An Application of Spectral Analysis to the Soil-Plant-Atmosphere Continuum

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An Application of Spectral Analysis to the Soil-Plant-Atmosphere Continuum

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Abstract

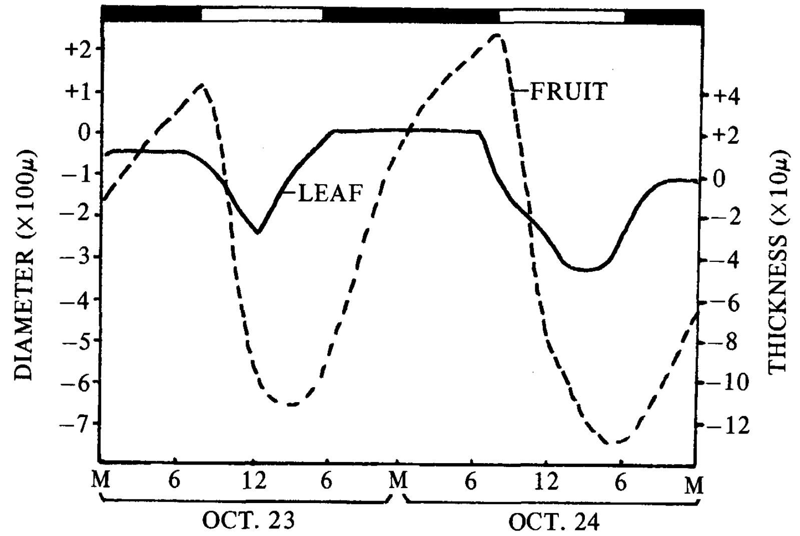
The spectral analysis technique was applied to the investigation of oscillatory phenomena existing in the soil-plant-atmosphere continuum. Changes in corn stalk circumference, solar radiation, ambient temperature and soil moisture level were recorded as analog data. The spectral properties of measured parameters were determined to investigate the cause-and-effect relationships between the papraameters.

A strong linear correlation between the amount of soil moisture level change and the corn stalk enlargement was found, using coherence estimates.

Introduction

Plant growth is affected by many environmental factors such as temperature, humidity, solar radiation, soil fertility, carbon dioxide concentration and so on. Many attempts to investigate the intricate relationships between plant growth and environmental factors were made in the past mostly by biologists and plant scientists including horticulturists. Recently, however, scientists from other disciplines have become involved in studies dealing directly or indirectly with plants. The cause-and-effect relationships that involve the plant and its environment must be understood. The need for a systematic study of the physical principles with an appreciation of the physiological responses involved in these relationships is obvous.[1] For definite example, the development of mathematical models of plant growth has become important.[2),3)]

All intensive and extensive parameters that can be used to describe the plant environmental state are dynamic in the time domain. In other words the amplitude (magnitude) of the parameters quantified in a proper manner changes with time. In engineering analysis it is often necessary to deal with oscillatory phenomena existing in the system of the soil-plant-atmosphere continuum. Many of the signals detected from the oscillatory phenomena encountered in real life are random. However, it is possible to find a considerable amount of periodicity for the plant environmental parameters.[1] Water is an important factor in the soil-plant-atmosphere continuuum. Since the amount of water available for storage within the plant depends upon the difference between the rate of uptake by the roots and the rate of transpiration in the leaves, the plant water status depends upon the energy-balance considerations in the environment above ground, within the plant, and within the soil mass. Kozlowski[4] reported that, under sufficient soil moisture conditions, daily change in fruit diameter and leaf thickness of Calamondin orange coincide with the period from sunset to sunrise, as shown in Fig. 1. From a physiological point of view plants have a high demand for water when growth and expansion are occurring. Water is indeed one of the essential factors that influence plant growth. The most influential factors on the plant's growth, however, depend upon the



From Kozlowski (1972)

Fig. 1. Changes in fruit diameter and leaf thickness of Calamondin orange during a period of daily irrigation. Photoperiod is shown at top with darkened portion representing the period from sunset to sunrise. (M=midnight; 12=noon).

stages of the growing process and the parts of the growing plant.

In this study using sweet corn in a field, changes in air temperature, soil moisture, solar radiation level, and size of corn stem were recorded simultaneously as time dependent electric signals for a predetermined time span. Spectral properties of each parameter were determined from the processed data by utilizing spectral analysis.

Spectral analysis plays a key role in finding frequency or spectral properties of random signals. By using spectral analysis, Currie[5)] found evidence of the solar cycle signal in power spectra of the late 19th century and 20th century surface air temperature data (this is one of the important parameters of plant environment) which had been obtained for over 60 years from the North American continent.

An objective of this study is to discuss the possibility of applying spectral analysis to the investigation of the relationships between plant environmental parameters and plant growth.

Experimental Method

1. *Material*

Thirty "Haniibantam" sweet corn seedlings, 2 weeks old, were planted with in-row spacing of 50 cm on a field at the Experimetal Farm of the University of Osaka Prefecture on May 29, 1981. The corn plants were grown under the standard management.

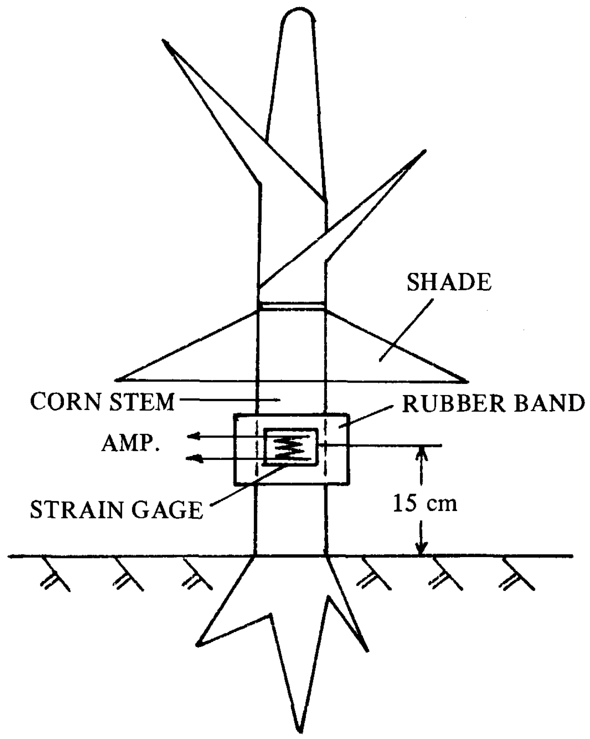


Fig. 2. Strain gages were used to record corn stalk enlargement. The amount of strech of strain gage due to the stem enlargement is reduced by the rubber band.

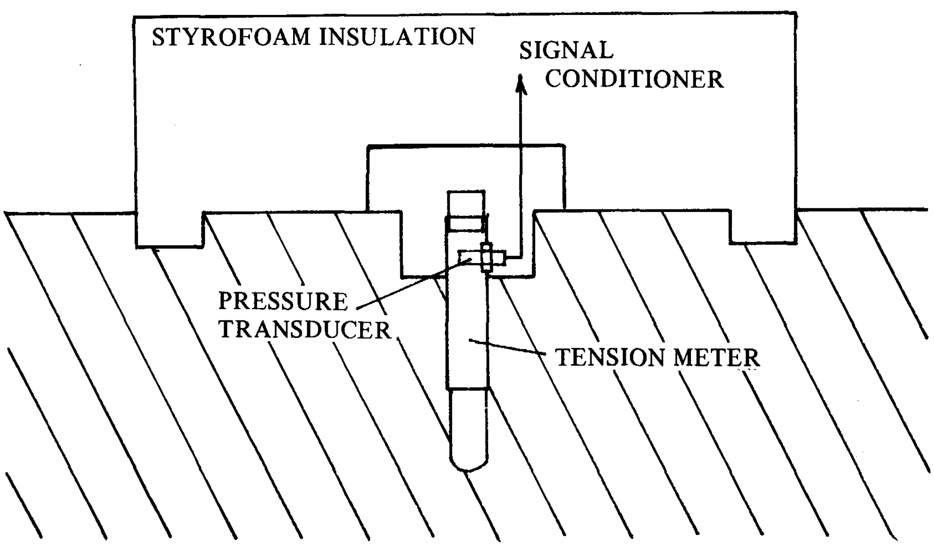


Fig. 3. Soil moisture level was converted to analog signal by a tension meter fitted with a pressure transducer.

2. *Measurement*

Three corn plants grown in a row next to each other were selected for this experiment. Plant height was measured in such a manner that upper leaves of each selected plant were first gathered into a vertical position and then measured from the ground surface to the tip of the longest leaf. The cross sectional area (assumed to be ellipsoidal) of each selected corn stalk was calculated based on its miner and major axes measured with a vernier caliper at a predetermined position (15 cm above ground) paint-marked on the stalk. A continuous measurement of change in circumference of each corn stalk was made, using strain gages which may be used for plastic deformation. A rubber band (1 mm in thickness) was wound around the stalk at 15 cm above ground. The deformation of the strain gage due to the stalk expansion was reduced by the rubber band which served as a buffer material. A schematic representation of the application of strain gage to this measurement is shown in Fig. 2. Since emphasis was placed on qualitative measurement for corn stalk expansion, i.e., the signal pattern was more important than its magnitude, the strain gage calibration for actual strain measurements of the corn stalk was not attempted, i.e., the amount of change in circumference of corn stalk was not calculated from the recorded data. A tension meter fitted with a pressure transducer was utilized to facilitate the continuous measurement of the soil moisture change. The lower part of the tension meter was buried in the ground and its upper part was covered with styrofoam insulation as shown in Fig. 3. An electric pyrheliometer and a thermoelectric thermometer were used to record solar radiation level and ambient temperature change, respectively. A schematic of the measuring system for this experiment is shown in Fig. 4.

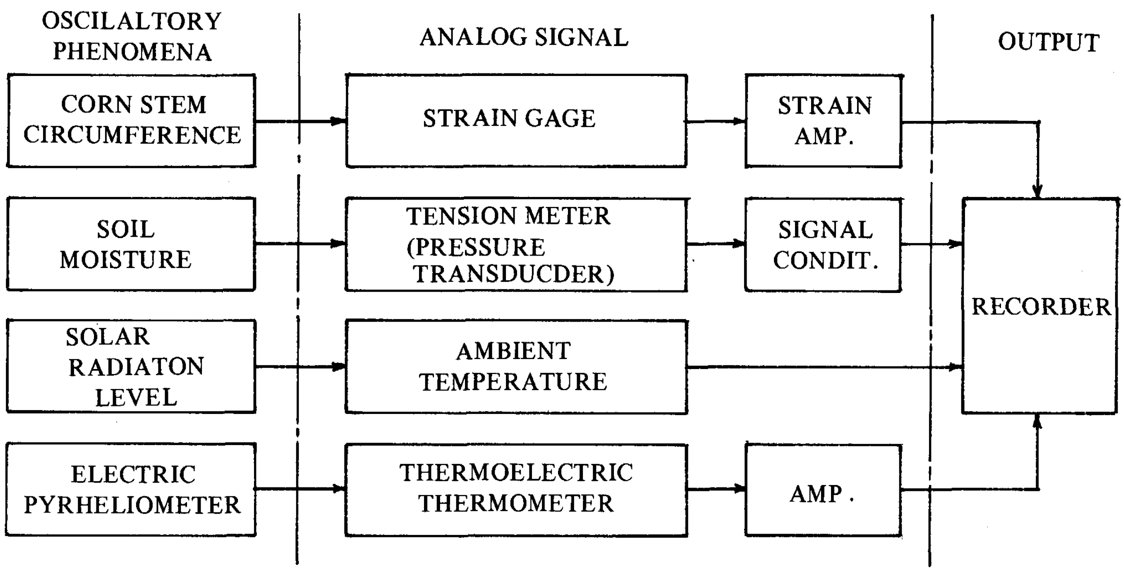


Fig. 4. Analog data were obtained by using electric transducers.

The measurement started on June 29, 1981. Changes in ambient temperature, solar radiation level, soil moisture level and circumferential change of the corn stalk were recorded continuously over 72 hours. Plant height and cross sectional area of the corn stalk were measured every 24 hours for 5 days.

3. *Analysis*

The correlation coefficients for sets of data points obtained from the measurements of (1) plant height elongation and (2) circumferential enlargement of corn stalk were calculated. A strong correlation between the two parameters ensures that circumferential enlargement is one of factors representing plant growth during the period when the experiment was carried out since plant height elongation was a major visual change.

Four sets of analog data were processed to obtain the spectral properties of each set of the data. The maximum entropy method[6] was employed to find specific frequencies at which a significant peak appears in the power spectral density diagram constructed from each set of the data. Coherence estimates were used to examine the cause-and-effect relationships between plant growth (stem enlargement) and each of the other three parameters (soil moisture level, ambient temperature and solar radiation) in terms of a signal transfer system as shown in Fig. 5.

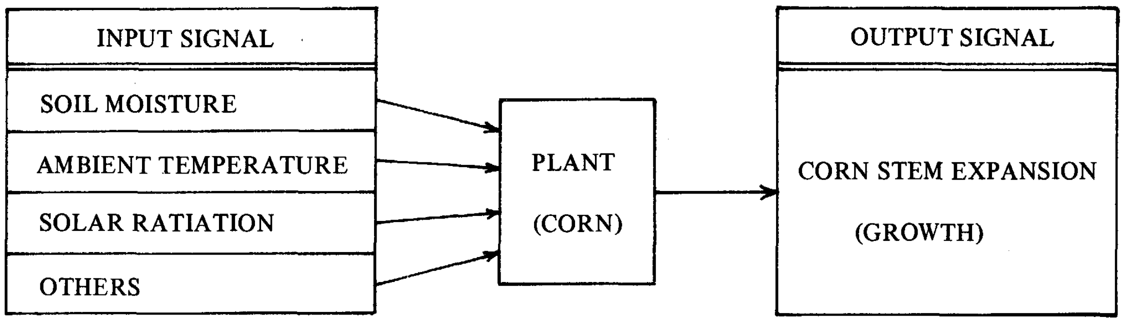


Fig. 5. The output signal is dependent of all input signals. Input signals, however, do not always equally influence the output signal.

Result and Discussion

The enlargement of plant height was 29.6 cm (mean value of three samples), and the cross sectional area of corn stalk was increased by 103 mm^2 (also mean value of three samples) during the period when the measurements were taken. All of the correlation coefficients calculated from the data obtained by plant height and stem cross sectional area measurements for three corn plants are greater than 0.96 with a value of 0.92 required for significance at the 99% confidence level. As is evident, it is justified that stalk enlargement can be chosen as a papameter representing the growth pattern of the corn plants during the period from June 29, 1981 to July 3, 1981.

The time series of data obtained form the continuous measurement of the four parameters is shown in Fig. 6. The output voltage changing with time shows a relatively periodic behavior of each parameter. In Fig. 6(a), a slight decrease in the output voltage toward the end of the recording is due to the overall enlargement of corn stalk circumference. Since the experiment was carried out during the rainy season, soil moisture level affected by rain showers varied largely as shown in Fig. 6(b). A diurnal period, i.e., one cycle per day, is roughly observable in both Fig. 6(c) and Fig. 6(d).

The time series data were processed to determine the spectral properties of each parameter. The power spectral diagram of each parameter is shown in Fig. 7. The non dimensionalized power spectrum (vertical axis) was calculated with the following formula:

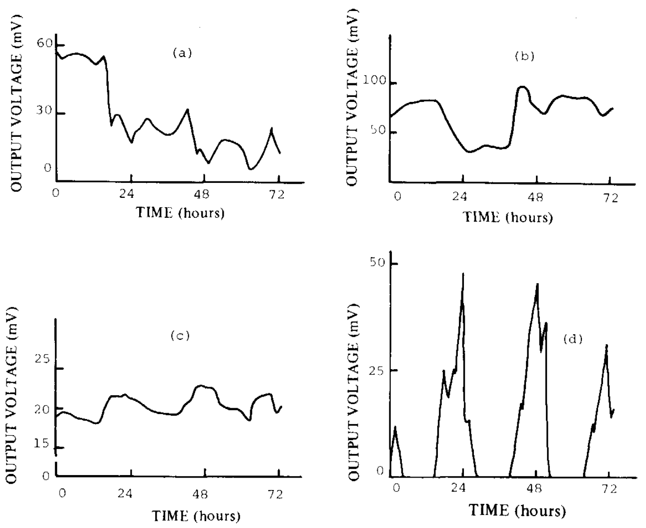


Fig. 6. Time series data obtained from the measurement of ; (a) Circumference of cord stalk, (b) Soil moisture, (3) Ambient temperature, (d) Solar radiation level.

$$\text{Non dimensionalized power spectrum at a frequency f Hz} = \frac{\text{Power spectral density at f Hz}}{\text{The maximum of all power spectral density values determined at each point on frequency axis.}}$$

The first peak of the power spectrum of corn stalk circumferential variation apperas at 0.34 cpd (cydle per day) and the second at 2.03 cpd (Fig. 7(a)). The power spectrum of soil moisture variation shown in Fig. 7(b) also has two large peaks at 0.34 cpd and 2.03 cpd. A large power spectal peak at 1.02 cpd can be found in both the ambient temperature spectrum (Fig. 7(c)) and the solar radiation level spectrum (Fig. 7(d)). Apparently, spectral analysis revealed that the solar radiation level and the ambient temperature vary diurnally. An explanation for the peak at 2.03 cpd is that the solar radiation level measured on the ground was affected once a day by overcast due to a daytime rain shower.

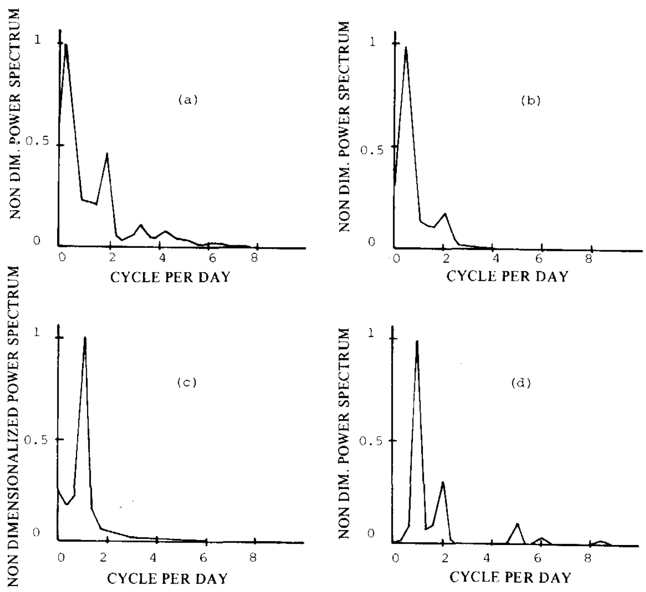


Fig. 7. Non dimensionalized power spectra were determined from the time series data, using MEM technique. (a) Circumference of corn stalk, (b) Soil moisture, (c) Ambient temperature, (d) Solar radiation level.

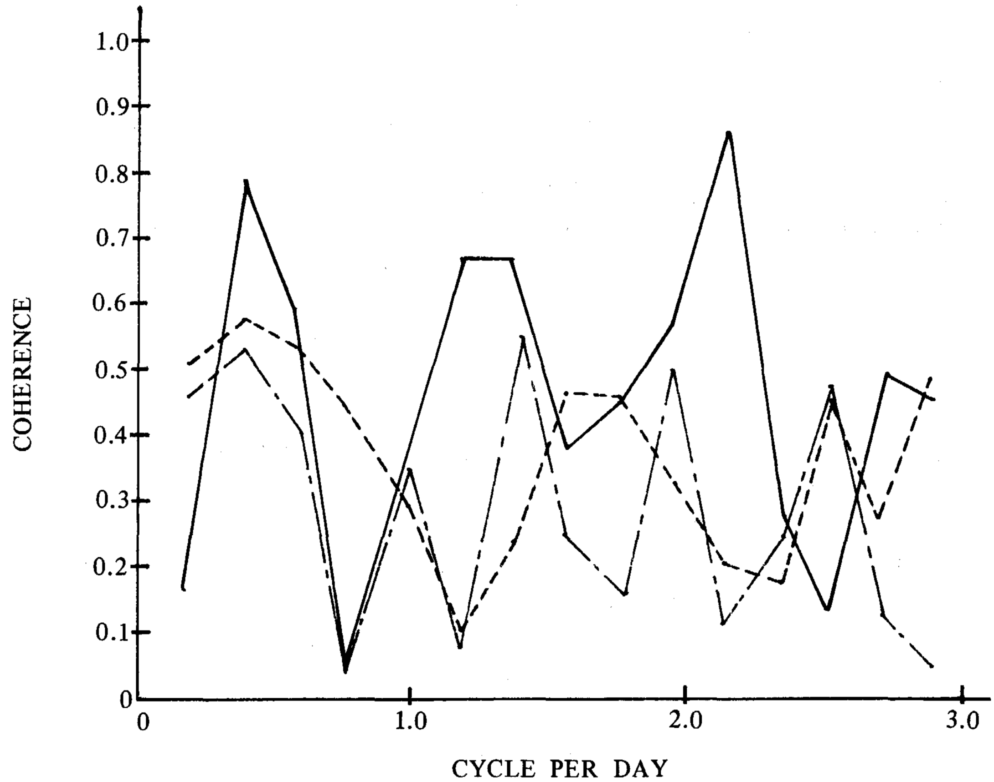


Fig. 8. Coherence diagram of input and output parameters.
——— Soil moisture – Corn stalk circumference
—·— Ambient temperature – Corn stalk circumference
----- Solar radiation level – Corn stalk circumference

Fig. 8 shows the results of the coherence estimates. All values of coherence of two input parameters calculated for the data (ambient temperature and solar radiation level) are less than 0.6. Two strong linear relationships exist at frequencies 0.38 cpd (coherence 0.791) and 2.1 cpd (coherence 0.897) on the coherence diagram of soil moisture level – corn stalk circumference. This result of the coherence estimates implies that the corn plants responded most sensitively to changes in the soil moisture condition during the period of this experiment. Since water is one of the essential element for plant life and growth,[7] this result seems obvious. The result, however, substantiates the feasibility of making use of spectral analysis in plant environmental studies.

Conclusions

The conclusions which can be drawn from this study are:

1. The dimentional enlargement of the circumference of corn stalks during the vegetative growth process is not monotonous but oscillatory.
2. The oscillatory variation of the circumference of corn stalks is mostly due to the change of water status in the environment.
3. It is possible to apply the spectral analysis technique to studies on measurable oscillatory phenomena existing in the soil-plant-atmosphere continuum.

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