Development of Soil Sampling System for variable rate application of fertilizer

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Introduction

Precision agriculture, also known as site-specific crop management, has attracted interest for following reasons: (1) social concern regarding environmental problems such as ecosystem damage and ground water pollution from the heavy use of agricultural chemicals that was seen as necessary to increase yields to feed rapid increasing populations on a limited amount of arable land, (2) global demands for environmentally safe agriculture, (3) pressure to strengthen the value of agricultural products to survive in competitive global markets, and (4) labor shortage due to a decreasing and aging rural population. These factors are driving the change of traditional agriculture to precision agriculture in Korea perhaps more than in North America, Europe, and Australia where precision agriculture has become well established.

First step to Korean precision agriculture was to collect field data and address the within- and inter-field variability, and investigate the inter-relationships between factors limiting crop yield. Activities have been mainly focused on rice production since rice is a major crop to feed the population. Site variables in interest are soil properties, crop growth status, and crop yield. Since rice paddy fields are flooded and flat, agricultural scientists have hypothesized that spatial variability in yields and soils might be negligible. However, significant level of variability in rice yield and many soil nutrients, even in small Korean paddy fields(0.3 to 1 ha in size), has been observed. Rice yield variations between high-yielding and low-yielding areas were about 2:1 in the small sized paddy fields. Spatial patterns of several soil properties (e.g., CI, EC and P_2O_5) also showed within-field variability and were somewhat related to irrigation water flow.

Korean version equipments are under development as well as adoption of technologies from foreign countries. Some of them include field data collection platforms with the capability of logging GPS (Global Positioning System) positional information along with sensor readings, soil sampling devices, sensors for soil properties such as organic matter content, soil hardness(CI), water content, and electrical conductivity(EC), and sensors for crop growth monitoring such as plant height, leaf coverage, and chlorophyll content. Rice yield monitoring systems and variable rate controllers for liquid and granular agrochemicals have been also studied.

This paper introduces precision agriculture and aims to attract the interest in Korean precision agriculture, focusing to sense soil properties and to use the measured the soil and yield information in variable rate application of fertilizer. The variable fertilizer application has been conducted on the base in the electronic map with the soil properties and positional information.

Development of soil sampling system

Design Concept

It is the basic work for precision agriculture to collect field data with positional information of each section(called as CELL) which will be treated as an identical area in soil properties. Traditional manual and/or automatic soil property sensors and detectors may take so much time to collect the data and may acquire only one or two piece of soil information. Thus soil sampling system which can sample test soil easily for physical and chemical experiments and is able to sense automatically the basic physical soil properties such as CI, EC and moisture contents, should be developed.

The soil sampling system should have the following simple and efficient functions for precision agriculture: to collect soil information quickly, to sample test soil in simple process, and to acquire positional information using GPS. The volume of each test soil collected to 200 mm in depth from the surface should be more than 100cm^3 for laboratory tests. The soil hardness measuring device is required to have load capacity of 3,000N, to measure the penetration resistance to 450 mm in depth, and to move into the soil constantly at one of the setup speeds 10mm/s, 30mm/s, and 50mm/s. The cone, tip of the cone penetrometer, is manufactured following the ASAE Standard(2003). The operation program is designed to control the soil sampling device and the soil hardness measuring device, to interpret the signals from GPS, to display the acquired soil properties with positional information, to print out the basic information of the CELL where the test soil is being sampled, and/or to store all/some obtained data into a file.

Detailed Design and Manufacture

The soil sampling system could be divided into three major parts; soil sampling device, soil hardness measuring device, and electrode for EC and moisture contents. The system was mounted to 3-point hitch system of a tractor. Soil sampling device was designed to sample test soil more than $100cm^3$ in volume to 200 mm in depth. After the tube was filled fully, the sampling device was pulled out of the soil and the label with soil information and positional information from GPS was attached on the tube. The soil sampling tip was shaped as saw teeth to penetrate easily into soil. Figure 1 in the next page is the schematic diagram of soil sampling system.

Hydraulic system was capable of controlling the working devices, and was composed of one 3-position 4-port directional valve, three ON/OFF valves, three flow control valves, three hydraulic cylinders, and four relief valves. The directional valve was set to push down and lift up the hydraulic cylinder. The control system has a quick return circuit for minimum time to initial status. Operating power was provided from the hydraulic take-out port of the tractor. The hydraulic oil from the port entered the hydraulic cylinder and the hydraulic motor individually to push the soil sampling tip into soil and to cut the soil. The hydraulic motor was operated simultaneously with the hydraulic cylinder, and the rotating speed was in the range of 100~180rpm. Cylindrical soil sampling tip could be penetrating vertically into soil at approximate 30cm/s with elongation of the hydraulic cylinder, and sample tube was being filled with the cut soil. The oil also was the source to operate the soil hardness measuring device and electrode for EC and moisture contents. Maximum hydraulic force loaded to penetrating device was about 3000N, and the relief pressure was set about 4.5MPa so that the hydraulic system could not be damaged for a very firm soil layer or stones in soil. Figure 2 and Table 1 show the schematic diagram of the hydraulic circuit and specifications of the hydraulic components respectively.

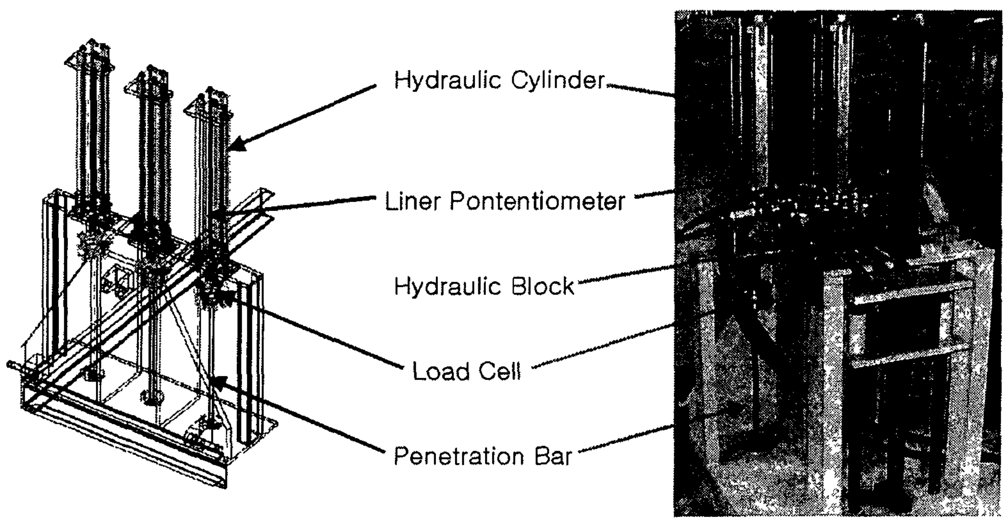

Figure 1. Schematic diagram of soil sampling system.

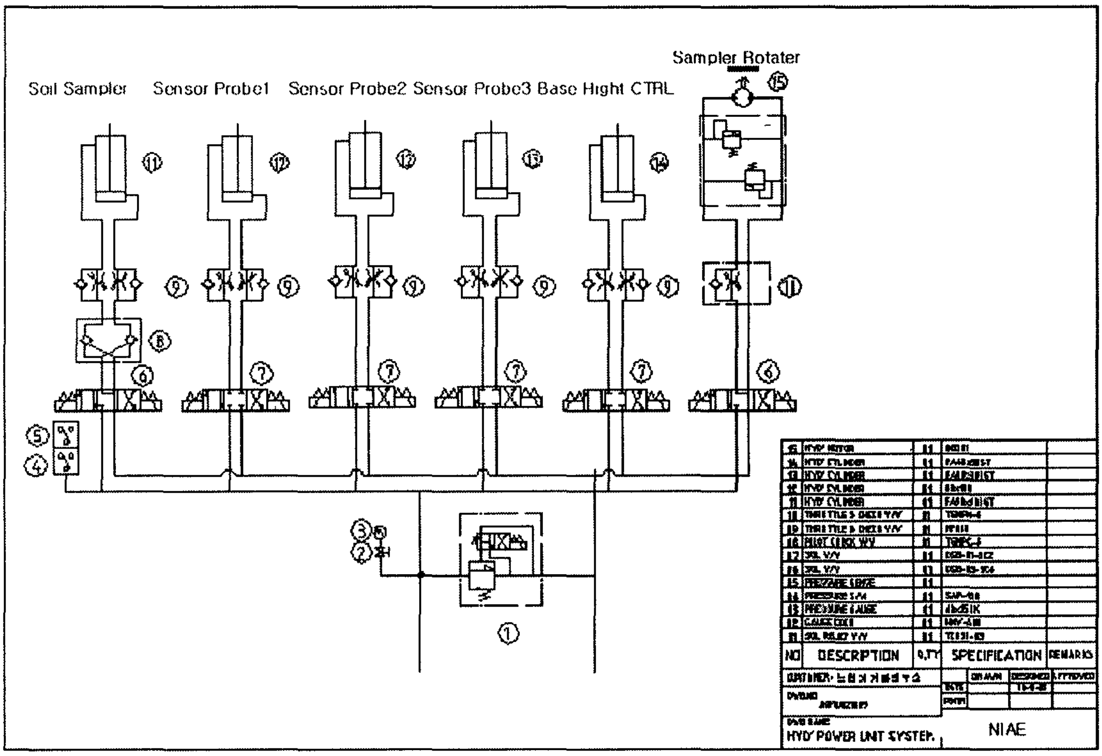

Figure 2. Schematic diagram of hydraulic control system.

Table 1. Specifications of the hydraulic control unit.

Hydraulic components	Specifications
Single-strike cylinder	Displacement: 500 mm Inner diameter: 30 mm
3-position, 4-port directional control valve	Maximum pressure: 15 MPa Maximum frequencies: 15 CPM Temperature: 5~60 °C
Flow control valve	Maximum pressure: 10.5 MPa Flow rate: 0.03~2 L/min Temperature: 5~60 °C
Relief valve	Pressure: 7~70 MPa Temperature: 5~60 °C

Soil hardness is defined as the extent of the firmness of soil, and the hardness was measured as cone index(CI) using the developed soil hardness measuring device. The device measures the cone index of the near point sampled by the soil sampling device.

The soil hardness measuring device was composed of penetrating rod, hydraulic control system, linear potentiometers and loadcells. Maximum penetration force is 3,000N, maximum penetration depth was 450 mm, penetration speed was set up one of 10mm/s, 30mm/s and 50mm/s, and the cone was manufactured following the ASAE Standard. Table 2 contains the sensors used in the soil hardness measuring device. The loadcell was mounted in the end of the penetration rod to detect the penetration force, and the linear potentiometer was used to measure the penetration depth.

Table 2. Specifications of the loadcell and the linear potentiometer.

Sensors	Specifications
Loadcell	Maximum pressure: 50 MPa Non-linearity: 0 1 % Excitation voltage: 10~15 V Temperature. -20~80 °C
Linear potentiometer	Maximum displacement: 500 mm Error: 0.05 % Limit velocity: 5 m/s Temperature: -30~100 °C

Development of map-based variable-rate fertilizer applicator

Design Concept

Current fertilizer applicators operate at uniform application rate under constant working conditions. These machines are not suitable for the precision agriculture. Thus a commercial fertilizer applicator should be modified or a new fertilizer applicator should be developed for variable application based on an electronic map with soil information collected by the soil sampling system. The cost- and time-efficiency is limited to modification of a commercial fertilizer applicator. The machine is a side dressing fertilizer applicator attached to a rice transplantor. The application rate could be controlled appropriately by a variable-speed DC motor. Control signal for the motor would be made by a microprocessor connected to a host computer with the field map. The required data of the machine for variable application are positional information, travel speed, working status, and fertilizer discharge volume per revolution of the motor. The positional information of the machine would be received from GPS and actual travel speed would be estimated by signals from a rotary encoder. The limit switch could detect whether the rice transplantor is in operation or not. Fertilizer discharge rate could be determined in laboratory experiment.

Detailed Design and Manufacture

A commercial side dressing 6-row fertilizer applicator was modified so that the application rate could be controlled. The built-in power transmission device with a universal joint was removed and replaced with an electrical motor and gear box to control rotating speed of rollers discharging fertilizer. Selected unit was a DC motor (12 V, 40 W, and 3,000 RPM rated speed), and the speed of motor rotation was reduced to 25:1. Since control of individual rollers was not necessary, the control system was simplified by coupling six rollers to a motor (fig. 3).

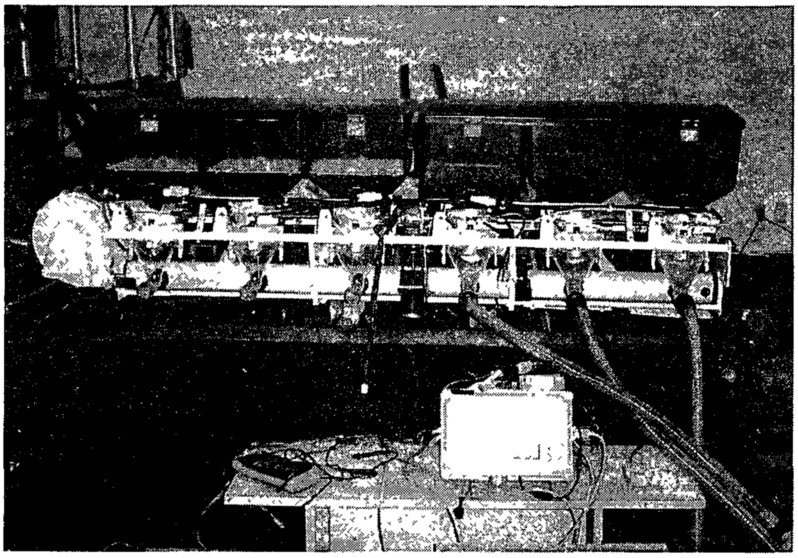

Figure 3. Modified side-dressing fertilizer applicator.

The system is for applying fertilizers during the transplanting operation. When the applicator turns around field edges, the seedling mount plate lifts and the transplanting stops automatically. A RUN/HOLD sensor was developed using a limit switch and tested to monitor the height of the seedling plate and turn the applicator off during turning and resume during transplanting.

Measurement of travel speed is critical for variable rate application as well as for uniform application but commercial sensing devices are often expensive. Therefore, a low-cost travel speed sensor coupled to an applicator wheel was fabricated and the performance was tested. The sensor used an encoder with a resolution of 60 pulses per revolution, to measure rotation of a wheel and estimate ground speed of the applicator. A 1:1 bevel gear was used to transfer the rotation of a wheel perpendicularly to the encoder. Material for the sensor was stainless steel considering moist operating field condition.

A PWM controller that input 12 V DC signal and output 256 levels of PWM signal was developed to apply fertilizer variably at different field locations. An electronic circuit was fabricated to interface and monitor the output of the controller using a computer. Input ports were also fabricated to test response of a RUN/HOLD sensor and performance of a travel speed measuring device. A motor driver was constructed to operate the motor to the output signal, and combined with the PWM control unit.

Since the variable rate applicator is for "slow release" fertilizers, a brand produced by the NAMHAE Chemical Corp. (Shinabro II, 22-10-10+2) was selected as a nominal test fertilizer. Diameter and bulk density of the fertilizer was analyzed.

An application recommendation map was constructed through an electronic mapping program, and the information was transferred to the applicator. Performance of the variable rate application was evaluated if the recommended amount of fertilizer was applied using the PWM controller. Algorithms to generate location information and corresponding target amount of application were added to the mapping program and simulation was conducted.

Results and Discussion

<u>Soil Sampling System</u>

Tractor stopped at the location where test soil should be sampled and the soil properties measured simultaneously, and the developed measuring system was taken down, and then the soil information was acquired. About 25 seconds to 30 seconds was required from handling the hydraulic lever for operating the soil sampling device to the sampling the test soil. Even in the hard soil, consumed time was not so different from the time in the soft soil. The amount of the filled soil into the test soil tube, however, varied in soil type and moisture contents to about 30~100% of the required volume. Especially in the dry sand soil with less than moisture contents of 10%, soil filled in the tube came out of the tube while the device was being pulled out, and the filling rate was less than 30%, which was not sufficient to analyze the soil. The soil sampling device should be improved to get the filling rate sufficient irrespective of soil type and moisture contents.

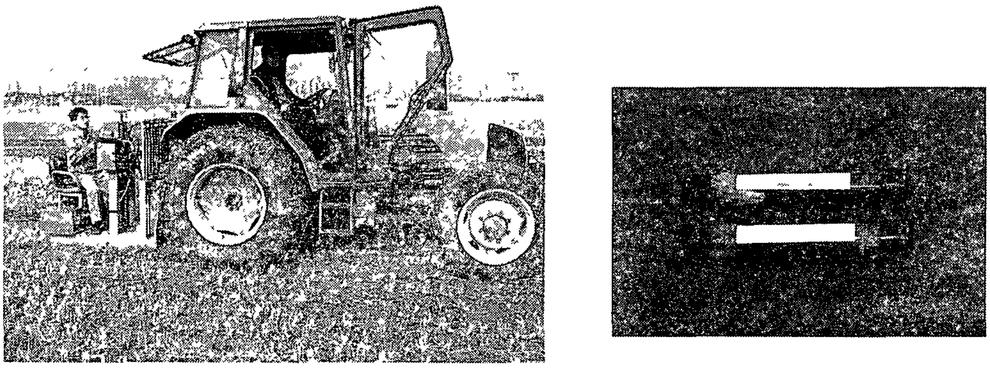

Figure 4. Operation view of soil sampling system and sampled test soils.

Using a cone penetrometer(SR-2) manually operated, the measured values might have a big error because of varying penetration speed and low readability of the indicator, and first of all the operation spends a lot of time. But the trend of the soil hardness along the depth could be referred to evaluate the developed soil hardness measuring device. Figure 5 and table 3 show comparison of cone indexes determined by the soil hardness device and a cone penetrometer(SR-2). The two graphs in fig 5 have similar trends and the developed device can be used to determine the soil hardness.

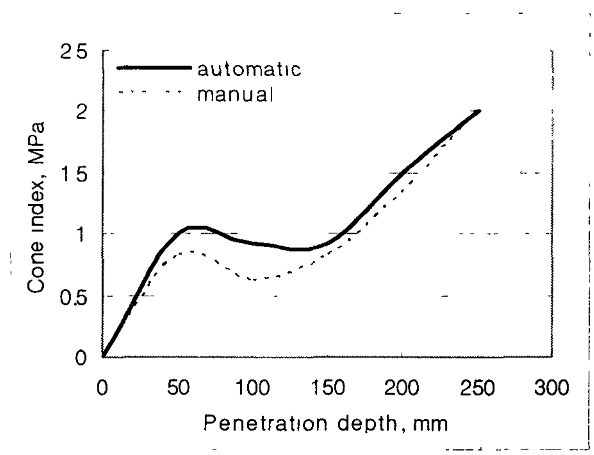

Figure 5. Comparison of CIs determined by the devepoled and a cone penetrometers.

Table 3. Results of measuring soil hardness using the soil sampling system.

Penetration depth(mm)	Soil cone index(MPa)									
	1	2	3	4	5	6	7	8	9	10
50	0.823	0.874	0.65	0.561	0.941	0.330	0.496	0.400	1.755	0.670
100	0.623	0.690	0.685	0.432	0.774	0.560	0.489	0.231	1.030	0.452
150	0.834	1.054	1.579	0.627	0.732	0.360	0.943	1.074	0.932	1.359
200	1.332	1 740	1.780	1.337	1.664	0.743	1.230	1.248	1.751	2.567
250	2.020	1.331	1.900	1.795	1.953	0.961	1.275	0.981	3.177	3.306
300	1 933	1.753	1.517	1.922	1.944	1.319	0.990	1.413	4.029	3.773

Variable Rate Fertilizer Applicator

The PWM controller generated output signal in 256 levels to change fertilizer application rate. At six levels of PWM duty output, fertilizer discharged through 6 rollers for 1 minute was collected. Figure 6 shows a linear relationship between PWM duty signal vs. application rate with a coefficient of determination (r^2) of 0.99. Assuming that travel speed of the applicator was 1 m/sec, the range of variable application was 15 to 75 kg/10a. For the slow release fertilizer with 22% of nitrogen, the range of nitrogen application rate was 3.3 to 16.5 kg/10a. When a single level of PWM duty was applied, accumulated amount of fertilizer against time showed a perfect linear relationship (r^2 = 1, fig. 7), indicating that the application rate could be maintained stably. Since application rate could be changed in 256 levels, application rate against small change in PWM duty output was also examined, and they were linearly related.

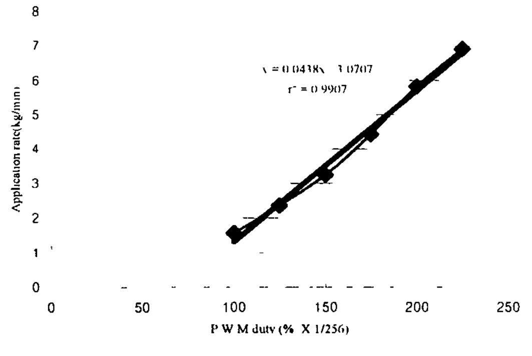

Figure 6. PWM duty signal vs. application rate.

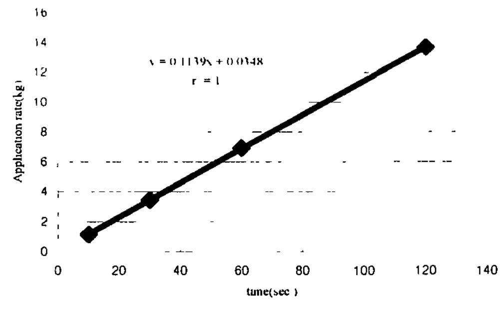

Figure 7. Operating time vs. accumulated amount of application.

Bulk density of the fertilizer was about 1 g/cm^3, and the diameters of slow release and rapid release particles were 3.96 to 4.41 mm and 4.02 to 4.24 mm, respectively. The selected fertilizer was considered good since, for actual application, application rate should be corrected for bulk density, and the optimum range of particles was 2 to 5 mm.

Travel speed of the applicator was estimated by measuring rotation of a wheel using encoder pulses, instead of measuring the engine RPM, since the applicator used a continuously variable HMTs (Hydro-Mechanical Transmission). Results of field tests indicated that the encoder output and travel speed were linearly related ($r^2 = 0.97$), and that the sensor could be used to correct application rate considering a slip ratio.

Based on field information such as amount of nutrients in soil samples in previous years, a target fertilizer application map corresponding to within-field locations was created on an electronic map. And an interface between the application map and the variable rate application unit was constructed and the performance was evaluated through simulation. The PWM output level generated by the controller and the target application rate showed a near perfect linear relationship ($r^2 = 0.99$), indicating a favorable performance of the system.

Figure 8 is the results of the simulation. Target application rate was displayed at the bottom of the map control signals were generated at 1 Hz, and application was stopped when the applicator was located out of the field.

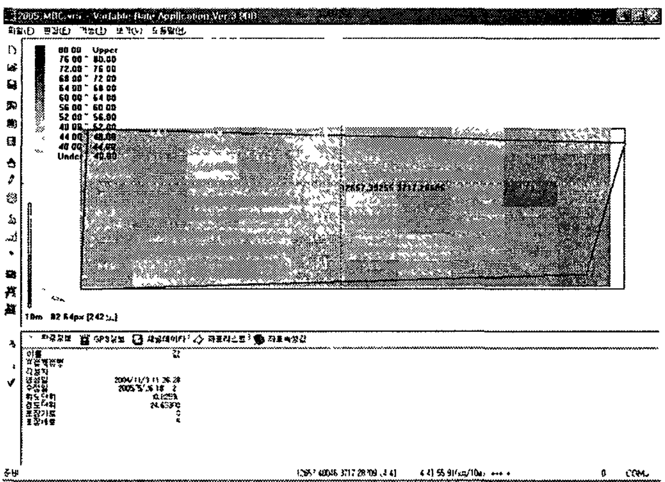

Figure 8. Results of simulated variable rate application, interfaced with and displayed on an electronic map.

After the basic study and the necessary tests in the laboratory were finished, the prototype applicator was attached to the experimental rice transplantor and the operation test in the field was conducted(fig 9.).

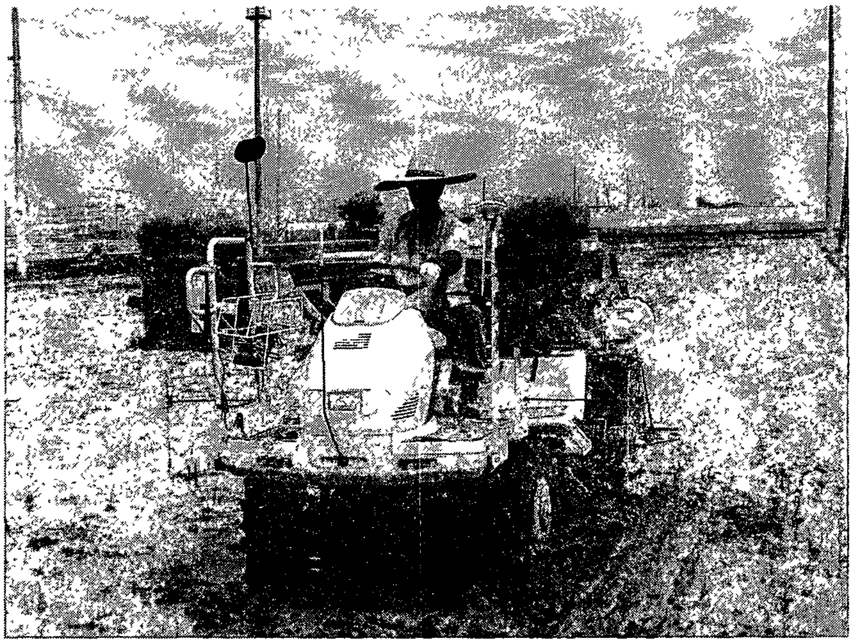

Figure 9. Field test of variable-rate fertilizer applicator

Conclusions

For precision agriculture, soil information is necessary for decision making of variable prescription. Current analysis method, however, needs a lot of efforts and time, and application of precision agriculture must be limited. We developed a useful system which measures soil properties in short time with simple structure and easy controllability. The soil sampling system consisted of the following three parts: soil sampling device(soil sampler), soil hardness measuring device and electrode measuring electric conductivity(EC) and moisture contents. The system was mounted to the 3-point hitch system of a tractor. The tractor was located a site and soil sampler sampled test soil in the following processes: the probe was pressed into the soil to 200 mm in depth by the hydraulic cylinder, and rotated by the hydraulic motor. The cut soil was filled into a plastic sample tube by $100cm^3$, and the probe was pulled out of the soil. Hardness measurement device was composed of two cone penetrometers, two loadcells, two hydraulic cylinders and two linear potentiometers. The cone penetrometer penetrates into the soil as the hydraulic cylinder was provided hydraulic oil. The penetration force was measured by the loadcells as the penetration depth was detected by the linear potentiometer by 450 mm in depth. Penetration speed was calculated using the depth and the measured time. EC and moisture contents of soil were measured by electronic pole which emited two microwaves whose wave lengths were 10MHz and 100MHz respectively. All acquired data were stored into a file in the computer with positional information from GPS. It was possible to take a soil sample in 46 seconds. Automatic soil hardness measuring device indicated less than 5% as error compared to data from manual soil hardness measuring device. The soil sampling system should be improved to get the filling rate sufficient irrespective of soil type and moisture contents.

The basic study to develop a side-dressing type variable-rate fertilizer applicator was conducted and the field test was made. A commercial 6-row side-dressing type applicator was modified to facilitate an electronic motor control. Application recommendation map was created using an electronic mapping program by combining within-field locations and the site-specific fertilizer requirements. A PWM control algorithm was developed to change the motor speed, resulting in change in fertilizer application rate, to meet the requirements received from the electronic recommendation map. For accurate control of the applicator, several sensors were used to measure travel speed, remaining fertilizer amount, and RUN/HOLD status. Application fertilizer rate vs. PWM output level showed a good linear correlation (r^2=0.99). After the laboratory tests, the prototype applicator was attached to the experimental rice transplantor and the operation test in the field was conducted. Further study to evaluate the integrated system in various field conditions is necessary to improve the application.

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