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The Changes in the Physical Properties of Soil with Tillage Methods (I)

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Abstract: In the study, the cone index, the cohesion and the internal resistant angle of soil were measured before and after tillage in order to suggest relative improvement in soil properties. The tillage methods tested in the study were five combinations of plow and rotary tillage operation and the experiments were performed on five selected test fields. The maximum tillage depth was 20 cm under the ground. The CIs for all the tillage operations were improved in comparison with those before tillage. The best combination of tillage operations for improving the CIs of soil was one plow operation followed by one rotary. After applying the tillage operations, the internal resistance angle reduced by 7-8 degree and the cohesion decreased up to about 1 N/cm^2 in comparison with those before tillage. We concluded that the cone index, the cohesion and the internal resistant angle of soil could be used as measures for representing the relative degree of tillage for a specific tillage operation. In addition, the study was useful as a basic research tool for developing an decision making system that determines an optimal tillage method with soil properties.

Keywords: Cone Index, Cohesion, Internal Resistant Angle, Tillage Operation

Introduction

In general, a proper soil condition for plant growth relates to moisture movement with porosity, root penetration toward the soil portion containing a lot of nutrient, and rootage for keeping up plant stems on the ground. It is very difficult to suggest the best soil condition because such soil factors are significantly correlated to one another. No absolute indexes have been developed to determine whether soil condition is suitable for plant growth. The previous researches reported comprehensively that soil status appropriate for root developing depends on the degree of soil compaction influenced by tillage.

Havlin et al (1990). emphasized the role of soil as a rooting medium because the yeild of a crop is directly related to the availability of stored soil water. Furthermore, most of soil factors can be controlled for maximum productivity. In general, soil properties were quantified by sampling and analyzing through a series of laboratory tests including nutrient status, water content, texture, density, porosity, pH, cation exchange capacity, and organic matter. Such tests suggested the chemical and biological properties of soil in crop field.

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Soil electrical conductivity (EC) is associated with soil physical properties such as clay content, soil pore size and distribution, soil water content as a measure of the ability of a material to transmit an electrical current. In addition, Koolen and Kuipers (1983) reported that soil compaction is one of important factors for characterizing soil properties, and influenced by texture, water content, organic matter, temperature, and water movement in soil. There are changes in soil structure, cohesion and adhesion, pore space and density affecting the growth and development of plants when soil compaction increases.

Horn et al (1995) showed that the increased bulk density and penetration resistance of soil restricted development and growth of plant root. Thus tillage reduces soil strength to help plant root to reach water and nutrients in the soil. Varsa et al (1997). studied the effect of deep tillage on soil physical characteristics and corn root growth and production, and found that deep tillage reduced penetration resistance and bulk density, and resulted in increased corn yield.

The soil cone penetrator is often used to quantify soil strength with depth. A measure of soil strength, cone index (CI) provided by a cone penetrometer is defined as the force per unit base area required to push the penetrometer. Hummel et al (2004) measured simultaneously penetration resistance and soil properties such as soil water content and EC by using a cone penetrator and other sensors together. Raper et al (1999) developed a multiple-probe cone penetrometer that could be tractor-mounted in order to determine soil strength profiles across the row. Whiteley (1981) represented cone penetration resistance in the tillage layer s a function of clay ratio, cohesive and frictional coefficients, soil water content, and soil specific weight. The reduction of soil strength resulting from tillage operation have been evaluated by various measures indexing soil properties.

In the study, the cone index, the cohesion and the internal resistant angle of soil were selected as general indexes for representing the degree of tillage. The three indexes are the comprehensive soil variables determined by various soil conditions including the soil water content, and the kind, porosity and size distribution of soil. No absolute criterions of the indexes for a proper soil condition have been suggested at present.

Hence the cone index, the cohesion and the internal resistant angle of soil were measured before and after tillage in order to suggest relative improvement in soil properties. The tillage methods tested in the study were some combinations of plow and rotary tillage operation. The results of the experiments can be applied for representing the relative degree of tillage by a combination of tillage operations; that is, the relative change or improvement in soil physical properties by a combination of tillage operations. Based on the results, we could establish an absolute measure representing soil status appropriate for root developing. The study was performed as a basic research for developing an decision making system that determines an optimal tillage method with soil properties.

Materials and Methods

The cone index, the cohesion and the internal resistant angle of soil should be calibrated on soil moisture content because of their sensitivity on the factor. The study included the measurement of soil moisture contents at tillage locations. The soil moisture contents were measured in depth of 10 cm by a EC meter with a electrical probe before tillage. The measurement was performed 5 times at each different location in a tillage row to obtain the average value on the assumption that the soil moisture contents before and after tillage be same averagely in the measurement depth.

The cone indexes were obtained 5 times up to the nominal tillage depth of 20 cm at each different location by using a cone penetrometer before and after tillage. Like the cone index, the cohesion and the internal resistant angle were also estimated 5 times at different locations by using a vane tester, SR2 before and after tillage, and averaged for comprehensive analysis of the changes in soil properties.

In actuality, the cohesion and the internal resistant angle of soil can be calculated from a correlation relationship between the normal pressure against soil and the shear force associated with the pressure. They can be determined by the following equation when the pressure and the shear force are represented on X and Y axis, respectively.

$$\tau = \tan\theta \cdot \sigma + c \quad (1)$$

where τ=shear force, σ=pressure, $\tan\theta$=slope, c=intercept

Then the slope and the intercept of the correlated line represent the internal resistant angle and the cohesion, respectively. The fitness of the line was verified by R^2 value.

In comparison with the conventional tillage operation, five combinations of tillage operations were selected for the experiments along with no tillage; one plow tillage operation, one plow followed by one rotary, one plow followed by two rotary, one rotary without plow and two rotary without plow. The experiments were performed on five selected test fields in Eybbuk-Dong, Suwon, Yeoju, Seodun -Dong, Suwon (especially, two different fields), and Danwol -Dong, Chungju. In specialty, three indexes for the field in Eybbuk-Dong were collected in autumn to compare with those in spring for the other fields.

The measurement of the cone index, the cohesion and the internal resistant angle of soil as measures for representing the relative degree of tillage was a new approach used in the study. Thus a lot of preliminary experiments were performed, and some cautions suggested for reliable data collection as follows.

(a) Divide a test field into 2 m×2 m square lots and place the sampling point at the center of each lot to increase the randomness of soil data sampling.
(b) Acquire more than 5 data points of shear force and normal pressure in order to decrease an estimating error in calculating the cohesion and the internal resistant angle.
(c) The commercial devices for measuring shear force and normal pressure require two persons with full knowledge and stable skill in treating them. Thus need to practice how to use the device, and keep the two experimenters to measure the shear force and normal pressure until the end of the experiment.
(d) Remove other materials that interfere accurate measurement for reliable data collection, such as bits of straw

and grass at data collecting spot in the test field.

Results and Discussion

Based on the suggested procedure, the five combinations of tillage operations were performed in five test fields; Eybbuk-Dong, Suwon, Yeoju, Seodun-Dong, Suwon (field I and II), and Danwol-Dong, Chungju. In addition to the experiments, soil samples were collected at 5 different spots in each test field before the experiment, and analyzed in a laboratory as basic data for the soil properties of the test fields. Figure 1 and 2 show the soil condition of an experiment field and the measurement of EC values, respectively.

The average moisture contents in five test fields were comparatively uniform in the range of 34~36% with the standard deviation of about 3%. Thus the cone index, the cohesion and the internal resistant angle of soil were not calibrated with respect to soil moisture content. It was a very interesting fact that the soil moisture content of the field in Eybbuk-Dong, Suwon in autumn was similar to those of the other fields in spring.

Figure 3 and 4 show the variation in CI with depth on the test field in Yeoju and in Seodun-Dong, Suwon (field I), respectively. The maximum tillage depth was 20 cm under the ground. As shown in the figures, the CIs for all the tillage operations on two different test fields were improved in comparison with those before tillage. The degree of improvement increased with the depth; that is, the CI before tillage was about 3 times as large as that for one plow operation followed by one rotary at the depth of 15 cm.

The CIs for one rotary operation between the ground and the depth of about 7 cm were also improved, but slightly larger than those before tillage under the depth. The reason for this was that the plowing depth of only one rotary operation without plowing was only 7 cm due to the hardness of soil, and the operation itself had an effect on soil compaction under the specified depth, resulting in the increase of the CIs.

The best combination of tillage operations for improving the CIs of soil was one plow operation followed by one rotary. Unlike our expectation, the CIs for one plow operation followed by two rotary were slightly higher than that for one plow operation followed by one rotary on all the test fields. The result suggested that the porosity of the soil decreased and its resistance against the penetrometer increased because one plow operation followed by two rotary crushed down the soil excessively.

Fig. 1 The soil condition of an experiment field.

Fig. 2 The measurement of EC values. in Eybbuk-Dong, Suwon.

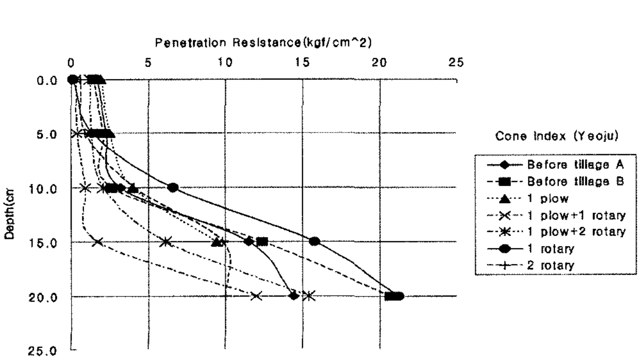

Fig. 3 The variation in CI with depth (Yeoju).

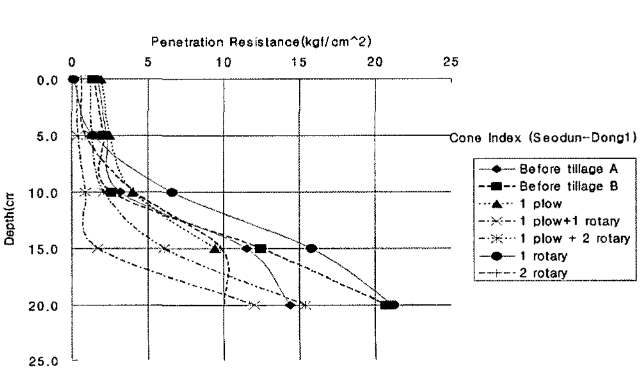

Fig. 4 The variation in CI with depth (Suwon, field I).

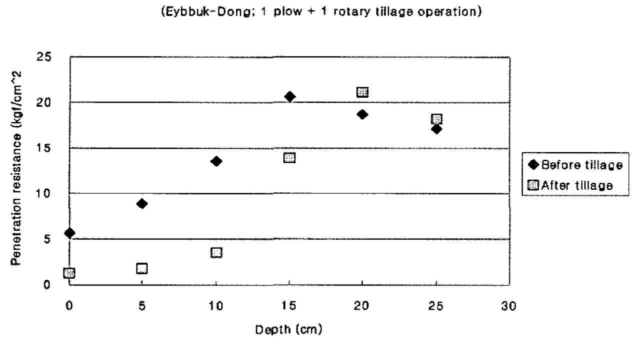

Fig. 5 The variation in CI with depth (Eybbuk-Dong, Suwon).

Figure 5 shows the variation in CI with depth for one plow operation followed by one rotary on the test field in Eybbuk-Dong, Suwon. The CIs increased with depth up to 21 kg/cm^2 at the depth of 15 cm before tillage, and decreased approximately by 75% (10 kg/cm^2) after tillage. Though the CIs slightly decreased under the depth of 15 cm as shown in the figure, the data supported that the hard pan of this test field would be located at the depth of 25 cm.

Figure 6 and 7 show the variation in the internal resistance angle and the cohesion on the test field in Yeoju and in Chungju, respectively. After applying the tillage operations, the internal resistance angle reduced by 7-8 degree and the cohesion decreased up to about 1 N/cm^2 in comparison with those before tillage. On the other hand, the indexes on the field in Seodun-dong, Suwon (field I) were improved only by 3 degree and 0.7 N/cm^2 because the kind of soil was sandy loam containing a lot of sand.

Unlike the above CI analysis, the internal resistance angle and the cohesion for one plow followed by one rotary operation was unexpectedly similar to those for the other combinations. This seemed to be compatible with the fact that the normal pressure and the shear force used in calculating the internal resistance angle and the cohesion were collected at land surface. The CIs at ground level were almost similar for all the combinations of tillage operations as shown in figure 3 and 4. The CI profiles suggested that the normal pressure and the shear force should be measured

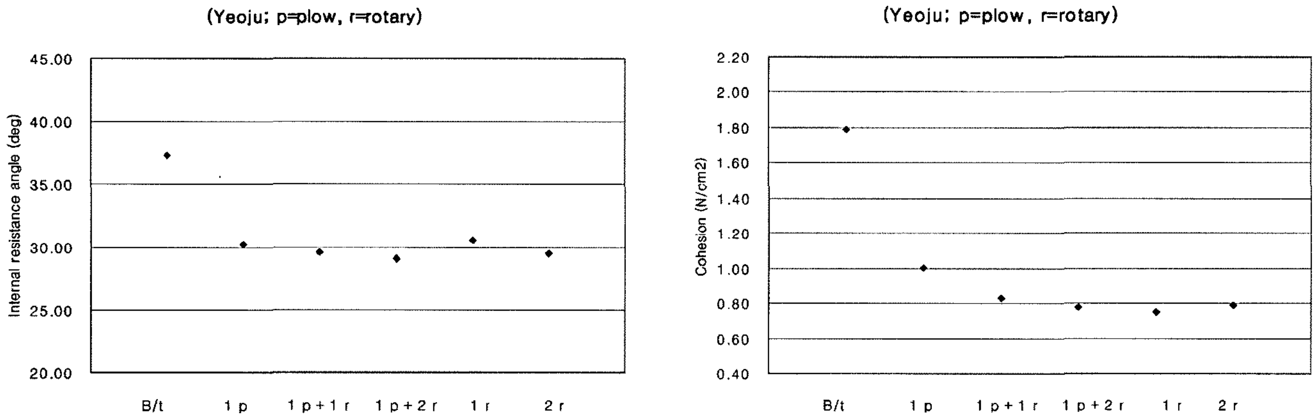

Fig. 6 The variation in the internal resistance angle and the cohesion (Yeoju).

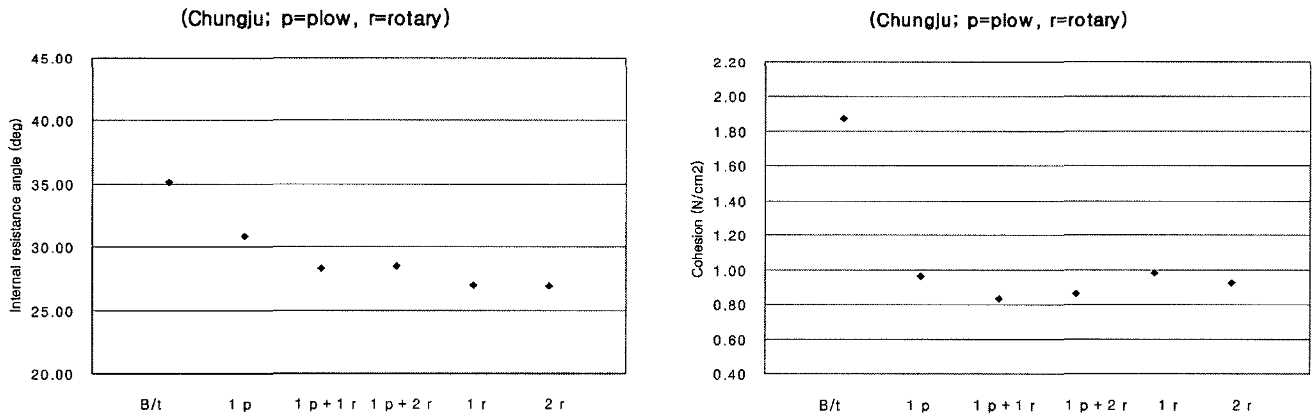

Fig. 7 The variation in the internal resistance angle and the cohesion (Chungju).

Table 1 Soil physical properties of test field (Yeoju)

Row/Rep. No.	Wet soil density (g/cm^2)	Dry soil density (g/cm^2)	Solid ratio of soil (%)	Liquid ratio of soil (%)	Air ratio of soil (%)	porosity (%)
A1	1.67	1.30	0.49	0.37	0.13	50.95
A2	1.73	1.33	0.50	0.40	0.09	49.75
A3	1.64	1.25	0.47	0.39	0.14	52.86
A4	1.88	1.47	0.55	0.42	0.03	44.62
A5	1.64	1.26	0.48	0.38	0.15	52.43
B1	1.73	1.35	0.51	0.38	0.11	49.01
B2	1.65	1.25	0.47	0.40	0.12	52.83
B3	1.66	1.24	0.47	0.42	0.11	53.33
B4	1.74	1.31	0.50	0.43	0.08	50.40
B5	1.72	1.32	0.50	0.40	0.10	50.31

at the depth of 15 cm under the ground based on the large distinction among the CI values at the depth.

Table 1 shows the soil physical properties of the test field in Yeoju, and row A and B in the table simply represent two different test rows in the test field. As shown in the table, the porosity of soil was in the range of 44 -53% even in one test field. The fact suggested that a method to adjust the indexes according to the non-uniformity of soil properties should be considered for precise analysis in future study.

Based on the above results and analysis, we confirmed that the cone index, the cohesion and the internal resistant angle of soil could be used as measures for representing the relative degree of tillage for a specific tillage operation.

Summary and Conclusion

In the study, the cone index, the cohesion and the internal resistant angle of soil were measured before and after tillage in order to suggest relative improvement in soil properties by comparing two measured values. The tillage methods tested in the study were five combinations of plow and rotary tillage operation; one plow tillage operation, one plow followed by one rotary, one plow followed by two rotary, one rotary without plow and two rotary without plow. The experiments were performed on five selected test fields in Eybbuk-Dong, Suwon, Yeoju, Seodun-Dong, Suwon (especially, two different fields), and Danwol-Dong, Chungju.

The maximum tillage depth was 20 cm under the ground. The CIs for all the tillage operations on the different test fields were improved in comparison with those before tillage. The best combination of tillage operations for improving the CIs of soil was one plow operation followed by one rotary. The CIs for one plow operation followed by two rotary were slightly higher than that for one plow operation followed by one rotary because one plow operation followed by two rotary crushed down the soil excessively, so that the porosity of soil increased.

After applying the tillage operations, the internal resistance angle reduced by 7-8 degree and the cohesion decreased up to about 1 N/cm^2 in comparison with those before tillage. On the other hand, such indexes on the field in Seodun -dong, Suwon (field I) were improved only by 3 degree and 0.7 N/cm^2, respectively because the kind of soil was sandy loam containing a lot of sand. The internal resistance angle and the cohesion for five combinations of tillage operations were similar to one another in the study. This seemed to be compatible with the fact that the normal pressure and the shear force used in calculating the internal resistance angle and the cohesion were collected at land surface. The CI profiles suggested that the normal pressure and the shear force should be measured at the depth of 15 cm under the ground, based on the large distinction among the CI values at the depth.

Thus we concluded that the cone index, the cohesion and the internal resistant angle of soil could be used as measures for representing the relative degree of tillage for a specific tillage operation. In addition, the study was useful as a basic research tool for developing an decision making system that determines an optimal tillage method with soil properties.

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References

Adams, M. L. and S. E. Cook. 1997. Methods of on-farm experimentation using precision agriculture technology. ASAE Paper NO.973020, Minneapolis, MN, USA.

Havlin, J. L., J. D. Beaton, S. L. Tisdale and W. L. Nelson. 1990. Soil Fertility and Fertilizers : An Introduction to Nutrient Management, 6th ed. Upper Saddle River, N.J., Prentice-Hall, Inc.

Horn, R., H. Donzal, A. Slowinska-Jurkiewicz and C. Van Ouwerkerk. 1995. Soil Compaction Processes and Their Effects on the Structure of Arable Soils and the Environment. Soil and Tillage Research 35:23-36.

Hummel, J. W., I. S. Ahmad, S. C. Newman, K. A. Sudduth and S. T. Drummond. 2004. Simultaneous Soil Mois ture and Cone Index Measurement. Transactions of the ASAE (in press).

Koolen, A. J. and H. Kuipers. 1983. Agricultural Soil Mechanics. Berlin, Germany, Springer-Verlag.

Raper, R. L., B. H. Washington and J. D. Jarrell. 1999. A Tractor-mounted Multiple-probe Soil Cone Penetrometer. Applied Engineering in Agriculture 15(4):287-290.

Varsa, E. C., S. K. Chong, J. O. Abolaji, D. A. Farquhar and F. J. Olsen. 1997. Effect of Deep Tillage on Soil Physical Characteristics and Corn (Zea mays L.) Root Growth and Production. Soil and Tillage Research 43: 219-228.

Whiteley, G. M. and A. R. Dexter. 1981. The Dependence of Soil Penetrometer Pressure on Penetrometer Size. Journal of Agricultural Engineering Research 26:467-476.