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원추지수 프로파일을 이용한 토양다짐 분석

Analysis of Soil Compaction Using Cone Index Profile

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1. Introduction

Soil compaction and the layers restricting crop growth need to be managed and minimized. Korean paddy fields have been conventionally subjected to uniform-depth tillage over the entire field, and the depth was limited up to only about 20 cm. These uniform shallow tillage practices have caused development of restrictive layers (e.g., hardpans), and there has been a need of soil management practices beneficial not only for crop production, but also for agricultural sustainability and the environment. Variable depth (and time) tillage based on site-specific soil physical characteristics such as degree of compaction and depth to restrictive layers would reduce tillage energy and increase crop yield. In a study on variable-depth tillage that changed tillage depth based on CI (Cone Index, MPa) values collected before the tillage operation, approximately 75% of the field area required tillage to depths shallower than the conventionally accepted uniform tillage depth, and energy savings of 42.8% and fuel savings of 28.4% were achieved with variable-depth tillage compared to conventional uniform- depth tillage (Gorucu et al. 2003). The overall objective of this research was to recommend soil management (or tillage) depth based on physical properties of soil for Korean paddy fields. Two specific objectives were (1) to investigate variations in soil physical properties and strength for Korean paddy fields, and (2) to recommend soil management depth nondestructively using CI profiles.

2. Materials and Methods

Korean paddy fields were surveyed and important physical properties of the soils were measured or determined. Thirty-three sites were selected over 16 soil series representing typical rice fields and covering 55.9% of the total Korean paddy field area, based on previous soil survey documents (NIAST 1992). The sites were surveyed from

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March to May 2005, before transplanting, for soil variables, and in October 2005 for rice growth. Variables selected for this research fall into 4 categories; (1) soil horizon: depth tothe hardpan (DH, cm) and tilled depth (DT, cm), (2) rice growth: rooting depth (DR, cm), number of tillering (TN) and leaf color (greenness, LC), (3) soil strength: soil hardness index (SH, mm), cone index, maximum CI (MCI, MPa), and depth to the MCI (DMCI, cm), and (4) other soil properties: clay ratio (CR), water content (WC, %), bulk density (BD, kg/m^3), and porosity (PR). Details on data collection methods are provided by NIAST (2000).

First, descriptive statistics and correlation coefficients were obtained in SAS version 8.2 (SAS Institute Inc., Cary, NC, USA) to address variability in the selected variables and to investigate relationships among the variables. Second, averaged CI profiles were investigated to recommend depths for soil management. CI profiles from 4 sites were removed for apparent problems. Soil management depth was recommended based on two different CI values: "measured" and "adjusted" CI values. CI can be expressed theoretically by Eq. 1 as a function of clay fraction, soil water content, and soil specific weight (Elbanna and Witney 1987).

$$CI = [K_c C_r e^{-n\Theta/(1+C_r)} + K_\Phi \gamma/(1+2C_r)] e^{\pi/(1+2C_r)} \quad (1)$$

where: CI = cone index, MPa

C_r = clay ratio (ratio of clay content to silt and sand content)

K_c, K_Φ = cohesive and frictional coefficients, 3.62 and 6.63 x 10^{-3}, respectively

n = exponent, 0.1; Θ = soil water content, % w/w; γ = soil specific weight, kN/m^3

Finally, depth to be managed or loosen were defined as 'soil management depth', and recommended based on both the measured and adjusted CI profiles. Rules used for the recommendation were: (1) management depths recommended were 10, 20, and 40 cm considering typical tillage practices for Korean paddy fields, (2) the critical CI value restricting rice growth and root development was set as 1 MPa (Cho et al. 1983), and (3) restrictive layers thinner than 4 cm were ignored (Gorucu et al. 2003).

3. Results and Discussion

Variations in and Correlations among Soil Physical Properties. Descriptive statistics for soil horizon, rice growth, soil strength, and other soil properties were summarized in Table 1. Examination of the data showed considerable spatial and vertical variations in all of the surveyed field variables, and for the following parameters the maximum values were greater than double the minimum values: DT, DMCI, MCI, SH_shallow, DH, CR, WC_shallow, WC_deep. Taking the variations and site-specific soil conditions into account would be useful when developing soil management strategies for better productivity and sustainability of agriculture.

Results of correlation analysis showed significant (<0.1) correlations among the field variables. MCI showed significant positive correlations with SH and BD, and negative correlations with TN, WC, and PR, indicating that soil conditions could be improved by reducing soil strength or CI levels. DT had significant negative correlations with soil strength (r=-0.62 with SH_shallow), and positive correlations with existence of restrictive layers (r=0.66 with DH), available amount of water (or nutrient movement; r=0.43 with WC), and resultantly with rice growth (r=0.87 with DR; r=0.62 with TN). DMCI showed a significant positive correlation with DT (r=0.60), and similar relationships with other variables as DT did. Based on these results, it was concluded that (1) variations in field variables were interrelated, (2) soil conditions and rice growth could be improved by tillage operations reducing soil strength, and (3) tillage practices could be recommended based on CI values.

Recommendation of Soil Management Depth. CI profiles observed from the typical Korean paddy fields were generally grouped into four types as shown in Fig. 1. For some sites, CI values increased rapidly and exceeded 1 MPa after depths shallower than 10 cm, and the restrictive layer continued up to 40 cm (Type A). In some other sites, CI values were smaller than 1 MPa or ignorable restrictive layers were shown at shallow depths and restrictive layers to be managed started at relatively deeper depths around 20 cm and continued to 40 cm (Type C). There were also type D that restrictive layers stopped at intermediate depths before 40 cm, and type B that layers limiting rice growth significantly were not existed. Examination of CI profiles confirmed possibility of site-specific tillage or soil management based on the variations in existence and degree of restrictive layers, and possible reduction in labor and energy for soil management.

Recommendation of tillage at different depths was summarized in Table 1. Based on measured CI, areas recommended to be managed were only 13.4, 16.8, and 95.3% of the total surveyed areas, and volume-based ratios of the soil were 10.6, 18.9, and 51.6% for management depth of 10, 20, 40 cm, respectively. The area and volume ratios were slightly reduced when adjusted CI was used as basis of the decision making. These results indicated that time, labor, machine use, and energy for soil management could be saved. For example, based on measured CI, 86.6% of the paddy fields would not limit significantly rice growth up to 10 cm, and do not require 10-cm rotary tiller operation.

Adjusted CI values could be used to manage soils more precisely and save more inputs if information on soil properties such as clay content, bulk density, and water content is available. It was concluded that Korean paddy fields could be managed differently based on site-specific physical properties of the soils for economic and environmental benefits.

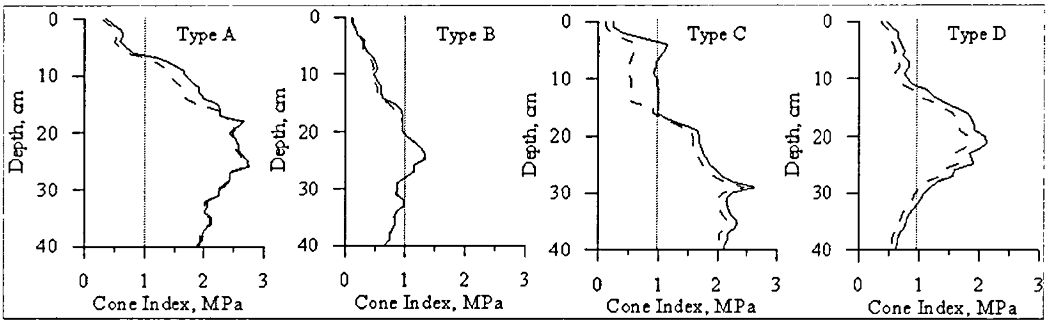

Figure 1. Types of the CI profiles observed in typical Korean rice paddy fields (measured and adjusted CI profiles are denoted as solid and dotted lines, respectively).

Table 1. Summary of recommended soil management depth.

	Depth of soil management (or tillage)		
	10	20	40
For measured CI			
Area, %	13.4	16.8	95.3
Volume, %	10.6	18.9	51.6
For adjusted CI			
Area, %	8.6	16.8	94.7
Volume, %	6.6	16.1	46.3
Example of management	Rotary tiller	Plow	Subsoiler

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