2. Summaries of Doctor Theses

Analysis of Green Condition using Spectral Reflectance

Kengo ITO

Subdivision of Natural Environment, Division of Arid Land Environment

(Doctor's degree received in March, 1997)

This paper describes estimation of vegetation condition by spectral reflectance. In the study of green by remote sensing, Normalized Differential Vegetation Index (NDVI) and Perpendicular Vegetation Index (PVI) have been commonly used. These indexes, which use the reflectance of red and near infrared, indicate the various information of vegetation inclusively. Therefore, we have arranged four studies to estimate vegetation condition in detail.

First, the experiments to estimate vegetation cover rates and vegetation vigor independently using manilagrass were made in the laboratory. The results show that the reflectance around 550nm and 980nm is not affected by vegetation vigor but vegetation cover rates. New indexes were derived based on the results. Vegetation Cover Index (VCI), the reflectance difference between 550nm and 980nm, indicates vegetation cover rate independently of vegetation vigor. Vegetation Vigor Index (VVI), the ratio of PVI to VCI, indicates vegetation vigor independently of vegetation cover rates. The experiment using sorghum shows the applicability of the new indexes to another crops in the field.

Second, VCI was applied to estimate vegetation cover rates in mixel models. The results show that VCI would be used to estimate vegetation cover rates of mixel models composed of vegetation, sand and NaCl. The reflectance difference of 350nm and 500nm indicates sand and NaCl cover rates. These methods are not affected by vegetation vigor, crystal size, thickness of NaCl and water contents of sand.

Third, the relationship between perpendicular structure of vegetation and spectral reflectance was investigated. The results indicate that the perpendicular structure of vegetation, sensor look angle and incident angle contributed to the spectral reflectance in near infrared. It is concluded that the measurement of different sensor look angles and incident angles should be obtained to estimate the perpendicular structure of vegetation.

Fourth, a spectral sensor composed of a photometer and a metalhalide lamp to monitor *Microcystis* was made. The photometer is made of nine photodiodes and three interference filters(550, 670, 800nm). Absorbance of some water samples, which were artificially mixed with *Microcystis*, *Spirogyra*, Andosol and Magnesium oxide, were measured using this sensor. The results show that the absorbance of *Microcystis* and *Spirogyra* is similar to the one of land plants. Therefore, concentration of these phytoplanktons will be estimated by difference of absorbance of 800nm and 550nm. *Microcystis* and *Spirogyra* are classified using the specific feature of Phycobilin, which is characteristic pigment of the blue-green algae, is not contained in *Spirogyra* but in *Microcystis*. Since Phycobilin absorbs electromagnetic wave in 500-650nm, the absorbance of 550nm significantly increases with increasing of concentration of *Microcystis*. Based on those results, following steps to measure *Microcystis* are derived. First, divide phytoplanktons and others by the difference of absorbance of 800nm and 550nm. Second, divide the blue-green algae and other phytoplankton by the difference of absorbance of 670nm and 550nm.

These results indicate that the wide-ranging wavelength of spectral radiation should be obtained to get detail information of vegetation.

Studies on Wheat Varietal Differences with Regard to Tolerance to Deep Sowing

Takehiko MATSUI

Subdivision of Plant Ecophysiology, Division of Biological Production

(Doctor's degree received in March, 1998)

In the arid regions, surface soils dry rapidly resulting in a water deficit that constitutes a major constraint to crop production. Crops often suffer serious losses in stand due to poor germination and emergence. To avoid poor germination and/or emergence, crops in the dry regions are sown deeper than those in the wet regions. This sowing method, known as deep sowing cultivation, is made feasible by the relative stability in water content of the deep soil layers. Deep sowing has limitation as it may impair crop emergence. The limits imposed by sowing depth are, however, different for each crop and variety. The mechanisms of varietal differences to deep sowing tolerance are not well understood. The objective of this investigation was to study, analyze and identify the morphological and physiological bases of varietal differences to deep sowing tolerance noted with some varieties of wheat (Tritium aestivum L.). Five wheat varieties: Hongwangmai, Ninchun No.10 and Mianyang No.11 from China, Sv 85131 from Sweden and Haruhikari from Japan were used in this study. In among these varieties, Hongwangmai is commonly used for deep sowing cultivation in the Loess Plateau of China. The study focused on :

1. Varietal differences of tolerance to deep sowing.
2. The effects of grain weight, embryo weight and endosperm weight on varietal differences in deep sowing tolerance.
3. The relationships between varietal differences in deep sowing tolerance and the ability of their plumule penetration in the vertical direction (plumule penetration force) from sowing place up to surface.
4. The relationships between tolerance to deep sowing and varietal differences in the final coleoptile length.
5. Varietal differences in their ability to produce the large seed under low soil moisture conditions.

1. Varietal differences of tolerance to deep sowing in five wheat varieties.

When planting at 15 cm depth, the variety Hongwangmai showed the highest emergence under both wet and dry soil conditions.

2. Relationships of grain weight, embryo weight and endosperm weight to varietal differences in deep sowing tolerance.

Within each variety, significant positive correlations were found between emergence and grain weight, embryo weight and endosperm weight. However, no such correlations were found among the varieties. Emergence was also evaluated using seeds of the same weight. Among the varieties, Hongwangmai and Haruhikari were superior to the others. These results showed clearly that, within a variety, emergence from deep sowing depends on the weight of grain, embryo and endosperm, while, among the varieties, tolerance to deep sowing is controlled by other factors.

3. The relationships between varietal differences in tolerance to deep sowing and plumule penetration force against soil.

A substantial plumule strength in vertical direction, which gives penetration force, is a prerequisite for successful emergence of a deeply sown plant. Hongwangmai showed the highest penetration force under different soil hardness among varieties. No differences in plumule strength was displayed among varieties. However, in plumule cross sectional areas, which is a criterion of easy elongation under the soil impedance when plumule elongates in soil, significant differences were observed among varieties. Hongwangmai showed the smallest area. The results show that the highest penetration force of Hongwangmai among all varieties derives from the pointed shape of tip more than plumule strength.

4. The relationships between deep sowing tolerance and the final coleoptile length.

Under deep sowing, the plumule has to elongate over a distance to emerge. The relationships between varietal differences of deep sowing tolerance and the final coleoptile length were investigated. The final coleoptile length varied among varieties. Hongwangmai had the highest final coleoptile length. High positive correlations were observed between the final coleoptile length and emergence. Varietal differences in final coleoptile length were not related to coleoptile length per unit dry matter (specific coleoptile length; SCL (cm/g)) and to coleoptile dry matter derived from seed nourishment. Differences in final coleoptile length were highly associated with number of cells in the midrib direction, not with cell length of the parenchyma in the elongated coleoptile and/or in the embryo prior to germination. These results indicate that the final coleoptile length is determined by number of cells along the midrib. Genetic analysis of F2 generation revealed that the final coleoptile length is controlled by several genes.

5. Varietal differences in the ability to produce the large seed under low soil moisture conditions.

As already mentioned in **1**, tolerance to deep sowing within a variety is positively associated with grain weight. The influence of low soil moisture on mean grain weight and its distribution among harvested grains were investigated. Grain yields of all varieties decreased significantly with decreasing soil water content. Among varieties, the most tolerant, Hongwangmai, displayed the highest yield under low soil moisture conditions. Varietal difference in grain yield under low soil moisture conditions were attributed, mainly, to differences in number of grains, mean weight of grains and harvest index. There were varietal differences in the distribution of grain weight. The mean grain weights of all varieties, except Hongwangmai, were significantly reduced by soil moisture stress. Hongwangmai was the only variety in which the standard deviation of the distribution of grain weight decreased under low soil moisture. The low variability in distribution of grain weight around the mean, in Hongwangmai, indicates that deep sowing tolerance is maintainable in successive generations.

In conclusion, varietal differences in deep sowing tolerance are associated with both the plumule penetration force and the final coleoptile length and not with the weight of grains, embryos or endosperms. Furthermore, the final coleoptile length is determined by several genes. On the other hand, within a variety, under deep sowing conditions emergence is positively associated with the weight of grains, embryos and endosperms. Moreover, the variety Hongwangmai, which has the highest tolerance to deep sowing, consistently produced high yield and uniform heavy grains under low soil moistures. The results of this study revealed adequate information on the mechanisms of tolerance to deep sowing. The information provided can be used as guides for breeding and/or screening of wheat varieties for tolerance to deep sowing.

Evaporation from Bare Soil Surfaces and Salt Accumulation in Sandy Soil

Haruyuki FUJIMAKI

Subdivision of Land Conservation, Division of Afforestation and Land Conservation

(Doctor's degree received in March, 1998)

Deficit of water and salt accumulation are serious limitation of crop production in arid and semi-arid land. Proper irrigation scheduling which can cope with both water requirement and water saving can be a key element of sustenance and development of agricultural production. Accurate predicting of water, heat, and solute transfer is essential to improve conventional irrigation management which depends largely on intuition or fixed periods.

Though water consumption and salt accumulation are driven by both evaporation and transpiration, I studied those driven by evaporation focusing, particularly, on validity of existing evaporation and solute transport model in this thesis. Both models are conventional, but the validity or applicability of the models has never proved experimentally, and therefore they have been questioned by several researchers. In assessment of the validity, each parameter which plays critical role in simulation was measured independently.

Chapter 2 was used to describe evaporation model and water, heat, and solute movement in soils which are widely used and specify the task of this study.

As preparation to assess the validity of existing evaporation model, a simple steady-state evaporation method for the determination of the hydraulic conductivity function is described in Chapter 3. Unsaturated hydraulic conductivity in the low pressure head range is important to predict evaporation rate accurately, but often estimated or extrapolated owing to lack of reliable measurement method. Three methods for the estimation of the hydraulic conductivity were used: the linear approximation method (LAM), which determines it directly from the flux-to gradient ratio assuming linear distribution of pressure head, the polynomial approximation method (PAM), which approximates water content profile with polynomial equation, and inverse method, which assumes unsaturated conductivity function beforehand and evaluates parameters by nonlinear parameter optimization of predicted to measured water content profile. Predicted water content profile was obtained with steady-state numerical solution of Richards' equation which includes isothermal water vapor movement. Since there had been no reliable method in low pressure head range, the ability and limitation of the method were evaluated using numerical experiments which prescribe true hydraulic conductivity for two soils and take experimental errors into account. Results indicated that the inverse method is not very sensitive to them, while LAM and PAM are influenced for wet condition (K>10-5cm/s). Sensitivity analysis was performed and showed that the optimized hydraulic conductivity in the wet range (K>10-6cm/s) can only indicate lower limit of hydraulic conductivity curve. A steady-state evaporation experiment for sandy loam soil was carried out in order to demonstrate the measurement. Transient numerical simulations were conducted to discuss proper groundwater depth.

Thermodynamic equilibrium condition between the liquid and vapor phases of water at soil surfaces has often been assumed for modeling evaporation from soil surfaces. In Chapter 4, the validity of the assumption by experiment and simulation is assessed. An evaporation experiment under a steady condition for sandy loam was carried out. Using its hydraulic and heat transfer properties measured independently, numerical simulations of evaporation, liquid water flow, water vapor movement and heat transfer were performed for various space increments. Simulated evaporation rates and soil temperatures given by the equilibrium model were in agreement with observed values if the topmost space increment was so small as to be 0.05cm. This confirms that the equilibrium assumption is valid so long as the topmost space increment is small enough to describe the steep pressure head profile near the soil surface. When the expression of hydraulic conductivity proposed by Campbell which has often used for evaporation studies was adopted, the simulated evaporation rates deviated from the observations even though small space increments were used. Since the scheme which uses surface resistance could offer computational savings, a simple and accurate method for determining the dependence of surface resistance on water content was outlined.

In Chapter 5, the applicability of the convection dispersion equation (CDE), which is widely used to predict solute transport, for solute transport near an evaporating surface is examined. An evaporation column experiment was conducted using Tottori dune sand with a shallow water table of NaCl solutions. Water and solute movements were observed. The diffusion and the mechanical dispersion coefficients as well as hydraulic properties for the Tottori sand were independently determined. The Richards' equation and the CDE were simultaneously solved with the finite difference method. Water vapor movement and crystallization of excess salts were also included for the prediction. The calculated concentrations near the soil surface were smaller than the measured data. This underestimation resulted in a significant delay of the salt crystallization at the soil surface compared to the observation, which would greatly reduce the evaporation rate. Since the CDE uses an analogy of the Fickian law to describe the mechanical dispersion, the dispersion term overestimated downward movement of solute regardless of the upward convective transport. The apparent dispersion coefficient, which agreed with the measured data in the evaporation experiment, was 1/3 of the dispersion coefficient in an infiltration experiment.

In order to overcome unacceptable error shown in Chapter 5, the convective random-walk model (CRWM) is proposed in Chapter 6. The CRWM uses an asymmetric probability density function (pdf) which is defined in the same sign as convection instead of normal pdf used in conventional random walk method. The CRWM was then applied to an initial value problem, which indicated that the CRWM does not induce back mixing due to mechanical dispersion and converge the solution of the CDE in large traveled distance. When the CRWM was applied to boundary value problem, it overestimated concentration near the soil surface. An inflow boundary treatment which eliminates the error was presented. Though physically proper time increment of random- walk methods would be large, it is recommended that upper limit of time increment be set in order to restrain "parameter gap" under water content gradient or unsteady flow. Methodology for including diffusive movement was also described. The evaporation conducted in Chapter 5 was used for model validation, where parameters were independently obtained. Crystallization as a consequence of capillary rise of salty water, was also included in the CRWM. Compared with the experimental data obtained, the CRWM described the observed salt profile better than that of the CDE.