |

| Soil sample | | | | Si | Fe | Aℓ | Ti | K | Ca | Mg | P | Zn | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Class. (loc.) | Horizon, cm | | % | % | % | % | % | % | ppm | ppm | ppm | ppm |
| J-13 | Red Yellow | $A_1$ | 0∿ 15 | 28.0 | 3.3 | 9.5 | 1.31 | 0.091 | 0.015 | 436 | 272 | 18 | 36 |
| | Latosol | $A_3$ | 15∿ 25 | 28.0 | 2.9 | 10.2 | 1.31 | 0.093 | tr. | 428 | 191 | 29 | 19 |
| | (CPAC) | $B_1$ | 25∿ 70 | 25.3 | 3.0 | 11.3 | 1.37 | 0.108 | tr. | 484 | 160 | 23 | 11 |
| | | $B_2$ | $70∿120^+$ | 26.1 | 2.4 | 14.0 | 1.52 | 0.077 | tr. | 443 | 130 | 37 | 6 |
| J-14 | Dark Red | $A_1$ | 0∿ 20 | 29.0 | 3.8 | 7.8 | 1.15 | 0.101 | 0.017 | 441 | 306 | 20 | 84 |
| | Latosol | $A_3$ | 20∿ 30 | 28.8 | 3.0 | 8.2 | 1.21 | 0.102 | tr. | 439 | 239 | 20 | 52 |
| | (CPAC) | $B_1$ | 30∿ 70 | 25.9 | 3.2 | 8.9 | 1.25 | 0.111 | tr. | 527 | 215 | 18 | 33 |
| | | $B_2$ | $70∿110^+$ | 28.0 | 3.2 | 8.9 | 1.25 | 0.118 | tr. | 573 | 183 | 25 | 25 |
| J-15 | Low Humic | $A_1$ | 0∿ 20 | 28.6 | 1.5 | 11.5 | 1.46 | 0.065 | tr. | 378 | 168 | 27 | 11 |
| | Gley | $A_3$ | 20∿ 30 | 28.8 | 1.0 | 13.1 | 1.49 | 0.061 | tr. | 460 | 115 | 27 | 6 |
| | (CPAC) | $C_1$ | 30∿ 60 | 25.5 | 0.9 | 15.2 | 1.67 | 0.060 | tr. | 505 | 115 | 29 | 3 |
| | | $C_2$ | $60∿120^+$ | 28.2 | 1.0 | 14.7 | 1.67 | 0.059 | tr. | 499 | 100 | 29 | tr. |

Table 7 Nutrient application rate

| Nutrient | Reagent | Reagent mg/pot |
|---|---|---|
| N | $NH_4NO_3$ | 171.5 |
| P | $NaH_2PO_4$ | 1,115.0 |
| K | $K_2SO_4$ | 200.5 |
| Ca | $CaCO_3$ | in Table 7 |
| Mg | $MgSO_4 \cdot 7H_2O$ | 304.3 |
| Mn | $MnC\ell_2 \cdot 4H_2O$ | 5.4 |
| Zn | $ZnSO_4 \cdot 7H_2O$ | 6.6 |
| Cu | $CuC\ell_2 \cdot 2H_2O$ | 0.81 |
| Mo | $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ | 5.3 |
| B | $H_3BO_3$ | 0.55 |

Table 8 Application rate of $CaCO_3$ or $MgCO_3$

| Soil samples | $CaCO_3$ ($MgCO_3$) g/pot |
|---|---|
| Red Yellow Latosol (medium) | 1.5 (1.26) |
| Red Yellow Latosol (clayey) | 3.0 (2.52) |
| Dark Red Latosol (medium) | 3.0 (2.52) |
| Dark Red Latosol (clayey) | 6.0 (5.04) |
| Quartz sandy soil | 3.0 (2.52) |
| Organic soil | 5.0 (4.20) |
| Humic gley soil | 4.5 (3.78) |

Appendix 1 Distribution of soils in the Cerrado region

| Soil class | | % area |
|---|---|---|
| LRd | - Latossolo Roxo distrófico | 1,34 |
| LRde | - Latossolo Roxo distrófico e eutrófico | 2,22 |
| LEd | - Latossolo Vermelho-Escuro distrófico | 18,00 |
| LEde | - Latossolo Vermelho-Escuro distrófico e eutrófico | 0,73 |
| LEe | - Latossolo Vermelho-Escuro eutrófico | 0,01 |
| LVd | - Latossolo Vermelho-Amarelo distrófico | 22,38 |
| LAd | - Latossolo Amarelo distrófico | 1,81 |
| TRe | - Terra Roxa Estruturada eutrófica | 0,41 |
| TSde | - Terra Roxa Estruturada Similar distrófico e eutrófico | 0,23 |
| TSe | - Terra Roxa Estruturada Similar eutrófica | 1,07 |
| PV | - Podzólico Vermelho-Amarelo distrófico | 6,18 |
| PE | - Podzólico Vermelho-Amarelo eutrófico | 0,34 |
| PVp | - Podzólico Vermelho-Amarelo Plíntico distrófico | 2,97 |
| PEp | - Podzólico Vermelho-Amarelo Plíntico eutrófico | 1,24 |
| BV | - Brunizem Avermelhado | 0,06 |
| NC | - Bruno não Cálcio | 0,04 |
| PLS | - Planossolo Solódico | 0,33 |
| SS | - Solonetz Solodizado | 0,02 |
| Cd | - Cambissolo distrófico | 2,73 |
| Ce | - Cambissolo eutrófico | 0,25 |
| Chd | - Cambissolo Húmico distrófico | 0,04 |
| HLd | - Laterita Hidromórfica distrófica | 3,74 |
| HLde | - Laterita Hidromórfica distrófica e eutrófica | 0,02 |
| HLe | - Laterita Hidromórfica eutrófica | 0,16 |
| HLi | - Laterita Hidromórfica indiscriminada | 0,31 |
| HGd | - Solos Gley distrófico | 1,68 |
| HGde | - Solos Gley distrófico e eutrófico | 0,25 |
| HGe | - Solos Gley eutrófico | 0,02 |
| AQd | - Areia Quartzosa distrófica | 14,55 |
| HAQd | - Areia Quartzosa Hidromórfica distrófica | 0,02 |
| V | - Vertissolo | 0,06 |
| Rd | - Litólico distrófico | 6,60 |
| Rde | - Litólico distrófico e eutrófico | 5,90 |
| Re | - Litólico eutrófico | 0,90 |
| HRd | - Litólico Húmico distrófico | 0,25 |

| Soil Class | % area |
|---|---|
| Rz - Rendzina | 0,10 |
| REde - Regassolo distrófico e eutrófico | 0,17 |
| SCd - Solo Concercionário indiviso distrófico | 2,71 |
| SCe - Solo Concrecionário indiviso eutrófico | |

After J. Macédo, EMBRAPA/CPAC.

Appendix 2 Description of the sampling sites and the soils samples

## POINT J-1

| | | |
|---|---|---|
| Classification | : | Red yellow latosol |
| Location | : | CPAC |
| Vegetation | : | Cerrado |
| Parent Material | : | Tertiary sediments |
| Altitude | : | 1,000 metros |
| Relief | : | Flay to gently rolling |

| | | |
|---|---|---|
| $A_1$ ∿ | 0∿ 15 cm | Dark Brown (7.5 YR 3/2 moist) clay |
| $A_3$ ∿ | 15∿ 40 cm | Reddish brown (5 YR 4/4 moist) clay |
| $B_1$ ∿ | 40∿ 70 cm | Yellowish (5 YR 4/6 moist) clay |
| $B_{21}$ ∿ | 70∿140 cm | Yellowish (5 YR 4.5/8 moist) clay |
| $B_{22}$ ∿ | 140∿230 cm | Yellowish (5 YR 4.5/8 moist) clay |
| $B_3CA$∿ | 230∿250$^+$cm | Yellowish red (5 YR 4.5/8 moist) clay very gravelly (lateritic concretions) |

## POINT J-2

| | | |
|---|---|---|
| Classification | : | Organic soil |
| Location | : | CPAC |
| Vegetation | : | Grassland (natural) |
| Parent Mateiral | : | Quaternary sediments |
| Altitude | : | 950 meter |
| Relief | : | Flat |

| | | |
|---|---|---|
| $A_1$ ∿ | 0∿50 cm | Black (N 1.5 moist) clay |
| C ∿ | 50∿55 cm | Dark gray (5Y 4/1 moist) clay |
| II A ∿ | 55∿70 cm | Black (N 1.5 moist) clay |
| II C ∿ | 70∿90$^+$cm | White (2.5 Y 8/2 moist) clay |

Appendix 2 Description of the sampling sites and the soils samples

## POINT J-1

| | | |
|---|---|---|
| Classification | : | Red yellow latosol |
| Location | : | CPAC |
| Vegetation | : | Cerrado |
| Parent Material | : | Tertiary sediments |
| Altitude | : | 1,000 metros |
| Relief | : | Flay to gently rolling |

| | | |
|---|---|---|
| $A_1$ | ∿ 0∿ 15 cm | Dark Brown (7.5 YR 3/2 moist) clay |
| $A_3$ | ∿ 15∿ 40 cm | Reddish brown (5 YR 4/4 moist) clay |
| $B_1$ | ∿ 40∿ 70 cm | Yellowish (5 YR 4/6 moist) clay |
| $B_{21}$ | ∿ 70∿140 cm | Yellowish (5 YR 4.5/8 moist) clay |
| $B_{22}$ | ∿ 140∿230 cm | Yellowish (5 YR 4.5/8 moist) clay |
| $B_3CA$ | ∿ 230∿250$^+$cm | Yellowish red (5 YR 4.5/8 moist) clay very gravelly (lateritic concretions) |

## POINT J-2

| | | |
|---|---|---|
| Classification | : | Organic soil |
| Location | : | CPAC |
| Vegetation | : | Grassland (natural) |
| Parent Material | : | Quaternary sediments |
| Altitude | : | 950 meter |
| Relief | : | Flat |

| | | |
|---|---|---|
| A | ∿ 0∿50 cm | Black (N 1.5 moist) clay |
| C | ∿ 50∿55 cm | Dark gray (5 Y 4/1 moist) clay |
| II A | ∿ 55∿70 cm | Black (N 1.5 moist) clay |
| II C | ∿ 70∿90$^+$cm | White (2.5 Y 8/2 moist) clay |

## POINT J-3

| | | |
|---|---|---|
| Classification | : | Quartz sands |
| Location | : | CPAC |
| Vegetation | : | Cerrado |
| Parent Material | : | Tertiary/quaternary sediments |
| Altitude | : | 1,000 meters |
| Relief | : | Flat to gently rolling (3%) |

| | |
|---|---|
| $A_1$ ∿ 0∿ 20 cm | Very dark brown (10 YR 2/2 moist), sand |
| $A_3$ ∿ 20∿ 60 cm | Dark grayish brown (10 YR 4/2 moist), sand |
| $C_1$ ∿ 60∿100 cm | Pale brown (10 YR 6/3 moist) with few, small brownish yellow (10 YR 6/8 moist) mottles, sand |
| $C_2$ ∿ 100 $130^+$cm | White (2.5 Y 8/2 moist) with few, small brownish yellow (10 YR 6/8 moist) mottles, sand |

## POINT J-4

| | | |
|---|---|---|
| Classification | : | Dusky red latosol |
| Location | : | Km 210 . Goiânia - Rio Verde road (BR 060) |
| Vegetation | : | Cerrado |
| Parent Material | : | Sediments derived from basic rocks |
| Altitude | : | 800 meters |
| Relief | : | Gently rolling. Upper 1/3 portion of the slope |

| | |
|---|---|
| $A_1$ ∿ 0∿ 20 cm | Very reddish brown (7.5R 2/3 moist) clay |
| $A_3$ ∿ 20∿ 40 cm | Dark reddish brown (7.5R 3/3 moist) clay |
| $B_1$ ∿ 40∿ 80 cm | Very dark reddish brown (10R 2/3 moist) clay |
| $B_2$ ∿ 80∿$140^+$cm | Dusky red (10R 3/4 moist) clay |

OBS: Date de collection 12/03/81

## POINT J-5

| | | |
|---|---|---|
| Classification | : | Dusky red latosol (?) |
| Location | : | Km 195. Goiânia - Rio Verde road |
| Vegetation | : | Cerradao |
| Parent Material | : | Sediments derived from basic rocks |
| Altitude | : | 820 meters |
| Relief | : | Gently rolling (approx. 8%) |

| | |
|---|---|
| $A_1$ ∿ 0∿ 20 cm | Very dark reddish brown (2.5 YR 2/3 moist), clay |
| $A_3$ ∿ 20∿ 40 cm | Dark reddish brown (2.5 YR 2/4 moist), clay |
| $B_1$ ∿ 40∿ 90 cm | Drak reddish brown (2.5 YR 3/4 moist), clay |
| $B_2$ ∿ 90∿150 cm | Dark reddish brown (2.5 YR 3/4 moist), clay |

CBS: Date of collection 12/03/81

## POINT J-6

| | | |
|---|---|---|
| Classification | : | Red yellow latosol |
| Location | : | Km 168. Giânia - Rio Verde road |
| Vegetation | : | Cerrado |
| Parent Material | : | Tertiary sediments |
| Altitude | : | 640 meters |
| Relief | : | Flat |

| | |
|---|---|
| $A_1$ ∿ 0∿ 20 cm | Dark brown (7.5 YR 3/4 moist) sandy clay loam |
| $A_2$ ∿ 20∿ 35 cm | Dark brown (7.5 YR 4/4 moist) sandy clay loam |
| $B_1$ ∿ 35∿ 85 cm | Brown (7.5 YR 4/6 moist) sandy clay loam |
| II B ∿ 85∿140 cm | Brown (10 YR 4/6 moist) sandy clay, with 20 ∿ 50% of gravel (lateritic concretions) |

OBS: Water table at 150 cm
Date of collection: 12/03/81

## POINT J-7

| | | |
|---|---|---|
| Classification | : | Dark red latosol |
| Location | : | Km 139 road Goiânia - Rio Verde |
| Vegetation | : | Cerrado |
| Parent Material | : | Tertiary sediments |
| Altitude | : | |

| | | |
|---|---|---|
| $A_1$ | ∿ 0∿ 20 cm | Very dusky red (2.5 YR 2/2 moist), clay |
| $A_3$ | ∿ 20∿ 40 cm | Dark reddish brown (2.5 YR 2/4 moist), clay |
| $B_1$ | ∿ 40∿ 90 cm | Dark reddish brown (2.5 YR 3/4 moist), clay |
| $B_2$ | ∿ 90∿140$^+$cm | Dard red (2.5 YR 3/6 moist), clay |

## POINT J-8

| | | |
|---|---|---|
| Classification | : | Dark red latosol |
| Location | : | Km 19 road Goiânia - Rio Verde |
| Vegetation | : | Cerradão (original), Pasture (induced) |
| Parent Material | : | Tertiary sediments |
| Altitude | : | 720 m |

| | | |
|---|---|---|
| $A_1$ | ∿ 0∿ 20 cm | Dark reddish brown (5 YR 3/3, moist) clay |
| $A_3$ | ∿ 20∿ 30 cm | Dusky red (2.5 YR 3/2 moist) clay |
| $B_1$ | ∿ 30∿ 60 cm | Dark reddish brown (2.5 YR 3/4, moist) clay |
| $B_{21}$ | ∿ 100∿185 cm | Dark red (2.5 YR 3/6 moist) clay |
| II $B_{22}$ | ∿ 100∿185 cm | Dark red (2.5 YR 3/6 moist) clay |
| II C | ∿ 185∿230 cm | Dark red (2.5 YR 3/6 moist) with presence of semi wethered material, black (N 1 moist) |

## POINT J-9

| | | |
|---|---|---|
| Classification | : | Humic gley |
| Location | : | Campus of Federal University of Goiás (Goiânia Universidade after crossing bridge over "meia ponte creck). |
| Vegetation | : | Humid Grassland |
| Parent Material | : | Sediments derived from basic rocks |
| Altitude | : | 720 m |
| Relief | : | Plain (1 ∿ 2%) |

| | |
|---|---|
| $A_1$ ∿ 0∿20 cm | Black (2.5 Y 2/1 moist), clay leom |
| $Cg_1$ ∿ 20∿50 cm | Gray (5 y 5/1 moist) with many small brownish yellow (10 YR 6/8 moist) mottles, clay |
| $Cg_2$ ∿ 50∿80 cm | Dark gray (5 Y 4/1 moist) wint few small brownish yellow (10 YR 6/8 moist) mottles |
| $Cg_3$ ∿ 80∿90 cm | Bluish gray (5 BG 5/1 moist), clay |

OBS: Stone line at 90 cm

## POINT J-10

| | | |
|---|---|---|
| Classification | : | Dusky red latosol |
| Location | : | Goiânia - Anápolis road |
| Vegetation | : | Semi-deciduos forest |
| Parent Material | : | Sediments derived form basic rocks |
| Altitude | : | 740 m |
| Relief | : | Plain (1 ∿ 2%) |

| | |
|---|---|
| $A_1$ ∿ 2∿ 20 cm | Dark reddish brown (2.5 YR 3/3, moist), clay |
| $A_3$ ∿ 10∿ 40 cm | Dark reddish brown (2.5 YR 3/4, moist), clay |
| $B_1$ ∿ 40∿100 cm | Dusky red (1 YR 3/5, moist), clay |
| $B_2$ ∿ 100∿150 cm | Dusky red (1 YR 3/5, moist), clay |

## POINT J-11

Classification : Plinthic yellow latosol (?)
Location : CPAC
Vegetation : Humid Grassland
Parent Material : Terciary sediments
Altitude : 1,000 meters
Relief : Plain (2 ∿ 3%)

$A_1$ ∿ 0∿ 15 cm — Very dark gray (10 YR 3/1, moist with few, medium distinct strong brown (7.5 YR 5/8 moist) mottles, silty clay loam.

$A_3$ ∿ 15∿ 30 cm — Dark grayish brown (10 YR 4/2 moist) with few, strong brown (7.5 YR 5/8 moist) mottles, sandy clay loam.

$B_1$ ∿ 30∿ 60 cm — Grayish brown (10 YR 5/2 moist) with common medium to small, distinct mottles of strong brown (7.5 YR 5/8 moist), sandy clay loam.

$B_2$ ∿ 60∿100$^+$cm — Very pale brown (10 YR 7/3 moist) with few, medium, distinct mottles of strong brown (7.5 YR 5/8 moist), sandy clay loam.

OBS: Water table approx. 100 cm
Date of collection 12/04/81

## POINT J-12

Classification : Red yellow latosol
Location : CPAC
Vegetation : Grassland
Parent Material : Terciary sediments
Altitude : 1,000 meters
Relief : Plain (2 ∿ 3%)

$A_1$ ∿ 0∿ 15 cm — Very dark grayish brown (10 YR 3/4, moist) dandy slay loam.

$A_3$ ∿ 15∿ 30 cm — Dark yellowish brown (10 YR 3/4, moist) sandy clay loam.

$B_1$ ∿ 30∿ 60 cm — Yellowish brown (10 YR 4/6 moist) sandy clay loam.

$B_2$ ∿ 60∿120$^+$cm — Yellow (10 YR 7/8 moist) sandy clay loam.

OBS: Water table at approximately 150 cm
Date of collection 12/04/81

## POINT J-13

Classification : Red yellow latosol
Location : CPAC
Vegetation : Grassland (Natural)
Parent Material : Tertiary sediments
Altitude : 1,000 meters
Relief : Plain (2 ∿ 3%)

| | |
|---|---|
| $A_1$ ∿ 0 15 cm | Dark brown (10 YR 3/3, moist), sandy clay |
| $A_3$ ∿ 15 25 cm | Dark yellow brown (10 YR 4/4, moist), sandy clay |
| $B_1$ ∿ 25 70 cm | Strong brown (10 YR 5/8, moist), sandy clay |
| $B_2$ ∿ 70 $120^{+}$cm | Reddish yellow (10 YR 6/8, moist), sandy clay |

OBS: Plintite Appears afer 110 cm
Date of collection 12/04/81

## POINT J-14

Classification : Dark red latosol
Location : CPAC
Vegetation : Cerrado (natural); Pasture (induced)
Parent Material : Terciary sediments
Altitude : 1,000 meters
Relief : Flat (2 ∿ 3%)
Date de collection: 12/04/81

| | |
|---|---|
| $A_1$ ∿ 0∿ 20 cm | Dark reddish brown (5 YR 3/3, moist), sandy clay |
| $A_3$ ∿ 20∿ 30 cm | Dark reddish brown (5 YR 3/6, moist), sandy clay |
| $B_1$ ∿ 30∿ 70 cm | Red (2.5 YR 4.5/8, moist), sandy clay |
| $B_2$ ∿ 70∿$110^{+}$cm | Red (2.5 YR 4/8, moist), sandy clay |

OBS: Date of collection 12/04/81

POINT J-15

| | | |
|---|---|---|
| Classification | : | Low humic gley |
| Location | : | CPAC |
| Vegetation | : | Humic grassland |
| Parent Material | : | Tertiary sidiments |
| Altitude | : | 1,000 meters |
| Relief | : | Flat (2 ∿ 3%) |

| | |
|---|---|
| $A_1$ ∿ 0∿ 20 cm | Brownish black (2.5 YR 3/1, moist) with common small distinct strong brown (7.5 YR 5/8 moist) mottles, sandy clay loam |
| $A_3$ ∿ 20∿ 30 cm | Yellowish gray (2.5 Y 5/1 moist) with common small distinct strong brown (7.5 YR 5/8 moist) mottles, sandy clay loam. |
| $C_1$ ∿ 30∿ 60 cm | Light gray (2.5 Y 7/2 moist) with few medium distinct yellowish brown (10 YR 5/8 moist) sandy clay loam |
| $C_2$ ∿ 60∿120$^+$cm | White (2.5 Y 8/2 moist) with few medium distinct red (2.5 YR 4/8) mottles, sandy clay loam |

# "Application of Remote Sensing on Cerrado Regional Evaluation"

## - A system consideration -

Yoshizumi Yasuda[1]

1. Expert of JICA - Institute of Color Technology, Chiba University

## 1. Cerrado Evaluation Program and Remote Sensing

### 1.1 Introduction

Remote Sensing technology provides scientific information useful for the intelligent management of natural resources as well as basic information for earth science.

Agricultural development may be summarized as follow:

1st Stage ..... Development of new agricultural fields.

Objective

increasing of crop production by introducing new areas of crop fields.

eg.) · reclamation of land by drainage,
· cultivation of fields from forest or grass land.
· soil improvement.

2nd Stage ..... Arrangement and improvements of basic agricultural conditions.

Objective

(1) increasing productive capability of crop fields

eg.) by using more fertilizer,
by improvement of soil.

(2) increasing productive capability of labour or man-power.

eg.) by mechanization, or by increasing of unit field size.
by establishment of dams and water heads.
by establishment of drainages.
by re-arrangements of agricultural land-use.

Dr. E. Robato showed me interesting statistics which area presented on Table 1. During 4 years, increasing in production was 100% through increasing in area was 30%.

Remote Sensing is useful in the planning and management of the policies for agricultural development.

Table 1 Increasing of area and production .

| | 1975 | 1979 | Increasing |
|---|---|---|---|
| Area | $4.5 \times 10^6$ha | $6 \times 10^6$ha | 30% |
| Production | $5.5 \times 10^6$t | $1.1 \times 10^6$t | 100% |

by Dr. E. Robato

CPAC Cerrado Evaluation program staffs have made soil maps (1/1,000,000) vegetation maps (1/1,000,000) and other maps by using visual interpretation technique.

Development of Digital Computer will improve our information processing capabilities.

Due to increasing necessity on digital information processing CPAC has introduced Earth Resources Management System II (EAR-MAN II) software package developed by NASA, and RAMTER CRT Display System for work with IBM computer at EMBRAPA.

1.2 Objectives of Cerrado Evaluation Program

1) Thematic Mapping

1-1) Scaling up from 1/1,000,000 to 1/100,000 ∿ 1/250,000

1-2) Subjects = Soil mapping
Natural Vegetation Mapping,
Land-use Mapping,
Crop Survey,

2) Crop Forecasting and Monitoring

1.3 Data Processing Facilities at EMBRAPA

Facilities at EMBAPA areas are as follow:

(1) IBM Computer, 380/158 for Analysis and processing
(2) RAMTEK CRT DISPLAY for man-machine interaction
(3) Earth Resources Management System II
(EAR-MAN II) .....

This is the best system in Brasil, being superior to IMAGE-100 at INPE.

EAR-MAN II and RAMTEK Systems with IBM computer allows interactive analysis of remotely sensed data.

The primary analysis software package, EAR-MAN II, are for pattern recognition application which performs multispectral analysis, and the image registration application. Those are fundamental and general purpose.

Fig. 1 shows structure of EAR-MAN II software package.

Functions of Registration and Pattern Recognition are especially useful for Regional Evaluation.

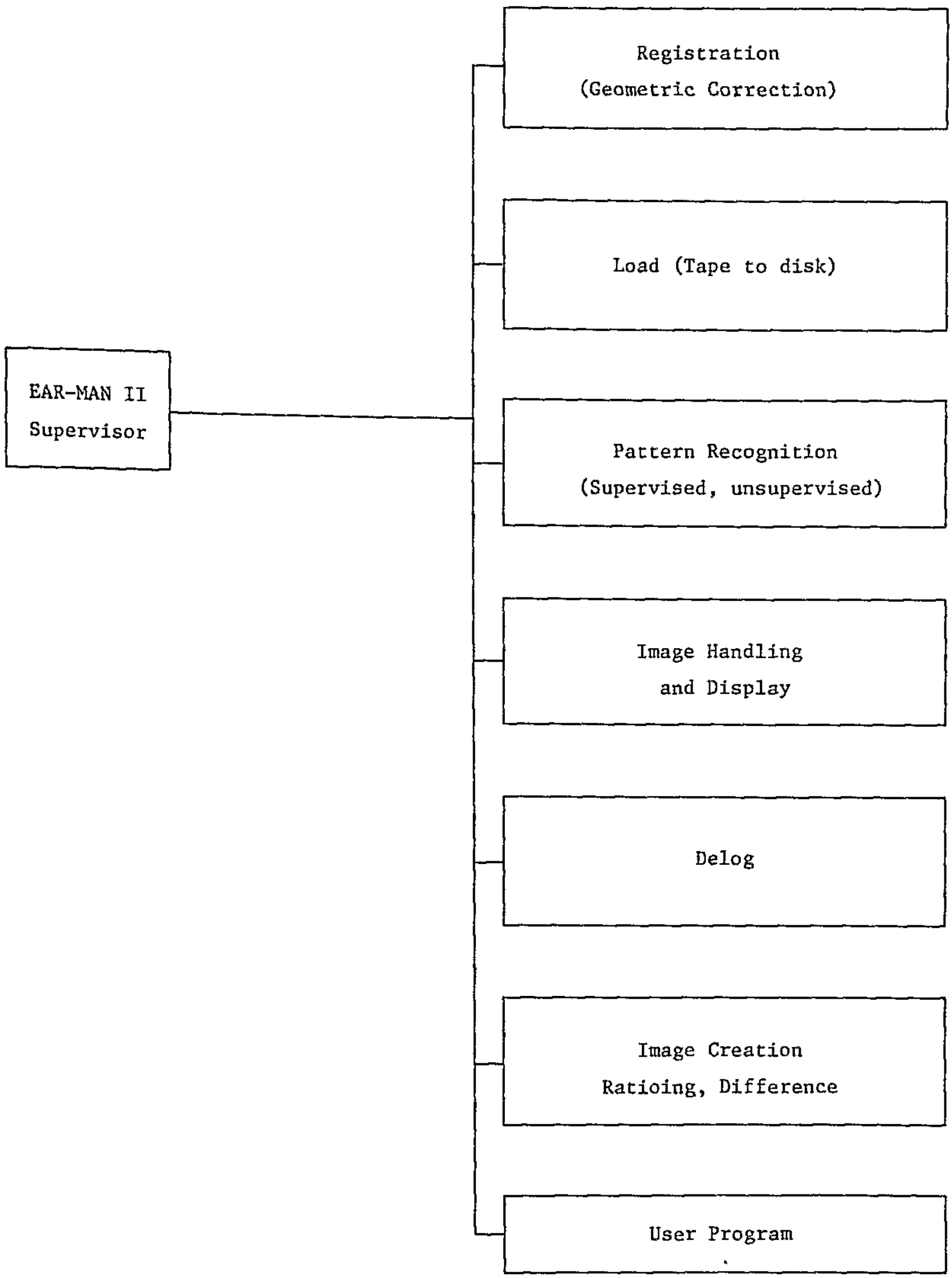



Fig. 1 EAR-MAN II Structure

The performance of the processing system may be presented by the following factors;

1. cost performance: the analysis cost per scene?
2. through put : processed scenes per week?
3. confidence level

### 1.4 Application Problems

Experiences gained by analysis of many scenes has taught us that there is no one optimum appraoch to processing all agricultural scenes.

There exists many ways to structure decision in image processing or interpretation;

eg.) · by spectral information
 · by relating spectral data to soil, yield, geology, climate, etc.

The problem is that remote sensors do not directly sense information of interest to us. Remote sensor is a scanning type spectral ratiometer. In order to solve this problem, we must have Models to relate Remotely Sensed Physical Data to required application information of interest to us.

Key Steps in carrying out a Remote Sensing Application project are as follows;

1. State requirements or objectives ... What needs do we have?
2. Establish feasibility ... Can it be done?
3. Plan the proejct ... What procedures should be done?
4. Implement the project ... Do it!
5. Assess the results (Ground Truth), ... Did it work?

We are now at steps 1 ∿ 3. We must make clear the objectives, of the Cerrado Evaluation Program, the feasibilities, the procedure or methodology, required input data and required facilities in order to get successful and useful results.

## 2. Analysis Procedures and Programs

### 2.1 Natural Vegetation Mapping and Land-use Mapping

Procedure for Natural Vegetation Mapping and Land-use Mapping are shown in Fig. 2.

In the consideration procedure, some problems for facilities are pointed out as follow;

1) Measuring the ordinates of ground control points (GCP) for geometric correction and scaling.

   - need of a digitizer.

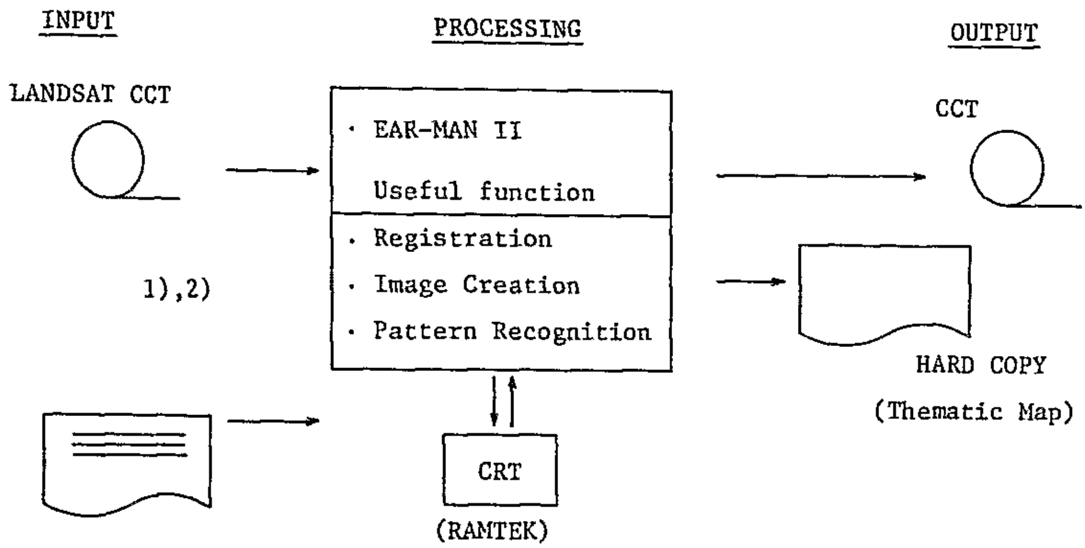
2) How to get scaled hard copy - need of a photoprinter.

RAMTEK system is for display the Landsat the Landsat image on CRT, check the data quality, select the training field, and check the processing results, that is man - machine interactive analysis.

The image size of RAMTEK system is 512 x 512 pixels.

Land sat scene have approximately 3000 x 3500 pixels.

By using the RAMTEK system, we can not get hard copy of processing results. The problem should be solved.




1) Ground reference data for supervise the pattern classifies, ordinates, vegetation type, land-use type,

2) Ground Control Point for geometric correction.

Fig. 2 Procedure for Land-use mapping

## 2.2 Crop survey through Remote Sensing

Effective production and management of the food supply depend on our knowlege of the current and potential supplies and their location.

Remote Sensing has been successfully used for making various kinds of crop survey in both research and operational projects.

Information about crops that is available through Remote Sensing are as follows:

1) crop identification,
2) gro nd area of a crop,
3) presence of crop stress
   (including extent and severity)
4) estimation of crop damage.

Crop production is estimating by using following foundamental equation.

Production = Area of a crop x Yield per unit area.

The area of the crop can be estimated, by using remote sensing technology. The yield per unit area is estimated mainlly by climate, historical statistics, soil types and meteorological sattelite data as NOAA and NIMBUS. NOAA and NIMBUS data are distributed from INPE.

The data format are photographic or high density CCT as 6250 bpi. Therefore, for analysis, a facility for inputing the photographies into the digital computer is needed. High density Magnetic Tape Unit as 6250 bpi is also needed.

In crop identification, Landsat data acquisition timing is important. In the case, multispectral data at key crop development stages are needed. Table 2 shows a statistics of obtained Landsat data by INPE in past 8 years and crop calendar. The obtained data are concentrated on dry season.

Crop-Uncrop is easily identified by using Landsat data acquired on dry season. But there are less data on wet season that is important growing season of the crops in the Cerrado region.

An alternative method of crop identification independent of the data acquisition must be developed.

## 2.3 Soil Mapping

In order to obtain soil map, vegetation free Landsat data are needed. Mix or interaction of reflectance of the vegetation with the soil information decrease the performance of the soil identification.

Cerrado Region is covered by high vegetation. We cannot use vegetation free Landsat data for analysis except the bare soil of crop area in dry season or just before or after seeding. A solution for the problem is challangeable.

CPAC staffs have already an experience to obtain the soil map from Landsat photographic image using visual interpretation. These procedure can be computerized.

The Procedure is complicated as follows:

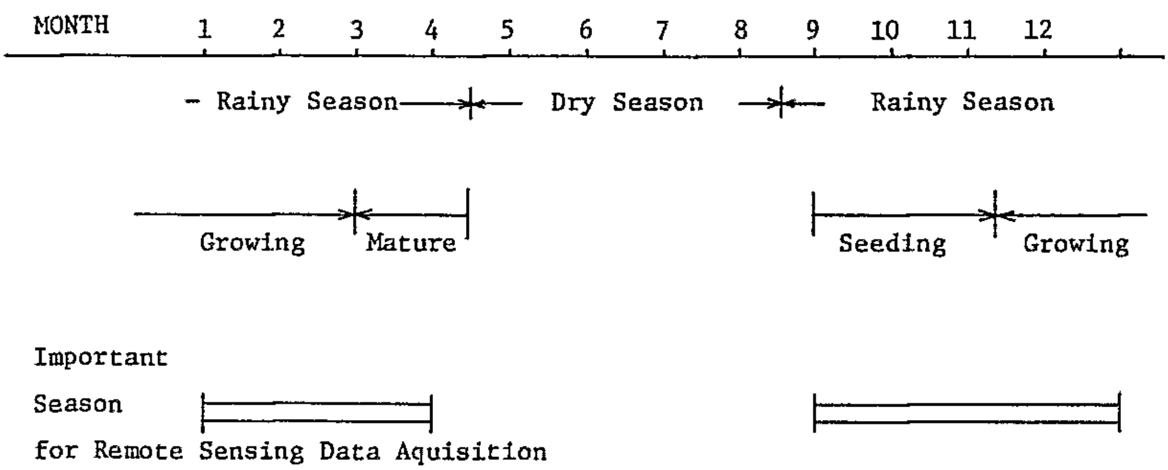
Table 2 Number of acquired Landsat Data by INPE and crop calender of Cerrado Region

Brasília, path: 192, Row: 23 (cloud cover .... below 30%)

(by M. Fukuhara)

| Month / Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | | | | | | 0 | $0_2$ | 0 | 0 | | | |
| 74 | | | | | | 0 | | | | | | |
| 75 | | | | | 0 | 0 | 0 | $0_2$ | $0_2$ | 0 | | |
| 76 | 0 | | | | | | 0 | 0 | | 0 | | |
| 77 | | | 0 | | | 0 | 0 | 0 | | 0 | | |
| 78 | | | | | | 0 | 0 | 0 | | | | |
| 79 | | | | | 0 | $0_2$ | 0 | | | | | |
| 80 | | | | 0 | | | 0 | | | | | |
| Total | 1 | 0 | 1 | 1 | 2 | 7 | 7 | 7 | 3 | 3 | 0 | 0 |

CROP CALENDAR (Typical)



1) Croping Field

Use vegetation Free Landsat data acquired at Dry Season. We can apply Soil Index analysis technique developed by Fukuhara, Yasuda and Iísaka.

2) Un-croping Field as Carrado ... high vegetation cover.

Developing moresophisticated soil mapping system, based upon the experience of visual interpretation.

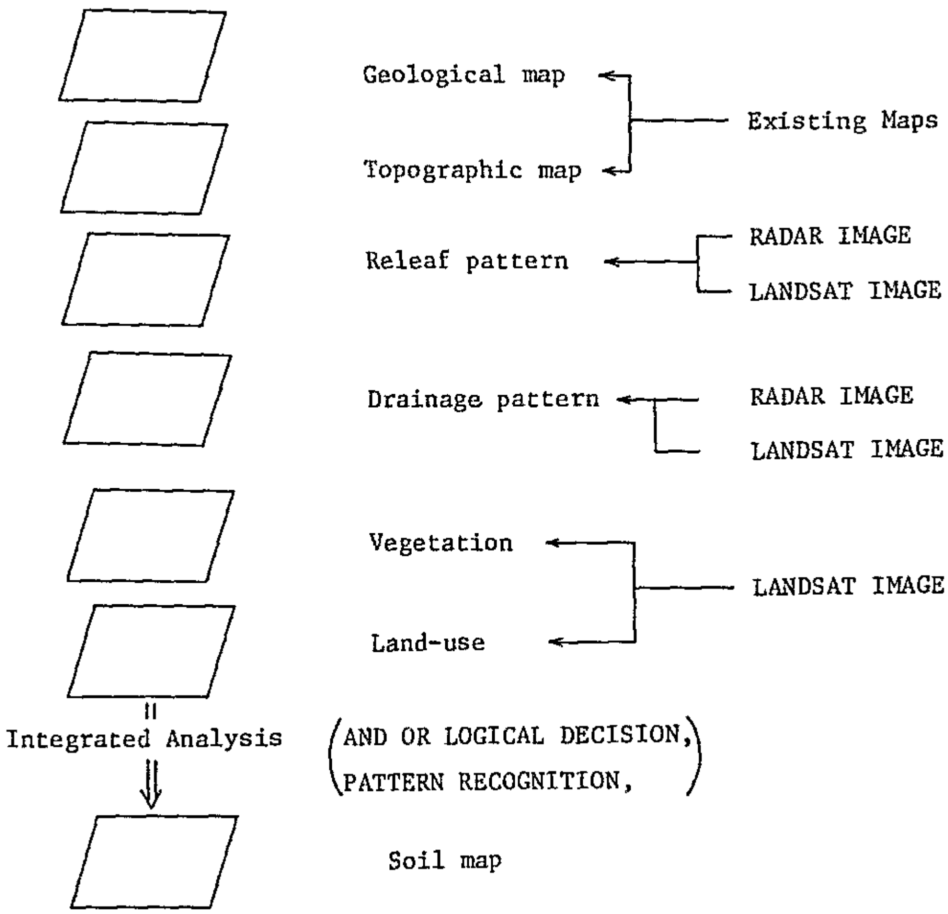



Fig. 3 Integrated Analysis system for soil mapping

For realizing the integrated soil mapping system, we must input many kinds of informations such as maps, photographics, and ordinates of the maps.

For the purpose, we must have a data input system or data handling system that involve a digitizer for inputing the ordinates, and an image scanner as drum scanner for inputing the photographs.

### 2.4 Utility function for Mapping

Additional functions as follows are important for mapping. For scaling up of thermatic mapper from 1/250,000 to 50,000, we must use data acquired by Landsat-D Thematic Mapper, which will be lounched on September 1982.

The data by Thematic Mapper have higher resolution than Landsat MSS and distribute on 6250 bpi high density format CCT through INPE as Meteorological Sattelite data.

### 2.5 Summary of input and output data

Figs. 6 and 7 shows the summary of input and output data. We must handle many types of data for Cerrado Regional Evaluation, but there is no consideration and discussion on the problem.

## 3. Future information processing requirement for Remote Sensing of CPAC

From previous discussion, you must introduce some facilities as the Natural Resources Data Handling System, shown in Fig. 8, and develop some application programms in order to improve the usefulness and efficiency of the computer system with EAR-MAN-II and Ramtek system in EMBRAPA.

The following items were discussed with the CPAC Cerrado Evaluation Program staffs.

Recommendation

1) Harware: Natural Resources Data Handling System/CPAC.

Objective
- Input the Remotely sensed data and the Reference data into computer.
- Out put the processing results in necessary formates.

The system introduced in EMBRAPA Computer Center is for processing. Analize and Estimation, and the recommended system is for data handling and data management.

2) Development of Software

1st Stage

- Soil mapping system.
- Radiometric Correction of LANDSAT MSS DATA.
- Multi variate Analysis/Regression Analysis.
- Graphic processing, etc.

2nd Stage

Cerrado Resource Evaluation and Development system

- Agricultural Development Planning System.
- Forest resource management system/Reservation system.
- Natural Resource Management system.
- Regional Planning, etc.

3) Training

A Training Plan for Cerrado Evaluation Program staffs for computer programming and system analysis are recommended.

- Understanding the processing functions involved in EAR-MAN II and the effective use of the functions to problem solving.
- Training programmers in Computer Center of EMBRAPA to get high level of understanding the resource problem in CPAC and to develop the necessary programms.
- Training the researchers in CPAC how to use the computer for their problem solving and necessary program development.

(1) Scaling Up the map

1/250,000 ⟹ 1/50,000 --- Landsat-D; Thematic Mapper (T.M.)

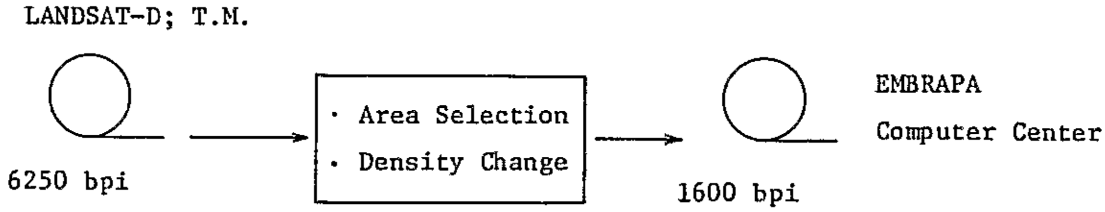



Fig. 4 Use of Landsat-D, T.M.

(2) Composite Mapping

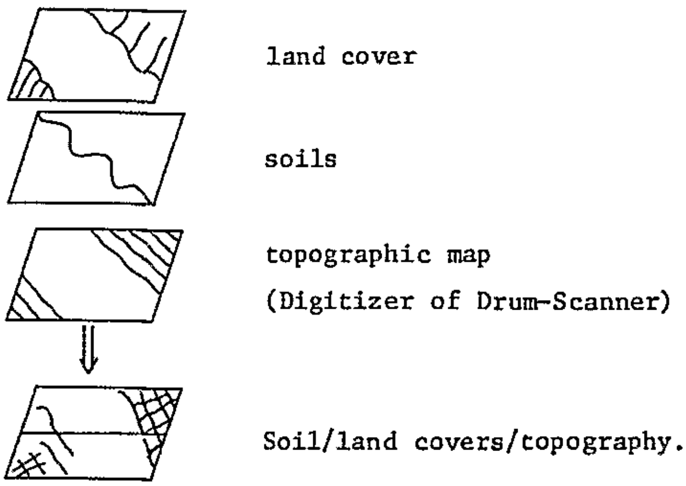



Fig. 5 Composite Mapping

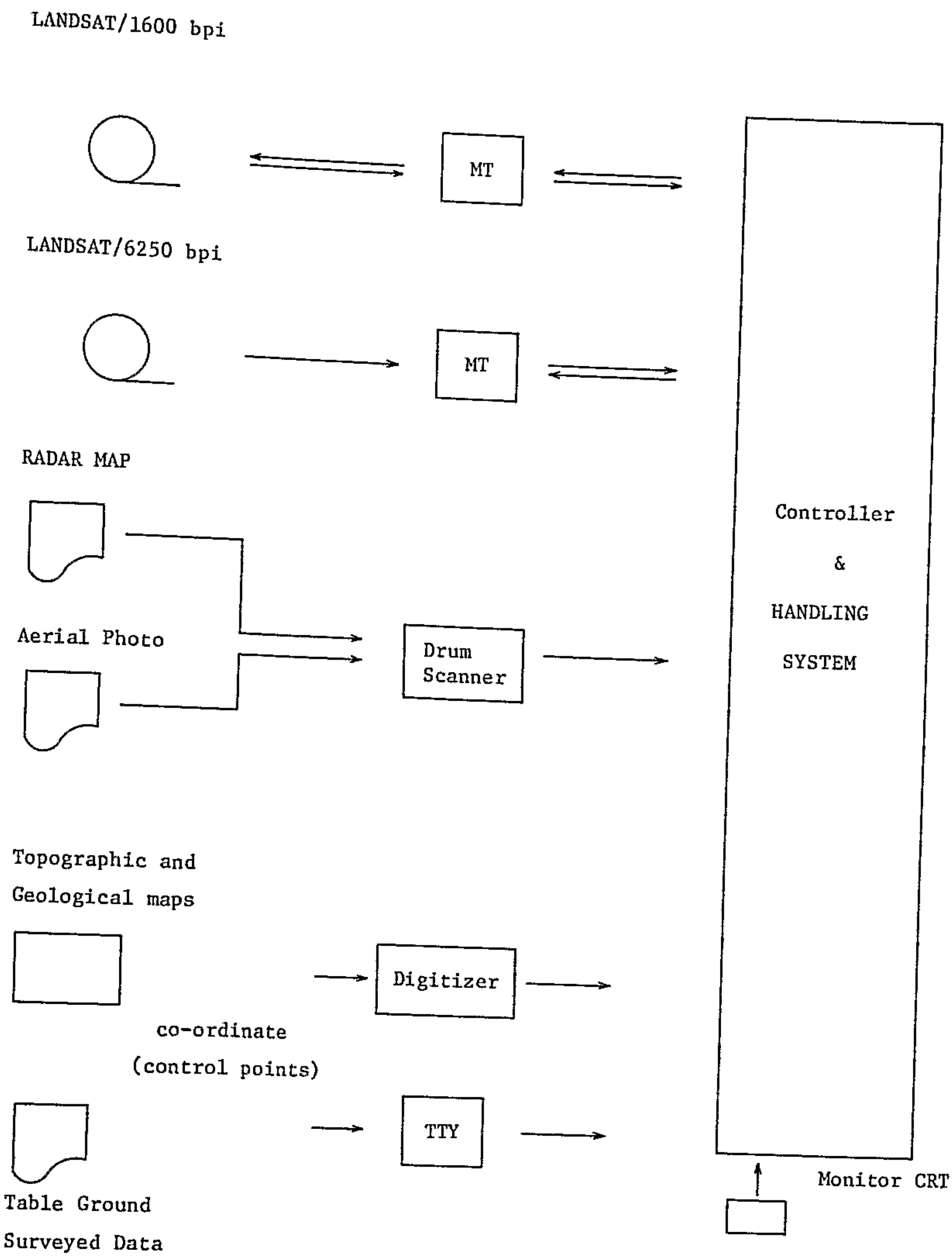



Fig. 6 Summary of Input Data

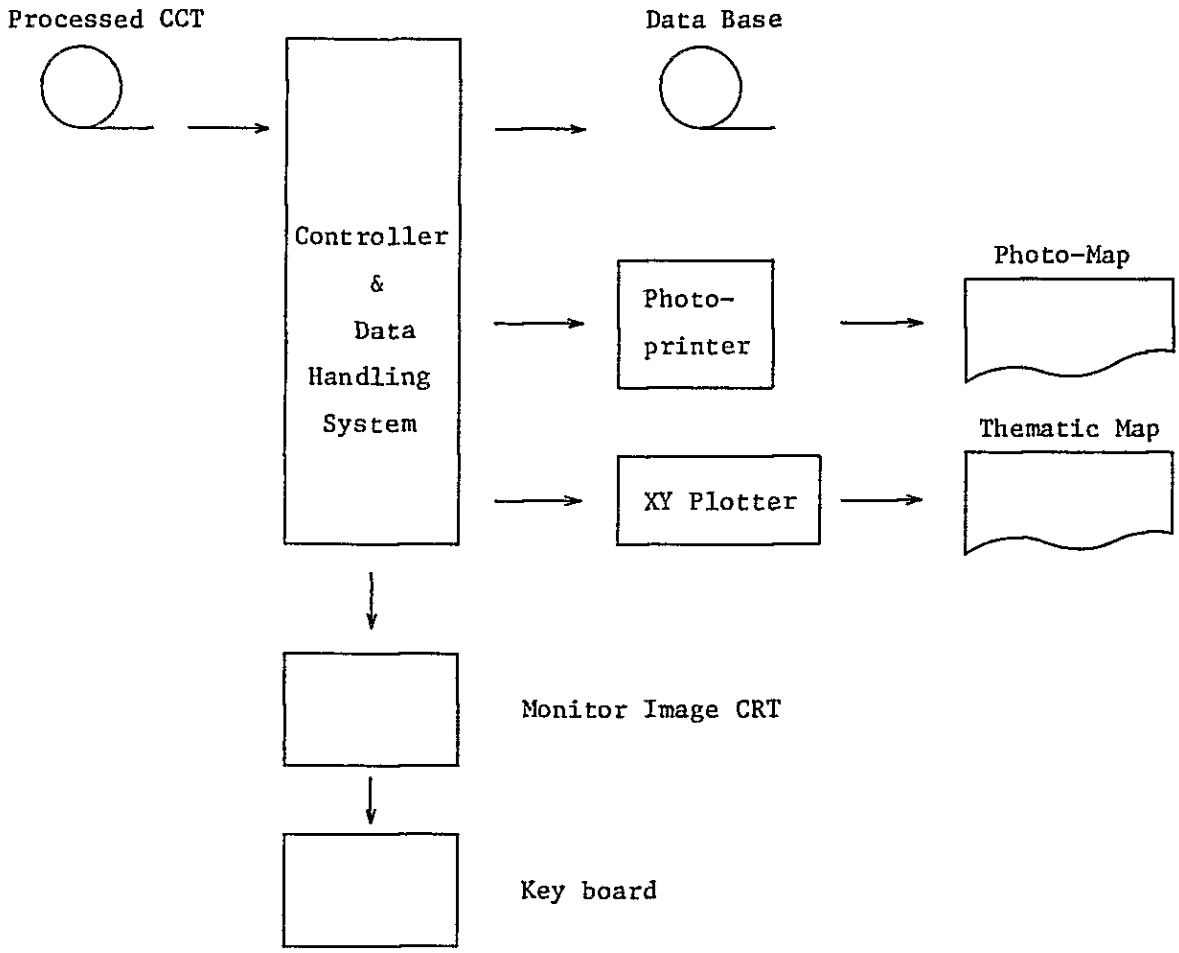



Fig. 7 Summary of Output Data

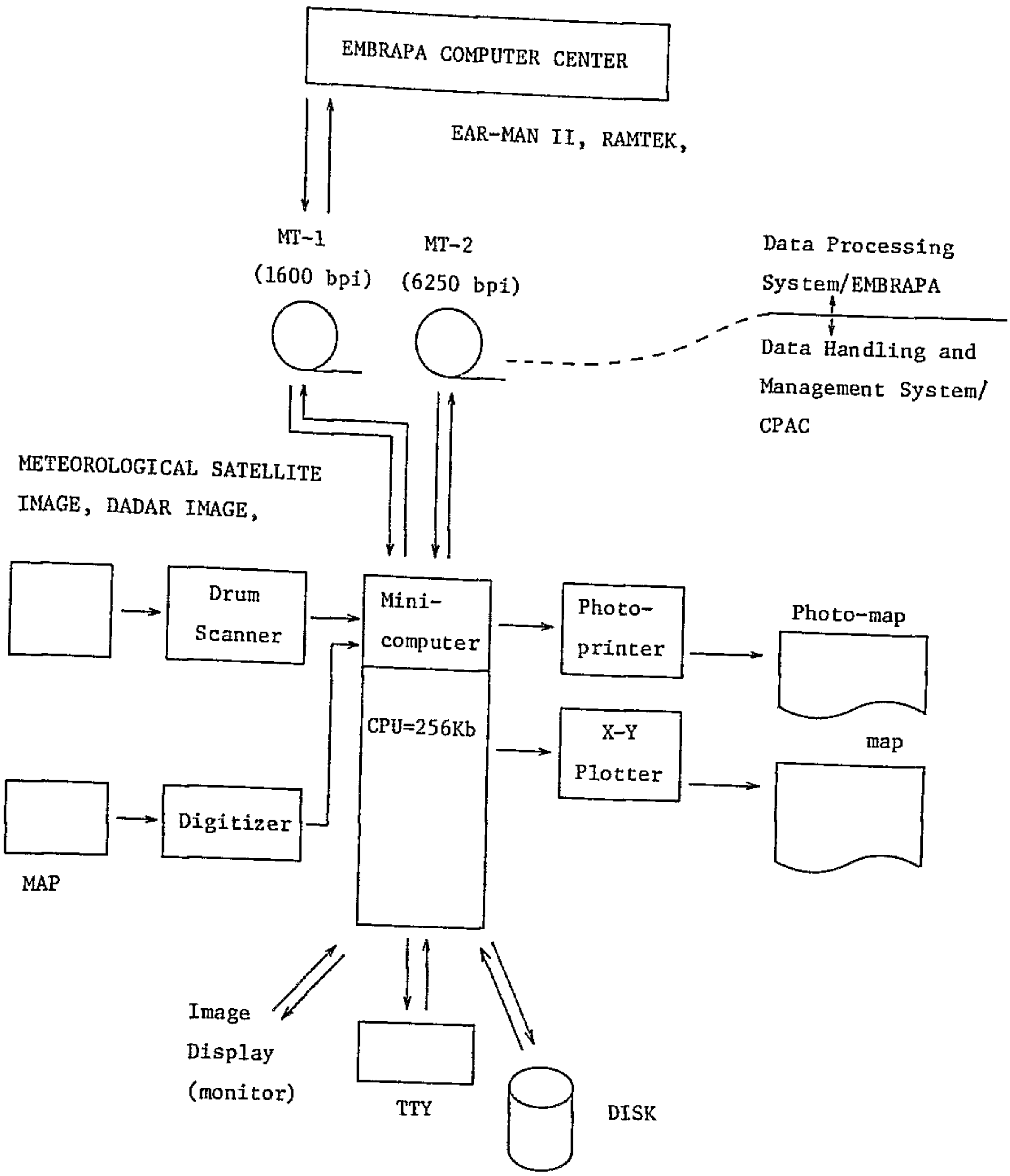



Fig. 8 Bloch diagram of Natural Resource Data Handling and Management System/CPAC

Acknowledgment

The author would like to express his sincere gratitude to Dr. Elmar Wagner, Director General of CPAC, Dr. Edson Lobato, Director of the Research Department and Dr. Tamotsu Ogata, the leader of JICA team dispatched to CPAC from Japan, for their kind arrangement in his consultanting activity.

Many thanks are also due to CPAC Cerrados Evaluation Program staffs, especially Mr. José da Silva Madeira Netto, Coordinator of the Program and Mr. Michikazu Fukuhara, a member of the JICA team, for their sincere helps to his work.

## Chapter 2 CONCEPT OF MULTISTAGE SCREENING PROCESS AND ITS APPLICATION

### 2.1 General

Remote sensing is a new information source, and it has an excellent capability of aquiring data over large area. By applying the low altitude survey, it is possible to examine definitely a particular local area.

On the other hand, recent development of the computer has not only enhanced the capability of handling data, but also given us a powerful information system.

Accordingly, by integrating remote sensing data, such as landuse, vegetation, drainage, etc., with already aquired data such as geology, topography, climate and soil, fine analysis and accurate assessment for agricultural development could be accomplished.

How to combine remote sensing technology with computer information system and how to apply this combined new technology for agricultural development are to be important subject of this project. In this chapter, fundamental and basic concept of the integrated technology necessary for agricultural development is firstly presented and secondly practical process for selecting the suitable agricultural land by the screening method is proposed.

### 2.2 Information system for agricultural development

Agricultural development program is designed and performed by assessing natural land conditions and agro-economical conditions.

However, this agricultural development project in North Smatra is limited only to assessment of natural land conditions.

As fundamental items necessary for assessment of natural land conditions, topography, geology, drainage, landuse, hydrography, vegetation, climate condition...etc., are designated. Data aquisition necessary for these items and their assessments are carried out by the following three steps.

Step 1: Establishment of data base for existing data.

Existing data concerning natural disasters, climate temperature, rainfall, sunshine, topography etc., are collected as computer based information system.

In order to realize the screening process for selecting agricultural suitable land, it is necessary to covert map level data to files of grid cell data, as described later.

Step 2: Establishment of data base for remote sensing data

Up-to-date are detail data concerning landuse, natural vegetation, drainage and etc. and aquired by remote sensing technique and filed in computer based information system in term of grid cell data file as same as in Step 1.

Step 3: Establishment of assessment system

By integrating the data obtained in Step 1 and Step 2, analysis and assessment of natural land condition and agro-economical condition which are necessary for agricultural development are carried out.

## 2.3 Assessment system for agricultural development

Three inventory items of resource base, production base and management base are necessary for assessment of natural land condition and agro-economical condition as shown in Fig. 2.1. Resource base items are topography, geology, soil climate, natural vegetation, etc. Production base items are landuse, yield etc. Management base items are production technology, production cost, development cost, distance to market and transportation.

Data files of the information system necessary for assessing natural land condition consist of inventory items of resourse base and production base. In addition, data files for assessment system for agro-economical condition consist of items of production base and management base.

From data files of the information system, production potential, suitability index are computed. From remote sensing data, vegetation index or biomass index are obtained. By using these assessment data, it is possible to classify the unutilized land into production potential area, units of agricultural development plan and agricultural land use district.

Items required for agricultural landuse classification, that is, slope, soil texture, depth of soil and gravel content are definitely described in chapter 4.

In the case when detail information about soil condition, climate condition, fertile condition and etc., cannot be aquired, it is necessary to introduced new biological factors which enable to evaluate the suitability of agricultural land.

In the developing country as Indonesia, it is impossible to obtain all of required data, because of lack of data.

Accordingly, an assessment system which effectively makes use of remote

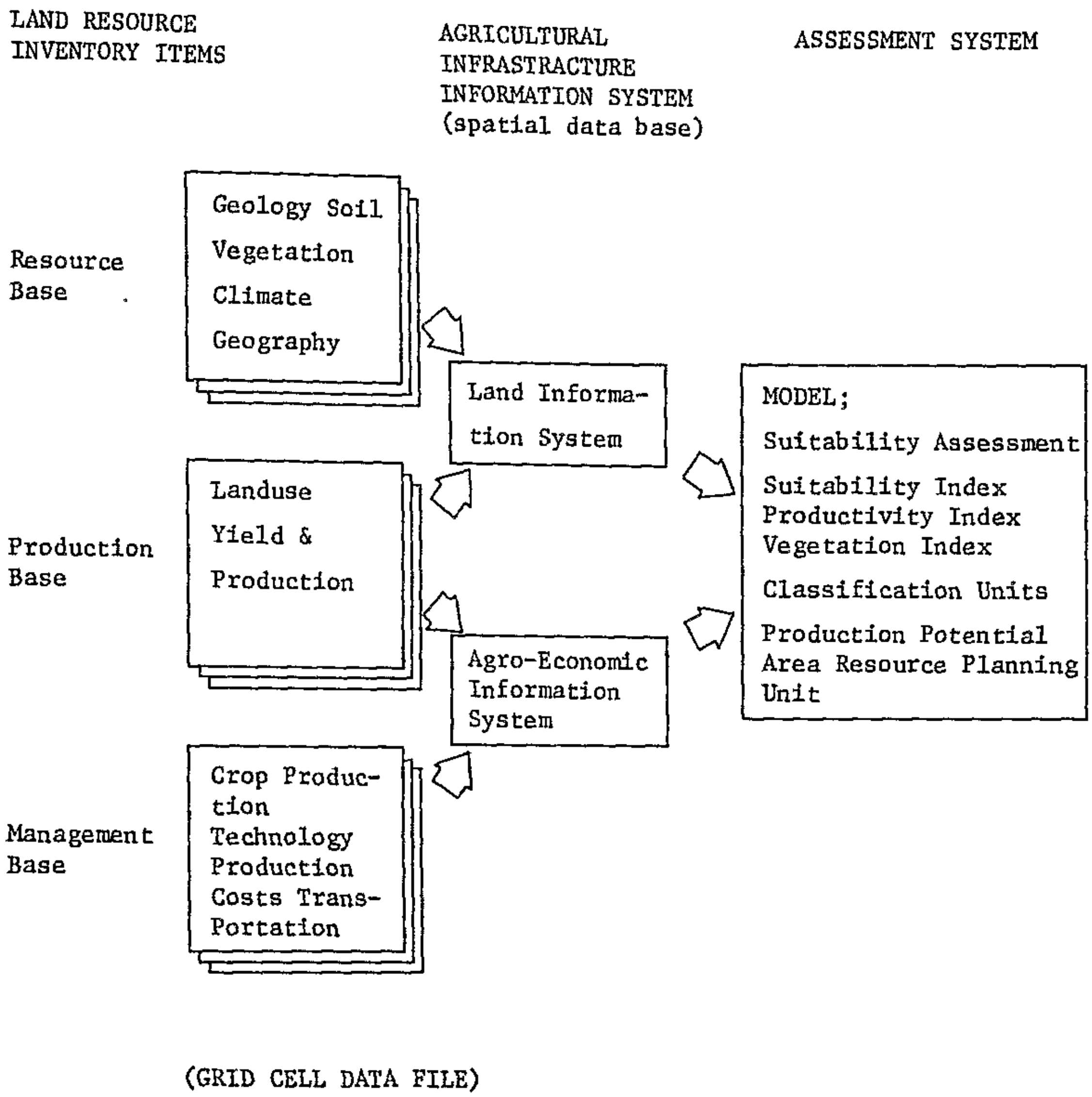



Fig. 2.1 Agricultural Infrastructure Evaluation System and The Major Factors

sensing data, must be developed. This is one of the important reasons to apply the remote sensing technique for assessment of agricultural development plan in the developing country.

### 2.4 Multistage screening process for site selection for agricultural development

#### 2.4.1 Multistage screening process

As described before, it is very important to develop a new evaluating system by combining Landsat data and other spatial information. In the developing countries, it is difficult to say all part of the land are thoughly investigated. So it is desired to apply the mutistage screening process. Large area of country wide level is firstly examined whether any part of these area can be developed or not, secondly smaller area of regional level is more definitely examined and evaluated, and finally final candidate sites are selected after evaluating their agro-economical and natural site properties. Fig. 2.2 shows a flow diagram of multistage screening process. Necessary spatial information factors and thematic maps are also indicated. It is noticeable that evaluating factors in each stage are different each other. For example in 1st and 2nd stages of sattelite level, agro-economical factors are not so important for assessment, but in 3rd and 4th stages, these factors become important.

#### 2.4.2 Data characteristics for multistage evaluation

Fig. 2.3 shows map scales which are considered to be necessary for evaluation in each stage as an example of North Smatra. In the country wide level, scale of 1:1,000,000 becomes a measure of evaluation and data are aquired from Landsat data, NOAA data and others. In 2nd stage of regional level, scale of 1:250,000 and the study area of 100 km x 100 km are reasonable and data are also obtained from Landsat and NOAA.

For the local are, scale of 1:50,000 and the study area of 20 km x 20 km are appropriate, and data are acquired with aircraft and/or the enlargement of Landsat data. For final condidate sites, the most suitable area is 4 km x 4 km and scale is about 1:5,000. Data are obtained by aerial survey and ground investigation.

#### 2.4.3 Grid cell data file and evaluation

Thematic maps classified by specified evaluating factors are encoded digitally and filed by grid cells as shown in Fig. 2.4. If necessary, these grid cell data are weighted with factors depending on contribution of each evaluating factor to the final objective.

In applying the grid cell system, the relationship between resolution size and size of each grid cell has to be noticed.

A smaller grid cell size as 10 m would minimize the geographical error but increase data volume. It is expected that size of grid cell is determined corresponding to scales of topographic features. Size of 500 m cell is appropriate for regional assessment. In Fig. 2.3 required resolution in the term of size of grid cell are indicated in each stage. Grid cell data file is enough to cover only the necessary area in line with primary objectives. For regional assessment, grid cell data file of mountain area are not necessary but limited to the objective study area.

### 2.4.4 Classification and total assessment of site selection system for agricultural development

It is necessary to totally evaluate all of evaluating factors such as soil condition, topography, landcover...etc., as well as other spatial information for selection of agricultural suitable land.

As shown in Fig. 2.5, total evaluation can be visually attained by overlaying thematic maps which are deduced from evaluating each factor.

Numerical evaluation is accomplished by summing evaluated values of corresponding grid cell in each grid cell data files.

In some case, weighted summation of evaluated values depending on importance of each evaluating factor to the final objective is used for total evaluation. Though there are many mathematical models to fulfill the total evaluation as shown in Table 2.1, the ranking method described in the chapter 4 is recommended.

Table 2.1 Mathematic for Total Evaluation

| | |
|---|---|
| · Statical pattern classification | |
| · Multi-variate analysis | |
| · AND/OR/NOT Logic | |
| · Weighting | · Filtering |
| · Screening | |
| · Thresholding | |
| · · · · · etc. | |

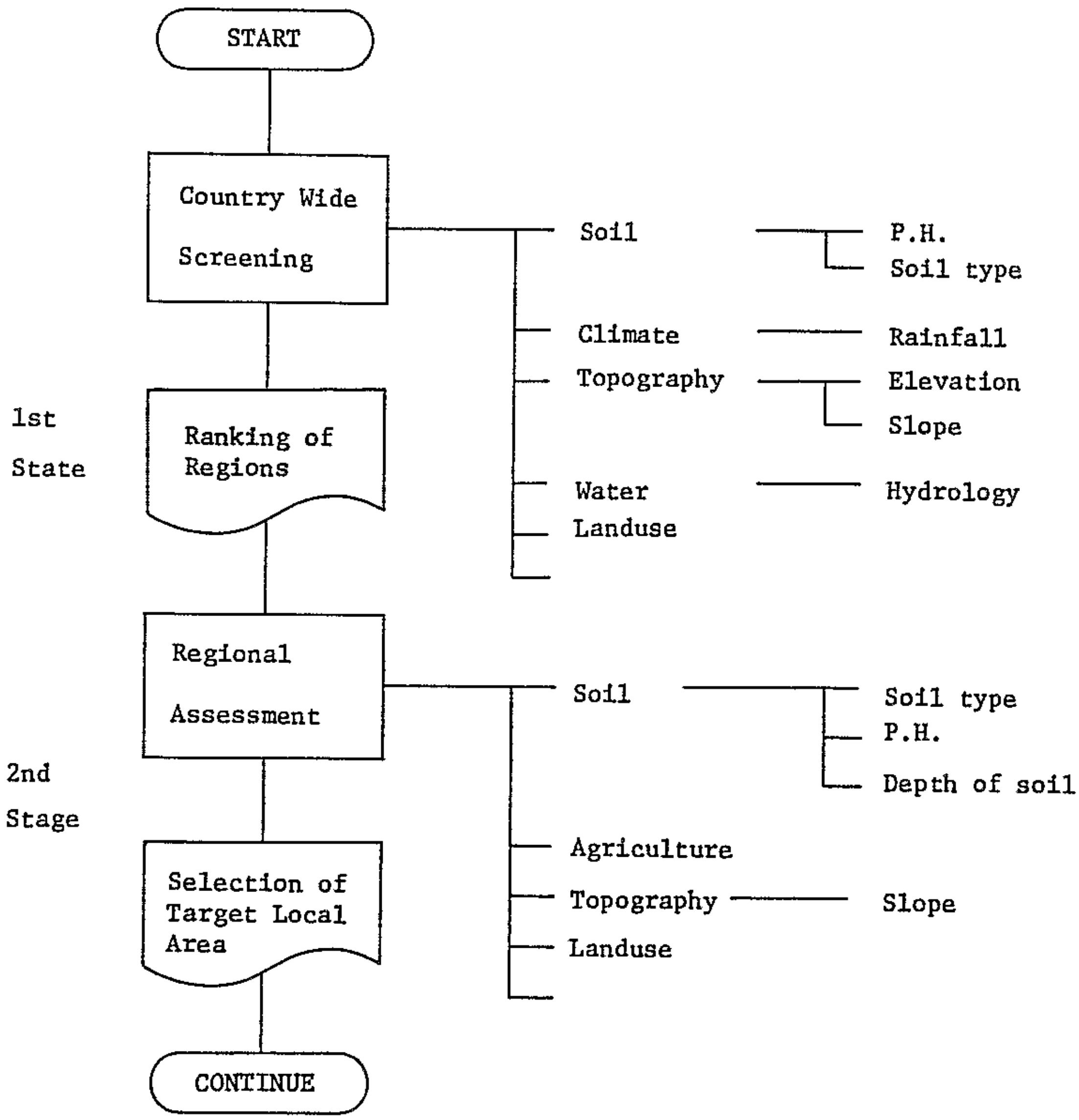



Fig. 2.2 Flow of Screening Process (1)

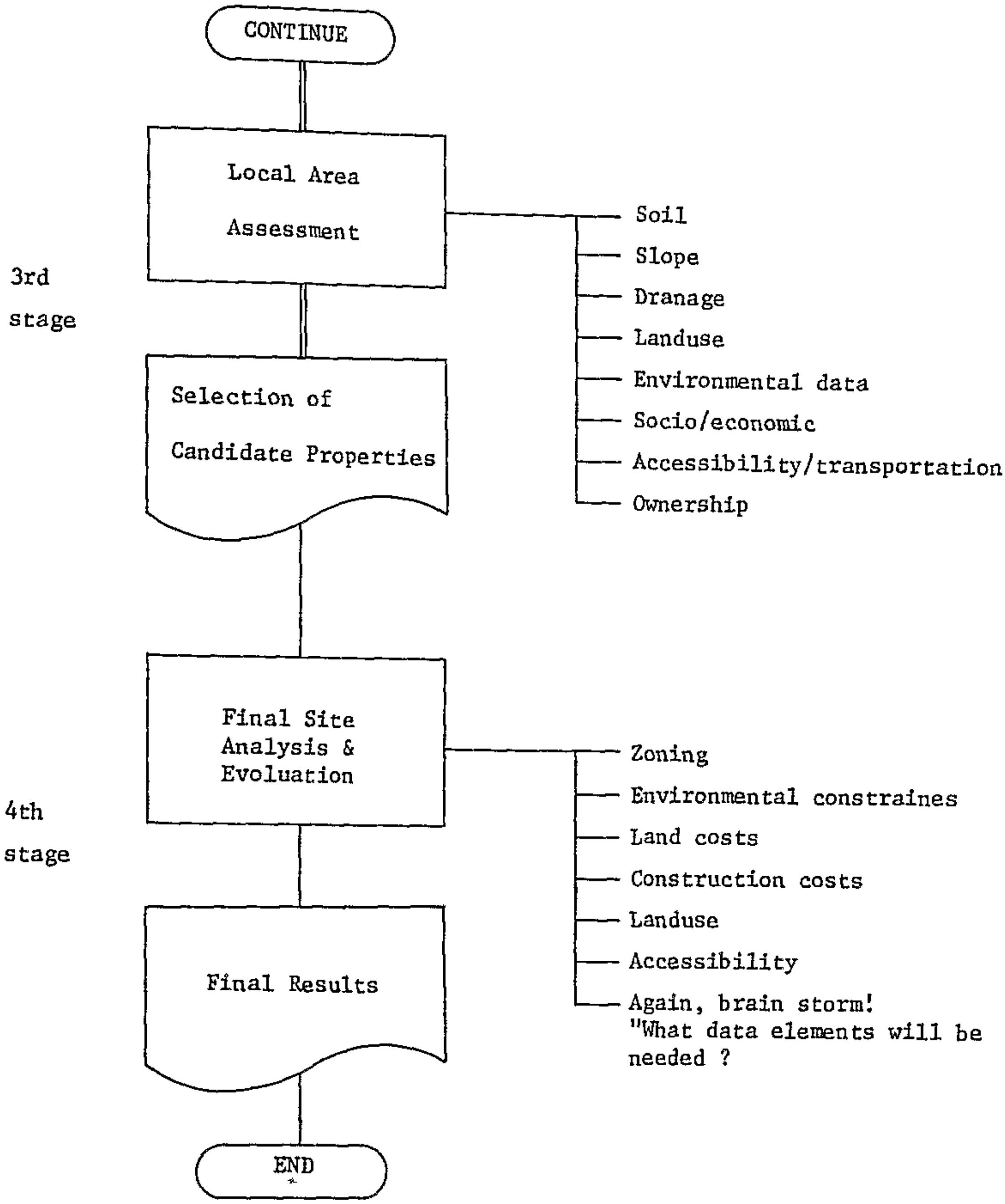



Fig. 2.2 Flow of Screening Process (2)

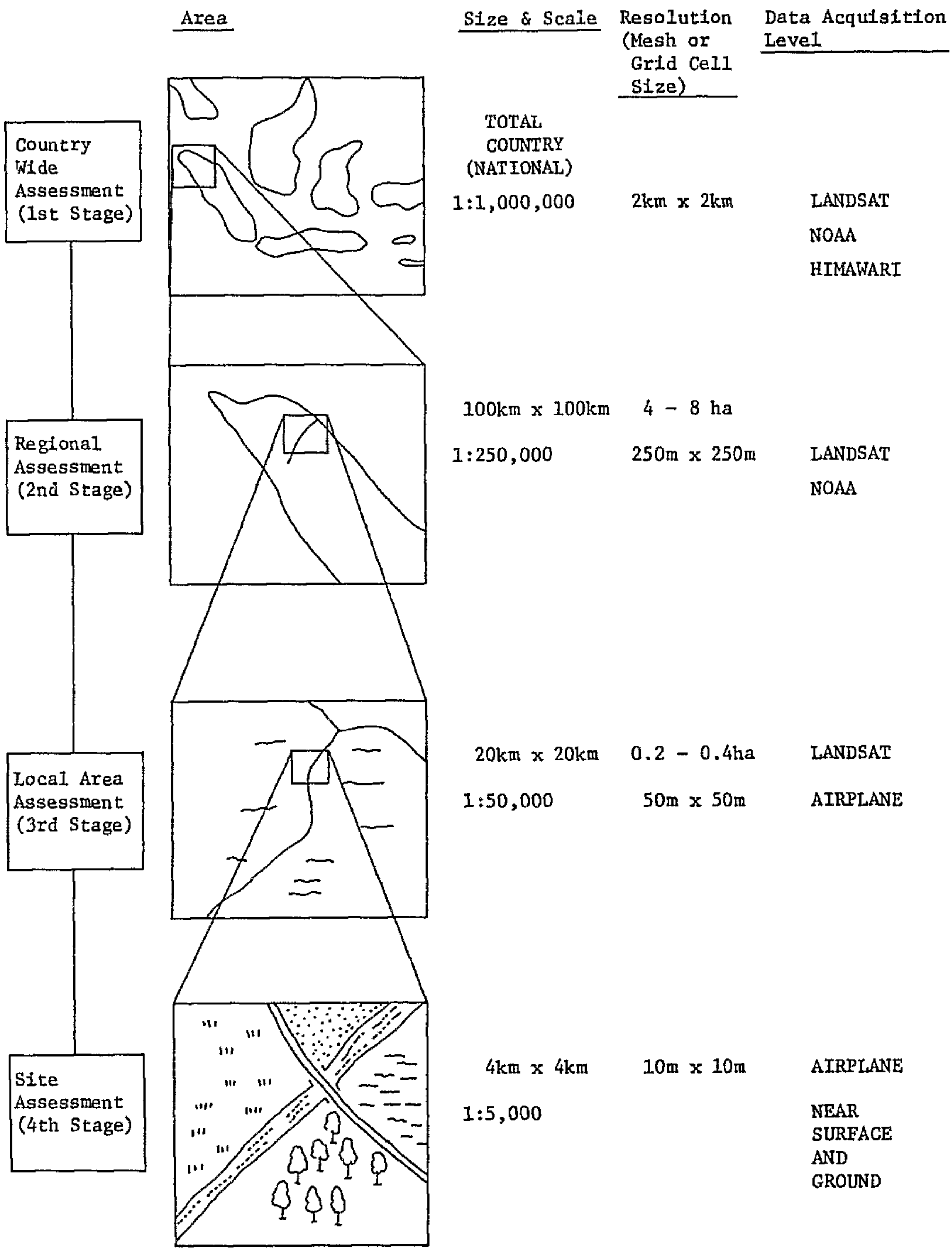



Fig. 2.3 Data Characteristic for Multi-Stage Evaluation

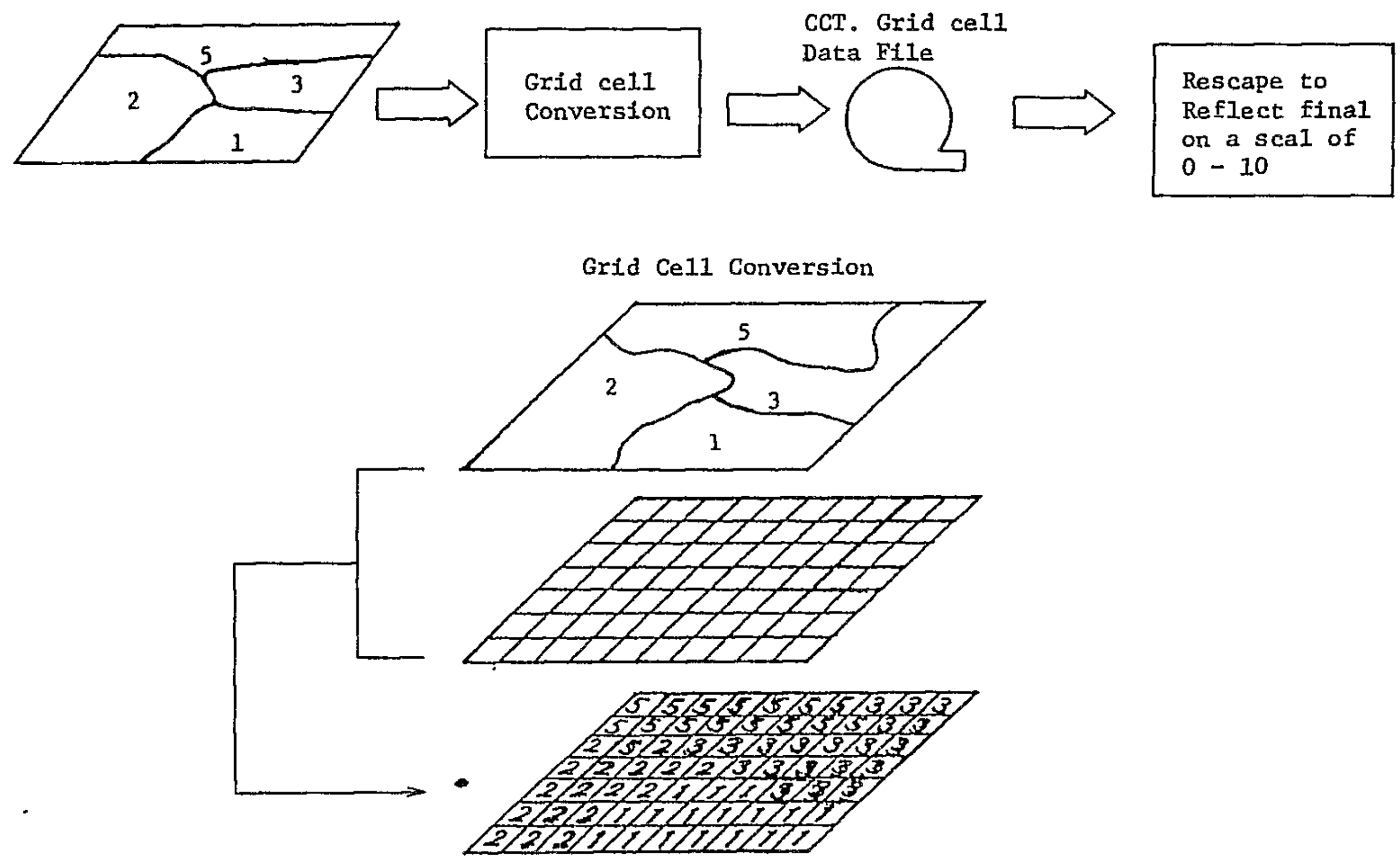



Fig. 2.4 Conversion of X.Y. Coordinate Data into Grid Cell Data File

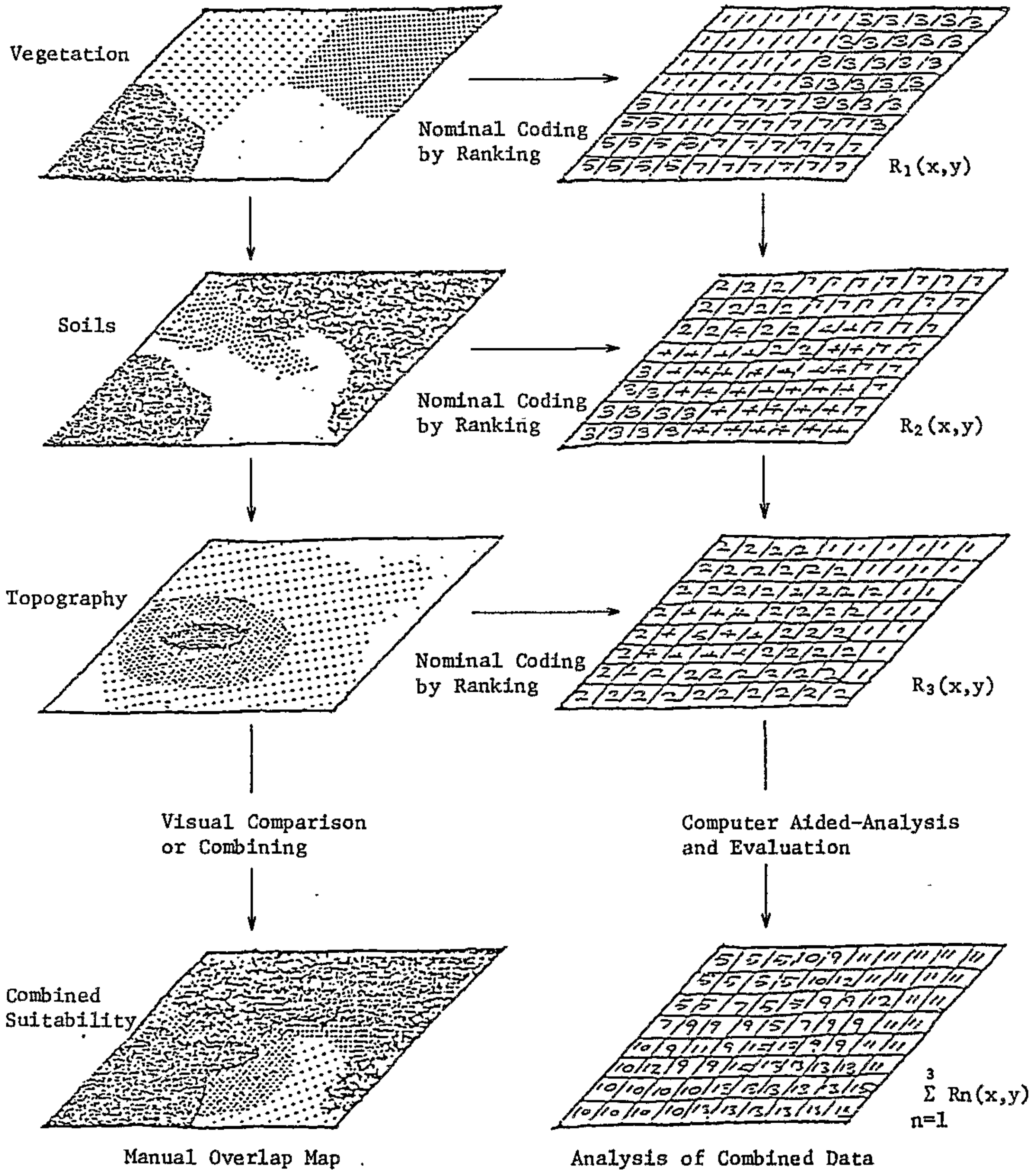



Fig. 2.5 A Simple Example of Integrated Analysis of Spatial Data (comcept)

# リモート・センシングの情報を"加工"する

千 葉 大 学 助 教 授
安 田 嘉 純

リモートセンシングの

# 情報を加工する

## ◆検出器と衛星の進歩で実用化

人間の情報収集の基本は観察である。目で見ることから始まり，触ったり，においをかいだりする。さらに物差しやはかりを用いて，大きさや重さを計る。目による観察は光の伝達による最近のセンサー（検出器）技術の進歩で，可視光だけでなく，紫外線や赤外線，マイクロ波などの電磁波，さらに重力や磁力の利用も考えられるようになった。身近な例としては，Ｘ線や超音波を用いた体内の観察，病気診断があげられる。

情報収集技術には，もう１つの進歩がみられる。それは気球に始まり，航空機，人工衛星に至る空からの視点の利用である。現在，地球を定期的に観測している人工衛星として「ランドサット」や「ノア」がある。これらのデータは日本でも受信，利用されるようになっている。また1986年には，海洋観測を目的とした国産衛星「ＭＯＳ－１号」の打ち上げが計画されている。

その技術の進歩の中で特筆すべきなのが，合成開口レーダーシステムである。レーダーシステムでは分解能をよくしようとすれば，たとえば，センサーの開口（アンテナの長さ）を大きくしなければならない。高度250㌔を飛ぶスペースシャトルから波長20㌢のマイクロ波を用いるセンサーでデータを得ようとすると，地上にある25㍍のものを識別するのに，約２㌔の開口が必要となるが，これは現実的ではない。

合成開口レーダーシステムは，実際には約８㍍の小さなアンテナを使って，２㌔のアンテナと同等の働きをさせる方法だといえる。つまり衛星が一定時間，移動する間に刻々と受け取る情報を，コンピューターによってすべて合成する。さらにいくつかの信号が合成されることによって干渉し合うが，この干渉波に重要な情報が盛り込まれていることもある。

マイクロ波は雲をよく透過するので，雲に覆われていることの多い熱帯雨林や日本の梅雨時の調査に対して威力を発揮する。またレーダー画像は地形構造の変化を，他のセンサーよりも強調するので，地形，地質の調査に適している。

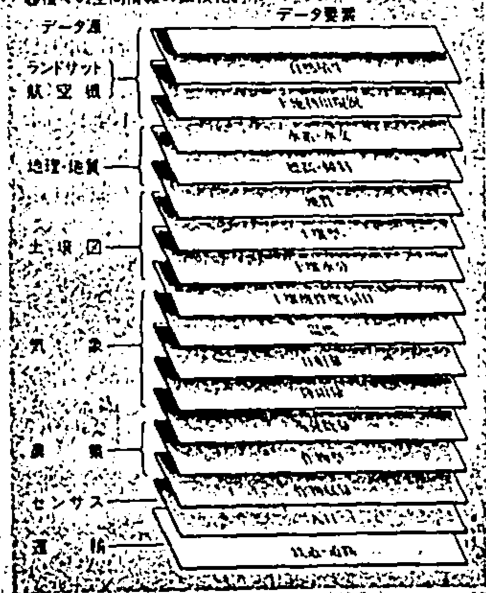
第３の進歩としてコンピューターを利用する情報システムがある。その一例が衛星を利用する情報システムであり，衛星で調べた土地利用や植生についての最新の情報を，従来の地理的情報，気象情報，農業情報などとともに集積化することにより，地球資源の開発・管理や環境の監視などを，より科学的に行うものである。

## ◆重要な生物現象からの情報

リモートセンシングによる空間情報システムの例として，農業開発への応用をあげよう。後述するように，種々の空間情報（❶）を集積することが重要であることを示す，よい例だからである。従来，農業開発に必要な自然土地条件，農業立地条件，環境条件などの評価は土地の傾斜，温度，日射量などの物理量，および土壌の酸性度，栄養塩類の量などの化学量をもとに行われてきた。しかし，環境は理化学的方法のみで測定できるものではない。とりわけ，生物生産に基盤をおく農業開発の適地を選定する場合には，生物反応を通じて環境を診断する必要がある。

生物現象には過去から現在に至るまでの積算効果がこめられており，それは空間的な広がりをも持っている。ある地域の植生の分布は生物現象の結果の１つの現れである。また植生の面的なパターンには気候，土壌，地形などの自然環境要因に

❶種々の空間情報の集積化。



加えて，生物間の相互作用も含めたさまざまな要因の総和が示される。

植生の分布はリモートセンシングによって測定しやすい対象の１つであるから，植物に反映されている環境要因を知ることにより，立地診断のできる評価システムの確立が可能である。その場合，従来の理化学的な測定のようにppmオーダーの精度を期待する評価方法は誤りであり，植生分布パターンを評価することに重点がある。

私は国際協力事業団による技術協力計画に関連して，ブラジルやインドネシアの農業開発研究者との研究協力の機会を与えられた。これら２国はともに広大な未開発地域を持つが，それら地域の資源や環境に関する物理的，化学的データは乏しい。また農業開発適地の選定に際して最も重要な土壌条件の調査を十分に実施することも不可能に近い。リモートセンシングによって土壌分類を行おうとしても，地表面を覆う植生のため，特殊な裸地部分に限られてしまうからである。

したがって，これらの地域は，まずリモートセンシングを用いて植生や水系，土地利用などについておおまかな調査を行い，次いで，植物の分布パターンの解析によって環境要因の総和を把握し，農業開発に適当な小地域を選び出すようなシステムの開発が必要となる。この結果を利用することにより，従来の物理的，化学的測定をより効率的に，重点的に行えるようになる。

### ◆多種類のデータの複合を図る

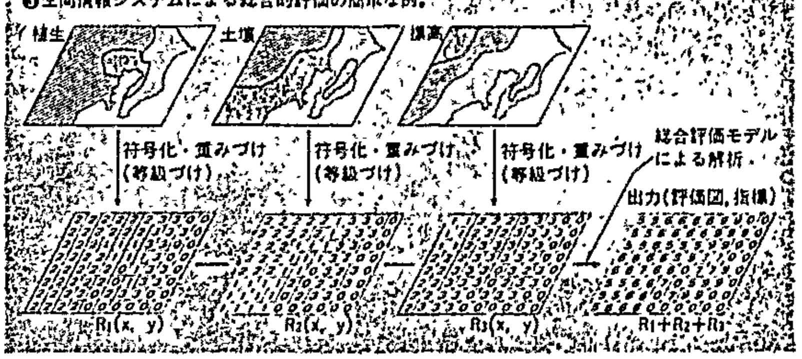
農業開発は自然立地条件の評価と，経済的立地条件の評価に基づいて計画・実行される。自然立地条件の評価に必要な基礎的調査項目とは地形，地質，水質，土地利用，水文，水利，土壌，植生，気象などである。これらのデータは地図や図表などさまざまの異なった形で与えられており，視覚的に比較，判定して，新しい主題図や評価図を作ることは難しい。それら多様な形のデータを共通の空間座標系で互いに参照できるようにすれば，データの比較は容易になる。❶は，ランドサットやその他の空間情報を有効に利用するための集積化を図示したものである。

❷標高データの濃淡表示の例。明るい部分が高く，暗い部分が低い。中心部分の暗いところは甲府盆地，左は赤石山脈，右下の特に明るい部分は富士山。

実際の空間情報システムの開発は３段階で行われる。第１は既存データのデータベース作成である。地形や地質，日照，気温，さらに自然災害などに関する過去のデータを地理座標系で重ね合わせてコンピューターに入力し，作成する。この場合，地図や図表は，マス目状のグリッドセル変換によって符号化され，ファイルされる。必要とあれば最終評価目標に対して重要度の大きい要因に重みづけや等級づけを行い，重みづけデータファイルとすることもできる。❷は250㍍幅のメッシュ化でファイル化された標高データをもとに，標高の違いを明るさに変換して表示した例である。

第２段階はリモートセンシング・データの処理である。リモートセンシングによって得られた土地利用，自然植生，水系などに関する最新データを同様にグリッドセル・データファイル化することである（84㌻E，F）。これらの結果をもとに，更新すべき牧草地や収量の低い牧草地がどこであるか，肥料が十分であるか，どのくらいの数のウ

❸空間情報システムによる総合的評価の簡単な例。



シを飼うことができるか，などを評価することができ，牧場経営に役立てられる。

解析・評価システムの作成が空間情報システムの第3段階である。ここで，作られた空間データベースから必要なファイルを選び出し，空間データの集積化と評価を行う。リモートセンシング・データと地理的データとを互いに重ね合わせたり，小領域のデータを互いにつないで，より広域のデータを作ったり，また評価モデルにデータを入力したりして，空間情報の加工を行い，必要な予測や評価図を得る（82，83ﾍﾟA～D）。

◆途上国の農業開発に威力発揮

評価モデルは入出力の空間的な見取りを与えるものであり，「自然」を取り出したものといえる。このようなモデルの開発には評価の目的や最終到達点を明確に決めておく必要がある。必要な入力データが入手できない場合は，代替データ，代替モデルを考える必要もあり，種々のデータ間の関連についての詳しい知識が重要となる。種々の因子のグリッドセル・データファイルをもとに，総合的評価図を得る様子を❸に簡単に示した。各グリッドセルの評価値を加え合わせることにより，総合評価指数を得る。総合評価には単純な評点加算法のほかに，多変量解析，パターン認識，AND／OR／NOT論理演算，フィルタリング，スクリーニングなどの数学的手段が用いられる。

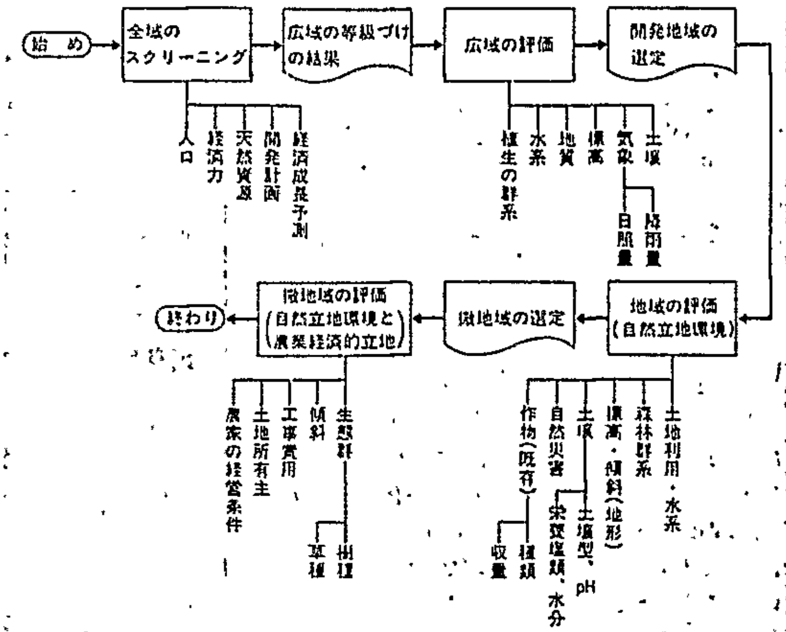
評価モデルが作りあげられる具体例としては，土壌条件，土壌侵蝕，気象環境，地理的環境，潜在的な生産量，バイオマス指数，農業適地指数などがある。未利用の土地の農業開発計画単位や農業土地利用区分の等級づけを行って，開発費用，開発後の生産性，関連産業の立地など地域開発効果の評価に用いることが考えられる。

一般に発展途上国では国土が十分に調査されていることは少ない。開発計画の評価には，まず広域について農業への適否を判定し，適当であると判定された地域について，やや詳しく評価を行う。さらに最小地域について順次調査し，最終的な開発候補地を決める。❹はこのような段階的スクリーニング方式の流れを示したもので，必要なデータの種類，評価要因は各段階で多少異なる。

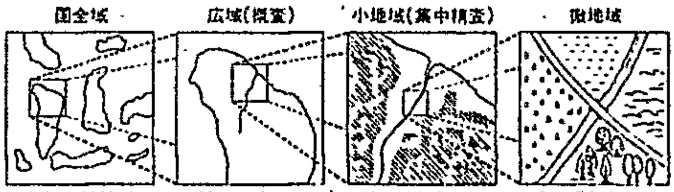
◆航空機や地表の調査も併用

ランドサット画像からは広域的な植生の群系型

❹スクリーニングによる農業開発適地選定モデルの流れ図。




❺リモートセンシングによる適地選定のための評価段階。

| 評価段階 | 国全域 | 広域（概査） | 小地域（集中精査） | 微地域 |
| --- | --- | --- | --- | --- |
| 対象地域 |  | | | |
| 調査単位（セル数） | 1000×1000キロ㍍（500×500セル） | 100×100キロ㍍（400×400セル） | 25×25キロ㍍（500×500セル） | 5×5キロ㍍（500×500セル） |
| 解像度（1セルの大きさ） | 2～4キロ㍍ | 250㍍ | 50㍍ | 10㍍ |
| データ収集レベル | 衛星 | 衛星 | 衛星および航空機 | 航空機および準地上 |

図が得られる。この群系型は気候型と密接に対応している。広域的な評価をもとに選ばれた地域段階の評価では立地環境要因を評価することが主となる。この評価を行う際に利用されるのは，比較的狭い地域に成立する森林群系は土質，降水量，土壌水分，母岩の性質，標高などとよく対応するという生態学的な事実である。農場や水田開発に適するかどうかの判定に必要な具体的資料を得るには，ランドサットのデータだけでは解像度不足であり，航空機による詳細な情報を併用することが必要となってくる。

農地開発に適すると判断された小地域の中で，具体的な道路や施設の配置，適作物の選定，水路の設置など，経済的立地配置を策定するためには，さらに詳しい準地表レベルの調査を併用する。生育する樹種，草種などの生態群から表土の厚さ，土の熟成度，酸性度，あるいは傾斜の方向など直接的に農業生産に結びついた情報の等級づけが，この段階で行われる。

❺はインドネシアの北スマトラ地域を例に，各段階で考えられる単位調査範囲，グリッドセルの大きさ，リモートセンシングの高度などの具体的な関係を示したものである。広域の評価は国および地方の２段階で行われる。地図でいえば，100万分の１から25万分の１の縮尺に相当する。広域評価における１つのグリッドセルの大きさは250㍍である。

ランドサットデータの１画素の大きさは約60㍍であるから，ランドサットの16画素（４×４画素）の解析結果をもとに，それぞれの地域について評価や等級づけを行うことになる。地域段階では50㍍のグリッドセルを用いて25キロ㍍四方を評価する。この段階は従来の５万分の１程度の縮尺に対応し，ランドサットだけでなく，航空機レベルでのデータも併用される。

ランドサット１号が1972年に打ち上げられて10年余りを経た。この間にリモートセンシングによって，なにがわかるかということが整理されてきた。これからは，資源や環境問題の解決にリモートセンシングをどう活用していくかが課題である。◆