1. Summaries of Doctor Theses

Agrometeorological Studies on Condensation of Water Vapor

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The water is lost through the plant to the atmosphere by transpiration. About 600 - 1000 g of water is regained in order to produce 1 g of assimilants. Water vapor has not yet been used as a water resource, because no pragmatic way to convert into liquid phase. In this study the objective was to convert water from vapor phase to liquid phase, "Dew" as a natural condition and "Soil-Air Heat Exchange Distillation System" as an artificial condition.

Sand surface soil water content is dry in the daytime and increases at night. The mechanism of this phenomenon has not quantitatively clarified because the continuous measurement of nighttime surface soil water content is very difficult. In this study, albedo and thermal conductivity changes due to soil water content were used for estimation of soil water content on "soil surface" and at "nighttime". It was concluded that thermal conductivity would have satisfying estimations of surface soil water content.

"Dew" derives from vapor in the atmosphere ("Dew fall") and soil ("Distillation"). "Dew fall" has been considered by heat budget and "Distillation" has been considered by using soil physical methods, so that these two processes can be detected independently. In this study, the simultaneous measurement of "Dew fall" and soil surface water content was conducted to consider the contribution of "Dew fall" and "Distillation" to the amount of "Dew".

From the experimental results, it was concluded that "Dew fall" would be negligible, because no correlation could have been established between changes in soil surface water content and amount of "Dew fall". At nighttime upward soil water movement, liquid phase movement is negligible, because of low soil water content near the ground surface, and vapor movement exists certainly, because of underground vapor pressure gradients. These results show that increased soil water content at the dune surface resulted mostly "Distillation" process, while "Dew fall" was negligible. Heat budget and under ground to over ground vapor pressure gradient indicate that vapor flux is almost upward. It means that "Distillation" is a part of nighttime evaporation. Soil surface is wetted by "Distillation", and is dried rapidly after sunrise.

"Soil-Air Heat Exchange Distillation System" was developed for collecting water from vapor originated in evapotranspiration. This system distills water from vapor by cooling the air in a greenhouse, using underground heat exchange pipes. It is similar to "Soil Heat Exchanger Storage Systems". A parameter for estimating daily amount of collected water was investigated, based on heat and vapor budget of the heat exchange pipe. From the experimental results it was found that daily amount of collected water is a linear function of integrated surplus of air and soil temperature.

In this study, a technical method to use water vapor as a new water resource was developed. However in order to implement the results, the subject should be further and intensively studied.

Soil Hydraulic Parameters as Affected by Water Application, Water Quality, and Soil Properties

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ON/OFF application of irrigation water to irrigation furrows (surge techniques), when effective, has the potential to enhance the performance of traditional furrow irrigation systems by beneficially influencing (reducing) soil infiltration rate in a furrow.

Furrow irrigation water advance rates and advance volumes were evaluated under both traditional (continuous) and surge (intermittent) flows at the Arid Land Research Center, Tottori University. The experimental plot had a sandy loam (*Masa* soil) specially designed to undertake water application trial. Parameters to estimate infiltration of water into the soil, according to Kostiakov and Modified Kostiakov form relations, were evaluated by monitoring cylinder infiltrometer as well as hydraulic variables from a volume balance approach during the actual water application to the furrow channel.

The study results indicated that up to 30 percent less water is consumed to complete furrow advance under surge compared to a continuous flow under similar set of conditions. Surge flow effects in reducing soil infiltration rate compared to continuous flow were observed to be pronounced during the first water application to newly formed furrows when soil water condition was at the minimum. The decrease in infiltration under surge is attributed to a sequential soil particle detachment, transport and deposition in water conducting pores. On resumption of successive surges following the OFF periods, the reduced hydraulic gradient on the previously wetted portion of the channel is also suggested to further decreases the infiltration making more water available to advance faster towards the end of the furrow.

Percent relative error, RE(%), is defined to compare the relative infiltration prediction levels of the coefficients derived from cylinder infiltrometer and volume balance methods (for continuous flow) against an ideal model that provides estimates equal to measured infiltration over the whole infiltration time. The volume balance approach that takes into account data on furrow advance, inflow rate, slope, roughness, length and geometry to derive the infiltration parameters provided an infiltration level closer to the actual infiltration in the furrow compared to the level of infiltration predicted using coefficients from cylinder infiltrometer records. The marginal advantage due the volume balance derived coefficients lie in the better representation of the way infiltration takes place in a furrow channel compared to ring infiltrometer that has very little, if any, in common.

Further, water quality and soil property induced changes in soil hydraulic behavior were evaluated by studying the response of low and high swelling clays to saline and sodic conditions. Soil samples from Ariake and Kamenose (Japan) represented the low and high swelling clays, respectively. Changes in hydraulic conductivity (HC) and clay dispersivity of soil-sand mixtures as a function of total electrolyte concentrations (TEC) and distilled water as well as various sodium adsorption ratio (SAR) of the percolating solutions were measured in the laboratory.

In the low swelling clay, no changes in HC were measured at high TEC for all SAR values. When the low swelling clay were leached with distilled water, the HC of the Ca-clay (SAR = 0) increased, whereas the HC of high SAR treatments decreased. Clay dispersion and migration out of the low clay concentration mixture column was substantial. The increase in HC in Ca-mixture of low swelling clay leached with dilute solutions was attributed to the collapse of the open microstructure which prevail in concentrated solutions. For the low swelling, clay dispersion was the main process responsible for HC decrease at high SAR and it

was prevented when TEC exceeded the flocculation value of the clay. Clay dispersion increased with an increase in SAR and it affected the HC of the porous media only when the pores are fine and the dispersed clay plugs the conducting pores.

In the high swelling clay mixtures, a gradual decrease in the HC was measured as the TEC decreased and the SAR increased. In these mixtures, swelling was the main process responsible for HC decrease even at high TEC. Swelling increased with an increase in clay percentage, SAR and decreasing TEC.

Both swelling and dispersion mechanisms have shown the potential to partially or fully block water conducting pores in the soil. However, swelling increases continuously and gradually with dilution of the percolating solution. Dispersion can, however, be prevented by dilute solutions whose TEC exceed the flocculation value of the soil clays. Understanding the relative significance of the two processes is of paramount importance to soil and water management.

Physical disintegration of aggregates as a response to externally imposed disruptive forces to soil can also cause changes in the hydraulic properties of soils. The joint effect of physico-chemical dispersion and swelling of soil clays (soil intrinsic behavior) and the physical disintegration of aggregates on the HC of various soils was studied. Three prewetting rates (PWR) and a water quality characterized by (SAR,TEC) and distilled water were studied.

The results showed that absolute values of HC and its relative changes over time depended on the type of soil, the PWR, the TEC, and the aggregate size. HC decreased with an increase in the silt and clay content, with an increase in the PWR, and with a decrease in the TEC of the percolating solution.

Soils that slaked into microaggregates under the effect of fast PWR, showed a substantial decrease in HC with an increase in the PWR. In structurally unstable soils, fast PWR caused more slaking and physical disintegration of aggregates that restricted water flow leading to low HC. Further, it decreased more in solutions of low TEC. The larger the aggregate size fraction, the more pronounced was the PWR effect on HC apparently due to greater pore throttling by the slakes.

Development of cohesive forces between clay structural units with time (aging) was suggested to counteract HC decrease as noted in some soil columns. HC of less aggregated or of structurally stable soils were less affected by the PWR.

The study indicated that PWR effects on soil HC could be satisfactorily predicted from soil aggregate stability tests. It also underlines the significance of soil aggregate stablization (by managing rate of water application) in maintaining favorable water movement in the soil even in conditions understood as dispersive and/or swelling.

Studies on the Application of the Sap Flow Measurement in Irrigation Management

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To establish sustainable agriculture as well as higher productivity and stability is top priority subject avoiding crop water stress by carrying out appropriate irrigation management. As water stress progressed, water movement from root to leaf cannot follow the degree with water content in leaf. Water stress cause stomatal closure, reduction of transpiration, restrict growth rate, reduction of production depend on degree of it. SPAC models widely used for irrigation scheduling are in accordance with these views. Recently, it is start to be known that if a fraction of root sense a reduction of soil moisture, increased plant hormone i.e. ABA in the body cause stomatal closure. As a result, it can be said that information for investigating irrigation needs not only the relationship between water amount and crop production but also water condition in the plant itself.

For the reasons stated above, sap flow measurement, which measures water flow rate in the stem, is paid attention for this research. This method are easily automated, so continuous records of plant water use with high time resolution can be obtained. The purpose of this study is to establish sap flow measurement and it’s application way for irrigation management. The information of actual transpiration rate determined by sap flow measurement is taken up for irrigation criteria.

In Chapter 2, studies related to sap flow measurement and its application way are reviewed. A subject examined in this study is classified.

In Chapter 3, the steady-state heat balance method and the heat pulse method were compared in order to estimate transpiration and to evaluate their accuracy. First, the flow rates in a glass pipe in which the sap flow of plants was simulated were measured for both methods. The results obtained in the experiment showed that the heat balance method tended to overestimate at flow rates higher than 100 g/h. The heat pulse method requires a calibration coefficient to convert the measured heat velocity to transpiration rate. The experimentally decided coefficient was 0.76, while the physical properties of the materials used yielded a coefficient of 0.71. The flow rate evaluated by the heat pulse method agreed well with the discharge rate even with a flow rate higher than 100 g/h. The computed sap flow was compared with transpiration from potted corn plants. The calibration coefficient for the heat pulse method was effected by the positions of the temperature sensors in the stem, while in previous experiments with plants of uniform size, the calibration coefficient was not effected. The hourly variations of transpiration were estimated by using both methods at the same time without using the predetermined coefficient for the heat pulse method.

In Chapter 4, it is described that field experiments in a grain sorghum sand field conducted to measure evapotranspiration, transpiration and evaporation from soil surface independently. Evapotranspiration was measured by weighing lysimeter and estimated by meteorological approach. Sap flow measurements applied to measure transpiration and microlysimeter method was used to estimate evaporation beneath the canopy. The results shown in this study are an example where the spatial variability becomes remarkable in large field experiments, so careful investigation of the uniformity of sprinkler irrigation and initial soil moisture condition are essential. Sap flow measurements used in this study were available for separate estimation of transpiration and evaporation from evapotranspiration.

In Chapter 5, transpiration rate on soybean plant determined by heat pulse method is taken up for irrigation criteria. An interrelation between timing of irrigation and transpiration rate was investigated, the

results show that crop transpiration rate responded each irrigation sensitively. It is concluded that sap flow measurement is effective method for irrigation management.

The recent water situation considered, it is necessary to place emphasis on saving water in water management as well as system such a drip irrigation. In chapter 6, a study was conducted to develop and examine a irrigation scheduling to determine water requirement and irrigation timing simultaneously based on the data of crop transpiration in a green house condition. The heat pulse method on sap flow measurements was applied to obtain transpiration rate of sweet pepper in two experimental control and stress plots. The control plot was irrigated every one or two days to maintain unlimited soil water availability. Irrigation in stress plot was applied 1.2 times of total amount of transpiration after last irrigation when the transpiration rate was decreased 80% of the control one. The results indicated that total irrigation amount in stress plot was conserved 20% of the control plot without yield loss and allow that water management in this study was available method for water saving. TDR technique was also examined for estimating water requirement under drip irrigation condition. Transpiration value was estimated by the soil moisture depletion in the root zone of sweet pepper and separate evaluation of evapotranspiration derived from a weighing lysimeter. The estimated value was agreed well with measured transpiration rate by the heat pulse method.

In Chapter 7, automatic irrigation system based on heat pulse method is constructed and applied on sweet pepper cultivation. In this system irrigation is practiced when transpiration rate of sweet pepper is dropped against potential transpiration rate estimated by Penman equation from meteorological data in the green house. The system worked without any trouble. Another automatic irrigation system based on soil moisture content is also investigated using TDR moisture sensor. TDR moisture sensor has advantage to obtain spatial average moisture content while other soil moisture probes are intended for spot area. As a result, frequent small volume irrigation in the shallow soil depth was obtained in this system and root zone is concentrated near surface 20cm. In case of automatic irrigation system based on transpiration rate, better yield was obtained compared to former one. Root growth at deep soil layer 50-60cm was observed.

The priority of an irrigation technique based on actual transpiration rate employed in this study was confirmed because the total information of plant canopy and structure under ground related to water consumption is included. Additionally the transpiration rate include the information about a concentration of soil solution and root temperature, comprehensive irrigation will be achieved by conducting a minute investigation with these parameters.

Saline-Sodic Soil Reclamation under Continuous and Intermittent Ponding Conditions

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Soil salinization and sodification caused by salt accumulation are the common phenomena that manifest in irrigated agriculture in arid and semiarid regions, and reclamation of salt-affected soils has become an important tool for improving crop production. The irrigated agriculture developed in the 1950s in the Central Asia, is suffering severe secondary salinization. A large quantity of irrigated land has been abandoned due to salt accumulation which is threatening local environment and socio-economy. In this study, a site investigation on the current situation of soil salinization and its relation to irrigation practice was firstly conducted in the Kzyl-Orda region in Kazakstan, and the existing problem for soil salinization was clarified. For reclaiming the abandoned land, effect of leaching methods on salt-affected soils was studied in terms of desalinization and desodification both in the laboratory and field conditions, and the optimum reclamation practice for the local farmers was suggested.

Field investigation in Kzyl-Orda, Kazakstan showed that all the irrigated lands in this region were salt-affected to varying degrees. Deserted lands due to salinization make up 30% of the total irrigated area. Being influenced by the arid climate, solid gypsum differing in amount exists in the whole soil profile. It was found that the dominant salts in the cultivated lands differed from that for abandoned lands; the chloride salts were the major component in the deserted field, whereas sulfate salts were the main one in the cultivated field. Water and salt balance observation which was done during one growing season, showed that the subsurface water supply to the upland crops through excessive seepage water from rice fields, which was conventionally practiced in the current rice-based crop rotation system, was the main reason for causing soil salinization. To halt and reverse the current situation of salt accumulation, changing water supply policy while improving drainage of the irrigation block and conducting leaching will be advantageous.

Field leaching experiments were conducted to investigate leaching efficiency of intermittent ponding and continuous ponding on soluble salt removal. The leaching efficiency of intermittent ponding was higher than that of continuous ponding for the whole range of leaching. However, only 85% of initial salinity was removed by intermittent ponding by $D_w/D_s=1$. Since water resource is limited in Kzyl-Orda, and the need to prevent water table rising, leaching equation based on intermittent ponding is recommended.

Column experiments were carried out to study the effect of water application mode, soil texture, and salt type on leaching efficiency. The effectiveness of intermittent ponding and continuous ponding on desalinization and desodification of a nongypsiferous saline-sodic soil was compared in the laboratory experiment. To achieve the same degree in salinity reduction on a clay loam, intermittent ponding was more efficient that saved 60% of water compared with continuous ponding. In the well-aggregated soils, the fact that unsaturated water flow prevails and longer time for solute transport explains the higher leaching efficiency under intermittent ponding compared with continuous ponding where saturated water flow prevails. The leaching process was studied by measuring ionic concentrations in the effluent from the two leaching methods. There were more Ca^{2+} ions in the effluent of continuous ponding than that of intermittent ponding, which indicated that there were less Na/Ca and Mg/Ca exchange reactions taking place under continuous ponding. Comparing the exchangeable sodium percentage remained in the soil

after leaching, it was found that the effect of leaching method on desodification of this clay loam is more pronounced compared with that on desalinization. Intermittent ponding was 3 times more efficient than that of continuous ponding. Removal of adsorbed Na (desodification) of this nongypsiferous soil is determined by the following three mechanisms: 1) the exchange rate between Ca^{2+} and Na^{+} on the clay platelets; 2) intra-aggregate Ca/Na diffusion; and 3) supply of soluble Ca and removal of soluble Na which are determined by salt leaching. It was concluded that for the well-aggregated soil, desodification rate was more controlled by particle diffusion than mass transfer in the aqueous phase. Compared with continuous ponding, water flow velocity is lower under intermittent ponding which favors Ca/Na particle diffusion, therefore, desodification rate is higher.

The effect of soil texture and the presence of naturally occurring gypsum on removal of both soluble salt and exchangeable sodium under leaching conditions were also studied in the laboratory. Two soils were studied: a sandy loam from the A horizon and a clay loam from the B horizon of the experimental site in Kazakstan. Water application method greatly affected the efficiency of desodification of these two saline-sodic soils compared with that of desalinization. In the clay loam soil, intermittent ponding was more efficient than continuous ponding in both of desalinization and desodification of the soil. Whereas in the sandy loam, efficiency of desalinization was similar under the two leaching methods, and intermittent ponding was more efficient only in desodification of the soil. Salt leaching efficiency is determined by the uniformity of soil porosity which is a function of soil clay content, and the water flow in it. In the clay loam, there are more aggregates and more macropores between aggregates, and more micropores within the aggregates. Under continuous ponding, saturated water flow prevails and most of the leaching water with low salinity is conducted by macropores. Therefore, leaching efficiency for the bulk soil is low. Whereas under intermittent ponding, unsaturated water flow prevails, and most of water flow occurs in micropores, so leaching efficiency increases. In the sandy loam, unsaturated water flow prevails under both continuous ponding and intermittent ponding. Thus, the efficiency of desalinization in the sandy loam is similar under both leaching methods.

Ionic composition of the effluents showed that, gypsum dissolution was much enhanced under intermittent ponding irrespective of soil texture. In the clay loam, desodification rate was controlled by the rates of both particle diffusion and gypsum dissolution, and that of the sandy loam was controlled only by the rate of dissolution of gypsum because there is less aggregation and the intra-aggregate porosity is negligible. Both of these processes are slow and determine the Ca/Na exchange rate. Under intermittent ponding, water flow velocity in the soil is low which is favorable for both particle diffusion and gypsum dissolution, therefore, the efficiency in desodification of the two soils was higher compared with continuous ponding. However, under the same ponding condition (either continuous ponding or intermittent ponding), particle diffusion of Ca/Na is controlling the desodification rate which is negatively affected by the increase in soil clay percentage. Hence, desodification rate of soil is more efficient for the sandy loam than that for the clay loam.

Comparing laboratory and field experiment, both intermittent ponding and continuous ponding were less efficient in the field condition. The spatial variation of soil texture and substantial antecedent water content were considered as the reason.

To conclude, for reclaiming salt-affected soils in the Kzyl-Orda region, intermittent ponding is highly advised because it requires less water and the resulted less drainage can reduce the danger of ground water table rising.

Striga Germination Stimulants from Nonhost Plant Tissue Cultures

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Striga hermonthica (Del.) Benth is a root parasitic weed that reduces the yield of many important cereals in the semi-arid tropics in Africa. Vulnerable crops include sorghum [*Sorghum bicolor* (L.) Moench], maize [*Zea mays* (L.)], millet [*Penisetum glaucum* (L) R. Br.] and rice [*Oryza sativa* (L.)]. Yield losses from damage by the parasite are often significant, and complete crop failure is not uncommon. The life cycle of the parasite is closely linked to its host. In order to germinate, a *Striga* seed has to be in a warm moist environment for several days (conditioning) prior to exposure to an exogenous stimulant. In nature the germination stimulant is exuded by roots of host and some nonhost plant species. For successful attachment and parasitism, germination has to occur in close proximity to a host root. Induction of germination in the absence of, or away from a host root, suicidal germination, has been considered to have great potential for *Striga* control.

Several germination stimulants, mostly strigol and strigol-like molecules, were identified from host and some nonhost plants, and many of their analogues have been synthesized and proved to be effective. However, further work revealed their extreme instability in soils and limited usefulness under practical field conditions. In addition, strigol has never been established as a plant product. It is difficult to ensure the sterility of the media for hydroponically grown plants.

The primary objective of the study described in this thesis was to identify, using nonhost plants, stable *Striga* germination stimulants or leading compounds from which stable derivatives could be synthesized. The low recovery of germination stimulants from intact plants, the difficulty of attaining aseptic conditions in hydroponic plant cultures together with the extreme instability of the natural germination stimulants, isolated so far, promoted the use of tissue culture techniques in this study. Tissue cultures offer several advantages over intact plants. Tissue cultures are less laborious, require less space, allow control of the environment and eliminate problems incited by microorganisms. Furthermore, as is the case with several other secondary metabolites from tissue cultures, it should be possible to establish high-stimulant-producing cultures by manipulation of medium composition.

In this investigation *Striga hermonthica* germination stimulants from root cultures of *Menispermum dauricum* (DC.), a nonhost broad-leaved herbaceous plant renowned for production of biologically active compounds, were reported. The culture was selected on the basis of preliminary screening of several plant cultures, which were established and grown in the laboratory. The report includes studies on activity, production, extraction and chromatographic properties. The latter was compared to that of strigol, a natural *Striga* germination stimulant isolated from several plants, including host and nonhost species.

Filtrates and extracts from three calli, two cell suspensions, and five root cultures, previously established in the laboratory, were probed for *Striga* germination stimulants. Conditioned seeds of *S. hermonthica* and *S. asiatica* were used. Filtrates and extracts from *M. dauricum* root culture consistently demonstrated high activity on both *Striga* species. *M. dauricum* root culture and *S. hermonthica* seeds were selected for further studies.

The extremely low production of *Striga* germination stimulants by plants has been a major obstacle to isolation and further characterization of the compound. The need for establishing a high-stimulant-producing cultures is imperative. A high-stimulant-producing *M. dauricum* root culture was

established by manipulation of culture composition. A modified B5 medium (MB5) containing 35.7 mM nitrogen at a NO_3^-/NH_4^+ ratio of 1:42, 0.1 mM Fe^{2+}, 1.0 mM Ca^{2+}, 0.55 mM inorganic phosphorus, 0.28 mM inositol, 4.1 mM nicotinic acid, 3.7 mM pyridoxine hydrochloride, 14.8 mM thiamine hydrochloride, 1 ③M NAA, and 4% sucrose sustained root growth for a longer period and increased root biomass by > 30% and stimulant production by 5-fold, in comparison to the standard B5 medium supplemented with 3% sucrose and 1 ③M NAA.

Purification and isolation of the active substances from the culture filtrates were undertaken by adsorption of the stimulants onto XAD-4, desorption into methanol, solvent partitioning into ethyl acetate, and further separation on Sephadex LH20, C18 Sep-Pak Cartridge, preparative and analytical HPLC columns. Each step involved in the isolation procedure was followed by a bioassay using conditioned *S. hermonthica* seeds. Three stimulants were detected in the filtrate. On HPLC the major stimulant showed similar chromatographic behavior and co-eluted with authentic strigol. Furthermore, its UV absorption was similar with those reported for authentic strigol and strigol-like molecules. Its mass spectrum showed a similar fragmentation pattern to that reported for strigol. It was concluded that the major *Striga* germination stimulant produced by *M. dauricum* root cultures is strigol or a strigol-like molecule.

In this study, albeit no novel *Striga* germination stimulant was isolated from *M. dauricum* root culture, the investigation represents the first report on isolation of strigol or strigol-like molecule from plant tissue culture. Moreover, it provides unequivocal evidence that strigol and strigol-like molecules are of plant origin.

Non-destructive Measuring Method for Root System Using Acoustic Emission Sensors

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Continuous measurement of root development is important for evaluating its contribution to water and nutrient uptake as well as its responses to changes in soil environment. Various non-destructive methods have been developed for studying the distribution of root systems *in situ*. Some of these methods are based on a rhizotron or mini-rhizotron which observe root growth through a glass wall facing soil profiles. Solution, mist and agarose gel culture are used for direct measurement of root development. Recently neutron and NMR methods have been applied to follow root growth. Disadvantages of the transparent wall methods, however, are that some of the roots may be influenced by the soil-glass interface and do not reflect their actual development under field conditions. The shape of root system in solution, mist and agarose gel culture is different from that under field conditions. Neutron radiography and NMR have limitations in a sample size and resolution. The AE method has the advantage of obtaining information about the source of the AE pulses with time, when the events are actually occurring.

Non-destructive method for the measurement of roots in soil was developed using acoustic emission (AE) sensors for (1) vertical and spatial elongation of single root and (2) root distribution on vertical soil plane.

1. Non destructive method for root elongation measurement in soil using acoustic emission sensors.

(1) Vertical measurement of single root elongation.

Germinated maize seeds with a 2 cm radicle were transplanted in a container (200 % 100 % 5 mm). Four AE sensors were vertically set on the side wall of a stainless container at about 15 mm intervals. AE counts were recorded during growing period. AE counts increased as the root tip approached the sensor. The relative AE count (Ri) calculated from the values obtained from two sensors, vertically placed 15 mm apart, was only slightly influenced by the root elongation rate, soil water contents and soil bulk density. Relative AE count linearly correlated with the distance between the root tip and the center of the upper AE sensor. Accordingly the root tip position could be estimated using the equation. Calculated values for root elongation were comparable to those obtained from actual measurements.

(2) Spatial measurement of single root elongation.

A container (15 % 15 % 200 mm) was constructed from stainless steel plates. Three AE sensors were vertically mounted on each of the four side planes at 15 mm apart. Pre-germinated maize (*Zea mays* L. cv. Snowdent) seeds of 2 cm radicle length were transplanted in the center of the container. Spatial root tip position was expressed by the three axes (x, y, z). Relative AE counts on x, y and z axis (RxP, RyP and RzP) were obtained from three sensors on the same and opposite planes as a fraction of total AE counts on both side of this plane. RxP, RyP and RzP were linearly related to root tip positions on x- and y-axis. Spatial root tip positions can be estimated by the relative AE counts using this regressing equations. Thus, spatial root tip positions were expressed as a function of time. The trajectory of root tip position estimated by AE sensors was consistent with that obtained from actual measurements after excavation of the root from soil. This method can measure three-dimensional oscillation of root tip movements in the soil.

2. Non-destructive method for root distribution on vertical soil plane using acoustic emission sensors.

Observation plane (40 × 40 cm), made of steel mesh was installed in the root box perpendicular to soil surface at 15 cm apart from an edge. Seedlings were transplanted at the center of the box. The

observation plane was composed of sixteen grids (10 × 10 cm). The wave guide with an AE sensors were installed at the center of each grid. AE counts were recorded every ten minutes for a period of 40 days. Thereafter, the observtion plane was excaved carefully and the roots intersecting the observation plane were cut at 5 mm from the observation plane. The roots that had come into contact with the sensor and appeared on the observation plane, were counted in each grid and their diameters were measured by a caliper. Number of these peaks were in agreement with the maize primary root number contacted with the wave guide. The primary root number (X) contacted with the leader had a linear relationsip with the nodal roots number observed on the vertical plane. Significantly, the peak number of AE counts had a linear relationship with the root number in the grid on the vertical plane. Therefore, the root number in the grid on the vertical plane was estimated from the peaks number of AE count time course using this linear regressing equation.

In conclusion, this study established a new non-destructive method for root system measurements using AE sensors. The method has high potential for further development to overcome the limitations which usually hinder the continuous measurements of entire root system for prolonged periods during the plant growth. Certainly, the establishment of the AE method, with the capacity for measuring the spatial root elongation and root distribution and dynamics in the soil profile, will lead to a better understanding of the root growth and development interactions with the various environmental factors in the field.