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ANALYSIS OF FACTORS ACTING ON THE VARIABILITY OF SPECTRAL SIGNATURES OF NATURAL SURFACES

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SUMMARY

This paper discusses the problems relative to the determination of the spectral signature of natural surfaces : bare soils and vegetative canopies. It gives with some examples the order of magnitude of the spectral signature variability as a function of methodology and experimental conditions.

The spectral signature of a natural surface, which can be defined as the relative spectral distribution of the radiant energy reflected or emitted by this one, can vary on a same point in a relatively important way, in function of numerous factors depending on the measuring equipment, or the method of measurement, or the experimental conditions.

This paper will mainly deal with the problems relative to the determination of spectral signature of vegetative canopies near the ground surface in function of methodology and experimental conditions.

I VARIABILITY OF SPECTRAL SIGNATURES RELATIVE TO THE METHOD OF MEASUREMENT

The radiance of a scene depending on its own properties, but also on its irradiance, every time it is possible, it will be better, to take its reflectance (or its reflectance factor) (Krieble 1978, Nicodemus et al 1977) which only depends on its properties and enable comparisons in space and in time.

1.1 Influence of the determination method of the reflectance

Generally in the remote sensing studies the scene studied recieves hemispherical irradiance and its radiance is measured in a cone corresponding to the aperture angle of the radiometer which is used.

The spectral reflectance factor of a surface $R(\lambda)$ is defined as the ratio of the radiative flux reflected by the surface in the cone considered to that which should be reflected in the same direction by a perfect diffusing surface (white lambertian surface) and receiving the same irradiance (CIE 1977, Nicodemus et al 1977, Kriebel 1978).

In natural conditions the viewed scene irradiance can vary instantaneously in an important way. So it is better to measure simultaneously the radiance and the irradiance or to estimate the last one, if one only has one measurement apparatus. As an example, table 1 gives the results of the measurements of global radiation realized with a fast response pyranometer (Li-cor) in the course of characteristic days with a perfectly pure sky (06.16.76), with a clear sky but with haze passing in altitude (06.02.76) and with clouds passing (06.29.76). The examination of the standard deviation and of the variation coefficient of the values obtained enable to understand that even for series of measurements effectuated in rather short times (inferior to 30 minutes), it is not possible to neglect the irradiance fluctuations.

Table 1. Dispersion of the global radiation values in a course of different days. The time is given in solar time. N : number of points of measurement. Each point is the average of 6 instantaneous measurements.

	Time		N	Global radiation $W.m^{-2}$				
	Begin.	End	points	Maxi	Min.	Mean	Stand. dev.	Var. coef. %
06.16.76	12.01	12.22	19	892	873	883	6.11	0.69
06.02.76	14.06	14.44	19	803	727	764	25.0	3.27
06.29.76	12.06	12.19	31	928	284	568	264	46.4

If the radiance measurements are realized with a spectro-radiometer which takes several minutes to scan all the spectrum, it is necessary either to couple it with a second identical apparatus which measures the irradiance at the same time. If one only has one spectro-radiometer, it is necessary to measure the global irradiance with a pyranometer at the same time as the spectral radiance and to use a correlation between the global radiation and the spectral irradiance. Measurements performed in Avignon area (mediterranean climate) and in northern part of France (Bonhomme et al. 1978) enable to show that there were good correlations between the irradiance in Landsat spectral bands and the global radiation near solar noon (in the summer period) on the form :

$$\frac{L(\lambda)}{G} = a_\lambda + b_\lambda \sin h + c_\lambda (\sin h)^2$$

$L(\lambda)$: spectral irradiance
G : global radiation
h : solar elevation
a_λ, b_λ, c_λ are experimental coefficients.

1.2 Influence of the dimensions of the viewed surface

All the natural surfaces show heterogeities and the surface viewed by the radiometer must have sufficient dimensions to integrate the heterogeneities which correspond to phenomena of scales inferior to that of the studied phenomena, if one wants the measurements to be representative. Figure 1 gives an example of this proposition. It corresponds to measurements effectuated on a wheat field at the same points and at different heights above the canopy, with a radiometer whose objectives had a 15° aperture angle. The variation coefficient of reflectance measurements rapidely decreases when the radiometer moves away from the surface. And it is practically stable when the height of measurements is superior to 2.50 meters (viewed surface diameter : 0.60 m).

The measurements performed by Reichert (1978) at two different altitudes (1 000 and 4 000 m) over a red oaks forest give the same results.

1.3 Influence of the zenithal view angle

Natural surfaces are not perfect diffusing surfaces. In general, they do not follow the Lambert's law and the radiance varies in function of the zenithal viewed angle (Suits 1972) and in function of the orientation of the viewed axis relative to solar beams (Bunnik, Verhoef 1974). Two cases must be considered however : that of a bare soil and that of a soil covered with a vegetation.

When the soil is bare, the measurements effectuated show that the relative variation of the radiance (or of the reflectance factor) in function of the viewed angle is the same whatever the wave lenght may be, in the visible and in the near infra-red (Guyot et al 1978, Baret-Huet 1979). In those conditions, the relative spectral distribution of the reflected energy will not vary in function of the zenithal angle, only the global level will be affected.

When the soil is covered with a vegetation, the relative variation of the radiance or of the reflectance factor in function of the zenithal view angle only depends on the wave length. In fact, there is an interaction between the light and the vegetation whose optical properties are very different in the visible and in the near infra-red. The geometrical structure of the canopy also have an important part and also it evolves in function of time, the reflection indicatrix which can be obtained also evolves(Guyot and al 1978, Boehnel and al 1978, Kadro 1978, Emeri and al 1978). Figure 2 gives a few examples of the reflexion indicatrix variations in function of the orientation relative to the sun and in function of time. Indicatrix are represented in relative values taking the radiance measured vertically as a reference.

The numerous measurements effectuated show that important mistakes can be made if one supposes that natural surfaces are in accordance with Lambert's law,especially when the zenithal view angle is superior to 30°.

II VARIABILITY OF SPECTRAL SIGNATURE RELATIVE TO THE EXPERIMENTAL CONDITIONS

2.1 Influence of the sun elevation

The reflectance factor of a vegetative canopy or of a bare soil evolves in a course of a day in function of the sun elevation. In fact, the possibility for direct solar radiation to be intercepted by the vegetation decreases rapidly when the sun rises above the horizon (Fuchs and al 1972) and the contribution of the soil to the canopy radiance then becomes more important. As the soil reflectance is generally higher in the visible and lower in the near infra-red than that of the vegetation ; as on the other hand, the reflectance of an accumulation of leaves increases in the near infra-red with the number of superposed leaves (Gausman and al 1976); one can understand then that the reflectance of a vegetative canopy will increase in function of rising of the sun in the visible and will decrease in the near infra-red as we can see on figure 3, which is in good accordance with the results of Fuchs and al (1972) and those of Kriebel (1979) relative to a savanah.

For a bare soil the reflectance increases with the using of the sun whatever the wave length may be, since the diminution of the shadows given by the surface irregularities have a part. However, numerous measurements have shown that the reflectance factor of a soil or a vegetative canopy is practically constant during the 2 hours around solar noon. So every time it is possible, the measurements must be effectuated in that period.

2.2 Influence of nebulosity

The reflectance measurements cannot always be effectuated under a perfectly clear sky. In cloudy weather, not only the radiance is reduced, but the atmospheric diffusion is strongly increased. So the spatial distribution of the radiation received by a surface is strongly modified. Thus, we have tried to quantify the disturbance introduced in the reflectance factor measurements of vegetative canopies in cloudy weather for vertical and oblique view angles (Baret, Huet 1979).

2.2.1 Influence of the nebulosity on the vertical measurements of reflectance factor

The measurements have been performed with two identical radiometers (Exotech 100 A) looking one at the ground (with 15° objectives), the other at the sky (with 2π st. objectives). The radiance and the irradiance in each of the four Landsat channels were measured practically at the same time. As an example, table 2 gives the results obtained in a course of one of measurements series which have been realized by looking always at the same point and by effectuating one measurement every two minutes.

Table 2. Results of the global radiation G and reflectance factor measurements in the 4 Landsat channels (R_4, R_5, R_6, R_7) effectuated on a wheat crop on the 24th april 1979 between 10.46 and 11.43 (solar time) with important clouds passing in Avignon Montfavet

	G W.m^{-2}	R_4 %	R_5 %	R_6 %	R_7 %
Mean	736	5.10	3.57	37.76	51.02
Maximum	1069	6.80	4.19	42.29	54.70
Minimum	179	4.49	3.21	33.55	46.10
Stand. Dev.	309	0.36	0.20	1.45	1.84
Var.Coef. %	42	7.09	5.74	3.85	3.61

This table shows that the reflectance factor variability is much lower than that of the irradiance. The analysis effectuated on 9 measurements series corresponding to the same conditions shows that the variation coefficient of the reflectance factor, in the 4 Landsat channels is roughly the same and is about 7 times lower than that of the global radiation. However in the visible, an increasing of the diffuse radiation proportion is expressed by a diminution of the reflectance factor, whereas in the near infrared the contrary phenomenon is observed (Baret, Huet 1979).

2.2.2 Influence of the nebulosity on the oblique measurements of the reflectance factor

The reflexion indicatrix determinations effectuated under a clear sky and under a completely covered sky show that whatever the wave length may be, the reflectance factor increases very quickly in function of the zenithal view angle. As an exemple, figure 4 gives two reflexion indicatrix series obtained at the same place, in the same vertical plane and roughly on the same time under a clear sky and a completely covered sky on a winter wheat which do not practically evolve between the two dates (Baret, Huet 1979). These datas are also in perfect accordance with results obtained by Bunnik and Verhoef (1974).

So, those results show that when there are clouds passing, the values can be considered as representative if only vertical measurements are effectuated and if the radiance and the irradiance are measured at the same time. Important disturbances are only visible in oblique measurements.

2.3 Influence of the wind speed

The wind by agitating and deforming a vegetative canopy can affect its reflectance factor. The measurements effectuated in the Avignon area where there are often strong winds have not permitted to put in evidence a significative action of those winds on a wheat crop. On the other hand, the effect of wind is much more sensible on other crops such as the rice (Emori and al 1978).

2.4 Influence of the crop rows orientation

When row crops do not cover completely the soil, their reflectance factor or their emittance, depend between other things on the row orientation relative to the solar beams direction (Jackson and al 1978, Richardson and al 1975, Verhoef and Bunnik 1976). Their spectral signature varies in a course of a day not only because of the variation of the sun elevation, but also because of the variation of the sun azimuth. The theoretical studies of Verhoef and Bunnik also show that the row effect is much more sensible for the oblique measurements than for the vertical ones.

However, even for vertical measurements, the row effect is sensible and as an example figure 5 gives the results of measurements performed near solar noon on two points of two winter wheat plots, but one of them has its rows oriented North-South and the other one East-West. It shows that the reflectance factor of the plot whose rows are North-South becomes more important around solar noon when the solar beams reach the ground between the rows, whereas for the plot whose rows are East-West, the reflectance factor remains practically constant.

An analysis effectuated on all of the growing season has permitted to notice that around solar noon the mean reflectance factor of the plot whose rows are North-South is superior to that of the plot whose rows are East-West except during the period when the leaf area index (LAI) is at its maximum (between earing and the beginning of the maturing period).

2.5 Influence of the soil optical properties

The crop reflectance takes into account the optical properties of the vegetative part and of the lying soil. The importance of the soil optical properties effects depends on its coverage by vegetation. The theoretical studies of Suits (1972) and Bunnik (1978) and the theoretical and experimental studies of Bonhomme and al (1978) enable to have rather precise idea on the soil influence on the spectral signature of a crop. As an example figure 6 gives a result of calculations effectuated with Bonhomme's model (Bonhomme, Varlet-Grancher 1977). It enables to notice that when the L.A.I. increases, the reflectance factor in the near infrared also increases, whereas it decreases in the visible. But we must notice that the soil effect is sensible for higher LAI's than in the visible, where saturation is observed as soon as the LAI is superior to 3.

As the colour of a soil is a function of its humidity (Bowers, Hanks 1965), so after a rain or an irrigation the crop reflectance factor can be different because of the modification of the soil optical properties.

Table 3 gives two examples of the effect of precipitations on the reflectance factor of a wheat canopy with 2 different values of LAI.

Table 3. Influence of the precipitations on the reflectance factors in in the 4 Landsat channels of a winter wheat canopy and of a bare soil at 2 different periods in Avignon

Dates	Phenological stages	L.A.I.	R_4 %		R_5 %		R_6 %		R_7 %	
			Wheat	Soil	Wheat	Soil	Wheat	Soil	Wheat	Soil
05.17.79	Flowering	4.0	4.9	18.8	4.4	22.2	29.1	26.9	44.5	12.8
05.21.79	"	4.0	4.8	8.8	4.1	10.6	28.8	12.7	43.4	15.3
06.11.79	End. maturing period	1.5	7.9	25.1	10.1	26.9	18.5	30.5	23.4	31.4
06.14.79	"	1.5	6.9	11.6	8.9	12.8	13.8	16.9	16.6	18.5

2.6 Influence of the canopy geometry

The studies effectuated on leaves of different species by numerous experimentators (Fitzgerald 1974, Gates 1965, Gausman and al 1969) show that their optical properties do not practically vary during the major part of their life. So the evolution of the canopies reflectance factor in the course of time is essentially connected to the evolution of the leaves spatial arrangement. The theoretical studies and in particular those of Bunnik (1978) have permitted to show the importance of the leaf inclination effect. The leaves angles evolution is either connected to the plant phenology (Gurnade and al 1978) or to exterior stresses such as hydric deficit for example.

Figure 7 shows that when leaves inclination increases, the reflectance decreases as well as in the visible as in the near infra-red for high LAI values. But for low LAI values, the reflectance increases in the visible when the leaves inclination increases.

2.7 Influence of the phenological evolution of a vegetative canopy

When a crop evolves in a course of time, a theoretical study effectuated by Malet (1979) has permitted to show that the statistical distribution of the biological parameters follows a particular law.

Very roughly, one can say that the life of a plant is divided into growing periods separated by phenological stages. Figure 8 roughly shows how the statistical distribution of a biological parameter, between 2 phenological stages evolves. If the vegetative canopy structure follows this law, one can think that the statistical distribution of the values of the spectral reflectance factor will evolve on the same way. Experimental verifications performed on a rice crop in northern Italy (Agazzi and al 1977, Berg and al 1978) and on a wheat crop in Avignon (Gurnade and al 1978, Baret - Huet 1979) have confirmed the validity of the proposed hypothesis. Figure 9 represents the results obtained on the rice in Landsat channels 5 and 7. Pearson coefficient : β used, permit to characterize skewness of the statistical distribution. We note on figure 13 that the sequence of all the characteristic phenological stages connected with rice plant development produces either a change in sign or an inversion, or at least a slope change in the Pearson coefficient curves.

So the monitoring of a vegetative canopy by remote sensing will be done not only on the mean values of the reflectance factor, but also on its statistical distribution. Variability analysis seems to be an useful tool for the identification of crops phenological stages.

CONCLUSION

This short analysis shows that there are numerous factors acting on the spectral signature variability of a natural surface. In order to obtain in different places reliable and comparable datas, it should be necessary to take numerous precautions and to specify :

- detailed characteristics of the studied surface
- conditions of measurement
- characteristics of the instrument and experimental methology used.

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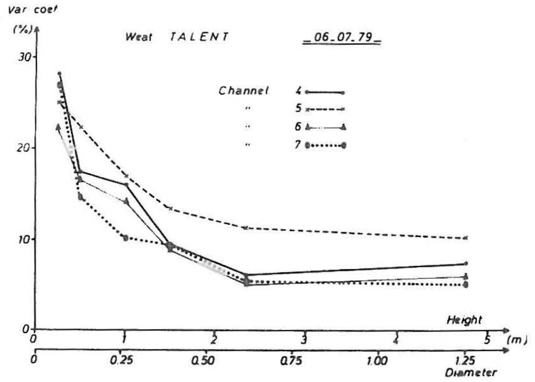

Fig. 1. Evolution of the variation coefficient of the reflectance factor in the 4 Landsat channels, of a wheat field as a function of the height above the top of the canopy. The second scale gives the diameter of the viewed surface

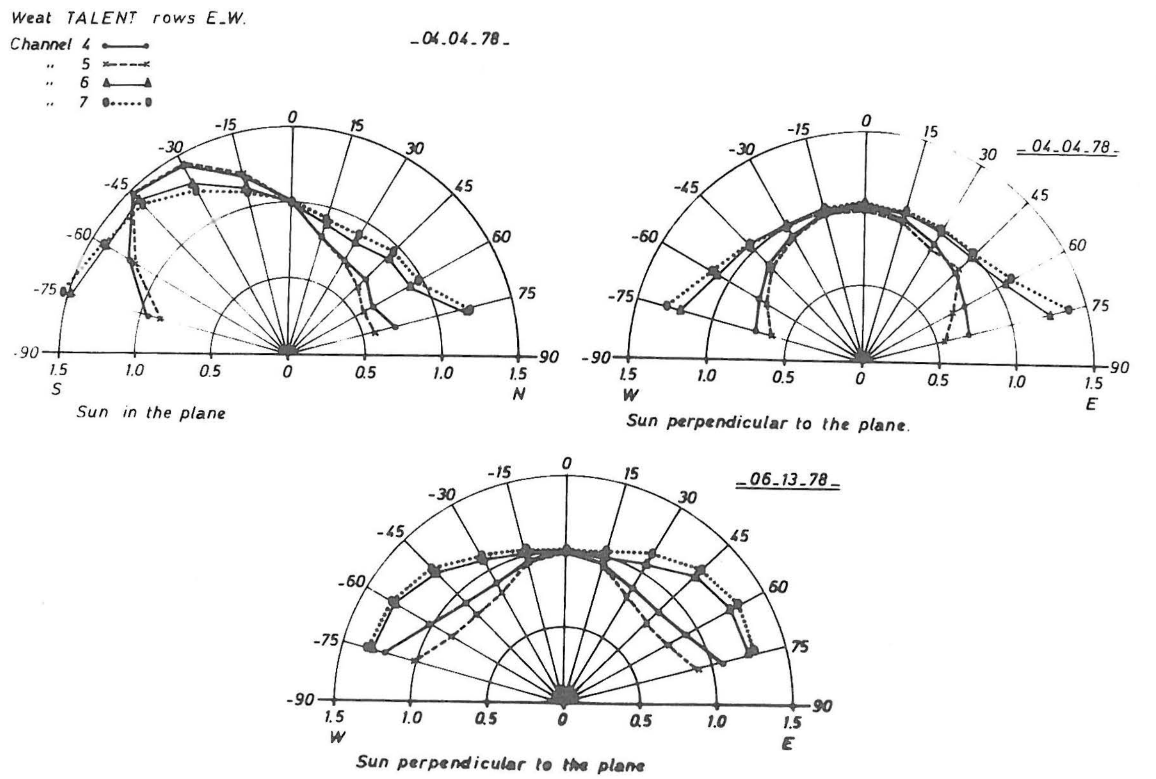

Fig. 2. Reflexion indicatrix of a wheat canopy determined in the 4 Landsat channels for 2 different dates and for 2 different orientations

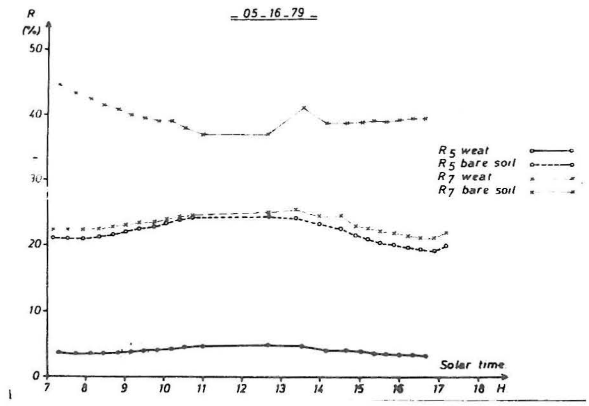

Fig. 3. Evolution of the reflectance factor of a bare soil and of a wheat canopy in the Landsat channels 5 and 7 as a function of the time

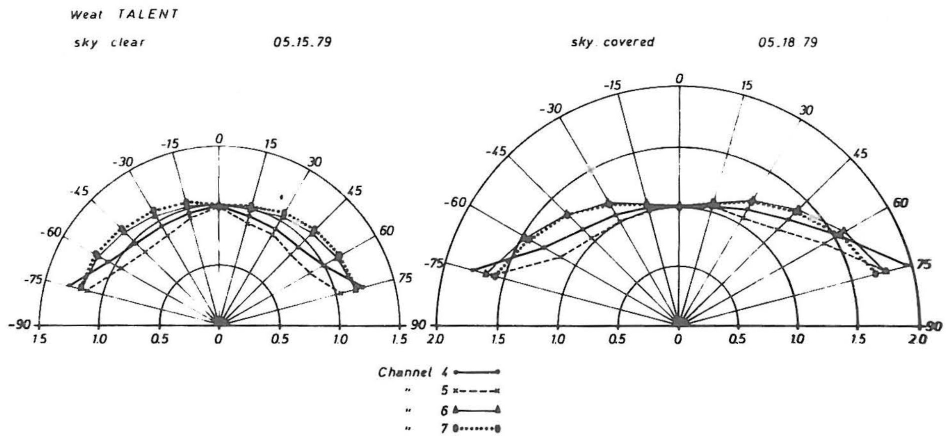

Fig. 4. Reflexion indicatrix of a wheat canopy obtained with different conditions of nebulosity

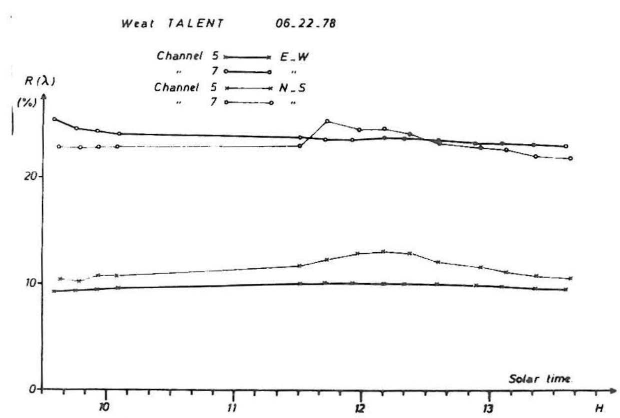

Fig. 5. Evolution of the vertical reflectance factor of two identical wheat canopies but with a North South or a East West row orientation around solar noon. As the measurements have been performed on 2 particular points, we do not obtain the same level for each corresponding curves

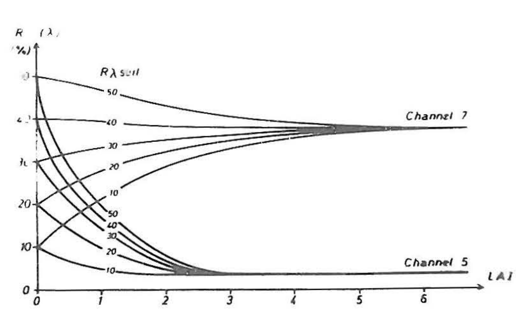

Fig. 6. Effects of reflectance factor of a soil in Landsat channels 5 and 7 on the reflectance factor of a canopy as a function of the leaf area index (LAI)

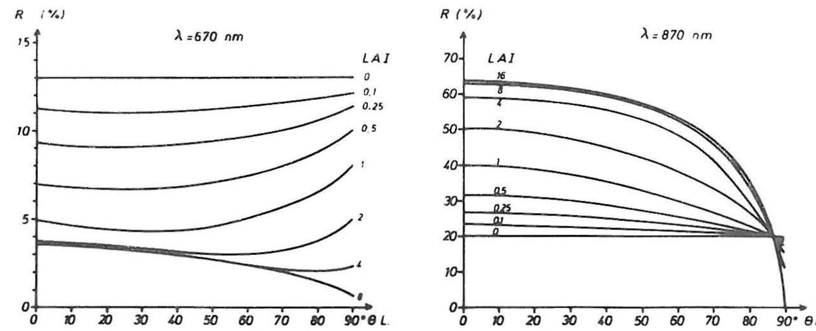

Fig. 7. Crop reflectance at 670 and 870 nm as a function of the average leaf angle θ_L, with LAI as a parameter (from Bunnik 1978)

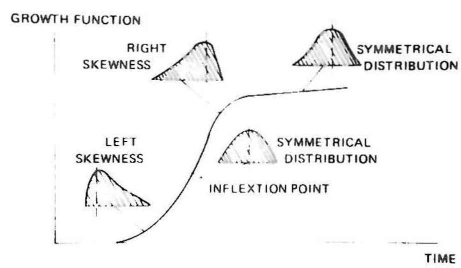

Fig. 8. Theoretical evolution of a vegetal population during growth between 2 phenological stages (Malet 1975)

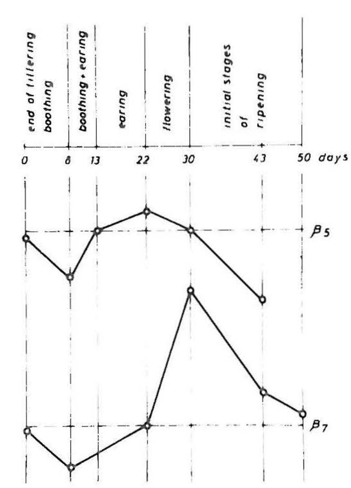

Fig. 9. Evolution of Pearson coefficient for channels 5 and 7 versus different phenological stages of rice (Agazzi & al. 1977)