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Rotary Tilling and Ridge-Making Methods for Heavy Clay Soil

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Abstract

In wet rice fields with heavy clay soil, the decrease of the rate of soil pulverization and excess moisture injury are major constraints on the cultivation of vegetables as alternative crops. Deep tillage which is very important for the consolidation of the paddy field soil structure leads to the decrease of the soil pulverization and small clod rates, resulting in the increase in power requirement. In this study, implements based on a reverse-rotating tiller (up-cut rotary tiller) equipped with tines differing in length, were developed. The use of the implements enabled to perform deep tillage in the ridges and shallow tillage in the inter-ridge spaces. It became possible to cultivate soil and make ridges simultaneously. The working efficiency was 2–3 times higher than that by other methods. Also the trafficability of the implements in the inter-ridge spaces was improved. The developed implements did not require a large amount of power and did not lead to a decrease in the soil pulverization rate. The rooting zone of the ridges expanded and the soil water content inside the ridges decreased. Furthermore, the oxygen concentration in the ridge soil increased and cabbage yield increased.

Discipline: Agricultural machinery
Additional key words: pulverization, simultaneous work, up-cut rotary, deep tillage, cabbage

Introduction

Recently rice consumption has decreased and production has exceeded the demand. As a result, the Japanese government decided to reduce the number of rice fields by more than 30%. Rice can be cultivated in wet fields, whereas dry fields are needed for the cultivation of various upland crops.

The Hokuriku district is located in the center of northern Japan, and it faces the Japan Sea. Wet rice fields account for 90% of all the cultivated land in the Hokuriku region. Therefore, many wet rice fields must be converted to upland crop fields. However, for about 30% of Japan's rice fields, it is very difficult to convert them to upland fields because of the presence of heavy clay soil. In addition, in the Hokuriku region, the percentage of heavy clay soil is very high, and the amount of precipitation is also about twice that of the national average. These soil properties make it difficult to grow crops except for rice. Barley, soybeans, etc. have been cultivated as alternative crops to rice. From a profitability standpoint, it is also necessary to grow vegetables. In converted fields, barley and soybeans cannot be easily cultivated, and even more so vegetables. Heavy clay soil and abundant precipitation affect the trafficability.

Promotion of drainage by the use of underdrain, etc. and improvement of the soil physical conditions are effective in accelerating the process of conversion of paddy fields to upland fields over a long period of time. Since the effects of underdrain on paddy field conversion are not apparent immediately, immediate improvement of friability and crop growth environment by tillers and/or ridge-making machines, new tillage concepts, and con-

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struction of ditches, are very important[1,3,10].

In fields with heavy clay soil, which have not been converted for the cultivation of suitable upland crops, the rate of soil pulverization (percentage of soil clod weight passing through a 2 cm sieve to total soil weight) is extremely low in the case of deep tillage. However deep tillage is important for the improvement of the soil physical properties and extension of the rooting zone of the crops[6,7]. On the other hand, in order to grow vegetables in converted fields (wet rice fields converted to upland fields), it is necessary to construct ridges for drainage and the crops are planted on the ridges[2].

Objectives and approaches

Objectives of the current studies are to:

1) develop new rotary implements and ridge-making machines that can be used simultaneously;
2) conduct deep tillage without increasing the power requirement and without decreasing the rate of soil pulverization;
3) construct ridges in such a way that vegetable yield and resistance to saturation increase.

The fundamental approaches to the development of the rotary implements and ridge-making machine are as follows:

1) The ridge part is tilled. A conservation tillage system is adopted;
2) Soils with small clods are efficiently utilized (soils with a low water content between the ridges are well cultivated and small clods are being formed);
3) The use of a rotary tillage machine system in which the soil clod size becomes smaller (up-cut rotary tiller machine which rotates reversely, mounting system of the tines to the rotary tillage shaft being of the holder type).

The water content of the soil surface is comparatively low even in heavy clay soil, and the rate of soil pulverization increases[8]. Shallow tillage is effective only for increasing the rate of soil pulverization, but not for extending the vegetable rooting zone and improving the soil properties (Fig. 1). Therefore, by tilling deeper soil layers in the ridge where the crop grows, the tillage depth increases and the rooting zone of vegetables extends. And by tilling shallower soil layers between ridges where the crop does not grow, fine soil clods of inter-ridge spaces can be obtained. Since these clods move to the ridge surface, the number of clods with a small size in the ridge surface layers increases (Fig. 2).

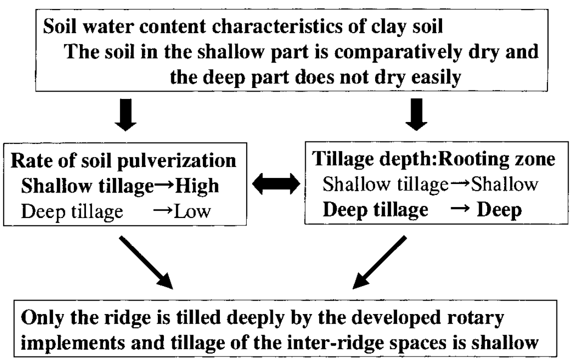

Fig. 1. Flow chart of heavy clay soil tillage

In heavy clay soil, to increase the rate of soil pulverization, the up-cut rotary device was used with the base machine to obtain fine clods compared to the down-cut rotary device[4,5,9,11]. The soil pulverization rate of the surface layers can increase even when the rate of soil pulverization is low by using the up-cut rotary (Fig. 3). Since the soil could be moved easily, the use of the up-cut rotary was effective for ridge-making. The rotary tillage shaft was improved into a tine mounting system of the holder type. The rate of soil pulverization was high, the mounting direction of the tine could be easily changed, and all the soil surface could be cultivated (Fig. 4).

Construction of the implements

Two types of implements, which differed in the size of the base rotary implement, were developed. For implement No. 1, a larger rotary was used for a base, and for implement No. 2, a smaller one. However, most of the other characteristics were almost the same. Each implement can be mounted on a tractor and PTO-driven. Implement No. 1 is mounted on 60 kW class tractors. Width is 217 cm, height is 104 cm, length is 205 cm and weight is 635 kg. The width for cultivation is 200 cm. Implement No. 2 is mounted on 30 kW class tractors. Width is 166 cm, height is 105 cm, length is 198 cm, and weight is 360 kg. The width for cultivation is 150 cm and the ridge width is 120 cm. Implement No. 1 makes ridges at an offset position of 40 cm from the rotary center. Implement No. 2 makes ridges in the center of the rotary. A rotary width of 150 cm is the minimum size for developing the implement, due to the power required and the width of the tractor. Fig. 5 shows the 2 types of implements.

The developed rotary tillage implements were equipped with tillage tines of different lengths in order to change the depth of tillage during cultivation. For the tine for tillage, the hatchet type blade was used. Standard tine with a radius of gyration of about 26 cm was attached at the ridge. The radius of gyration of a short tine was about 19 cm between the ridges. Since all the tillage

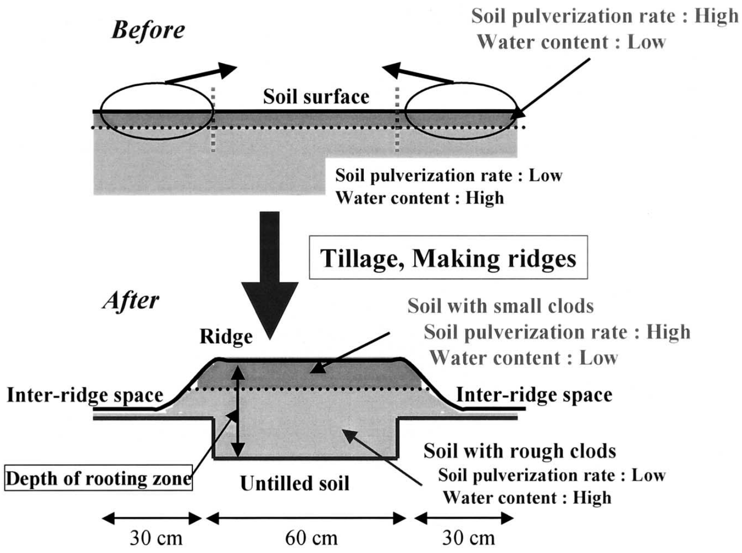

Fig. 2. Sectional view before and after ridge-making in heavy clay soil

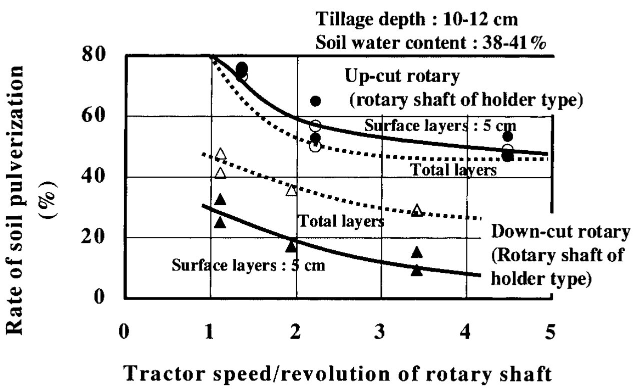

Fig. 3. Effect of up-cut rotary tiller on soil pulverization rate

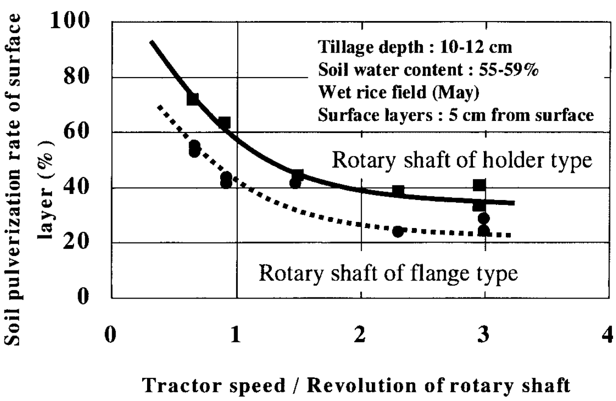

Fig. 4. Effect of mounting type of rotary tine on soil pulverization rate

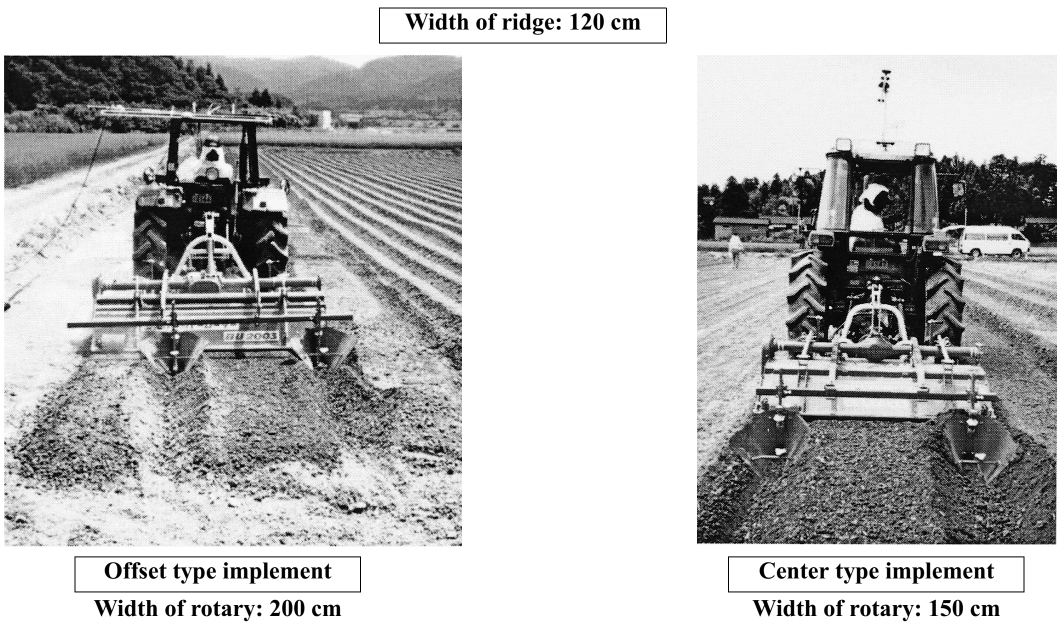

Fig. 5. Developed implements for simultaneous tillage and ridge-making

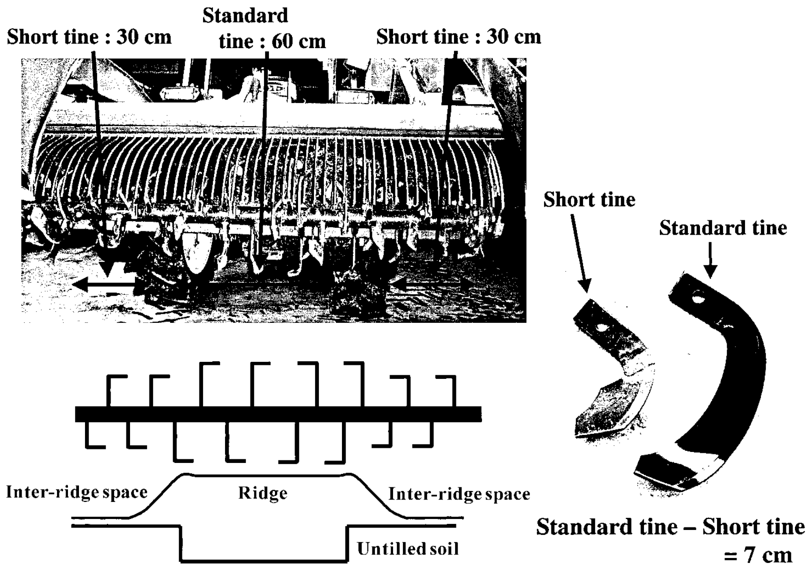

Fig. 6. Inner part of the developed implements and tines

tines bent toward the ridge center, the soil clods moved to that direction (Fig. 6). The rotary leveler plate was fixed to secure the height of the ridge. The smoother plates for oblique ridge were equipped with 2 ridge spaces in order to adjust the ridge shape after molding.

Materials and methods

Three kinds of ridges including the deep tillage ridge were made with the developed implements, and measurements were taken. The standard ridge was made by using a tine with the same length as that for the deep tillage ridge. A shallow tillage ridge was made by using a short tine at the ridge, and a standard tine for the inter-ridge spaces (Fig. 7).

The criteria for implement performance included ridge shape, tillage depth, soil pulverization rate of ridge (friability), soil water content, power requirement, working efficiency, travelling speed and penetration depth. In order to evaluate the effect of the deep tillage ridge, cabbage was transplanted in August and harvested in November. Matric potential of soil (pF) and oxygen concentration in the soil of the ridges were measured at depths of 10, 20 and 30 cm from the ridge surface.

The matric potential of soil was measured by using a porous cup with a pressure sensor. The oxygen concen-

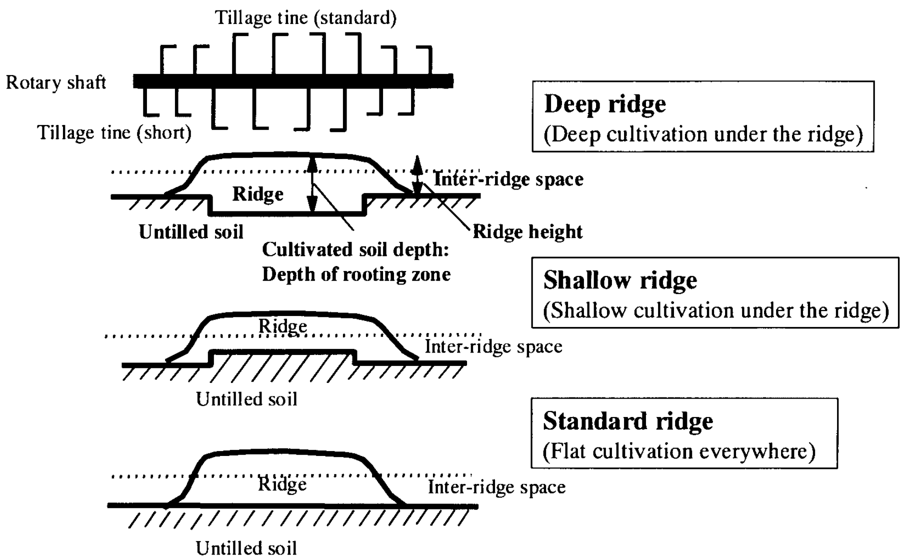

Fig. 7. Sectional view of experimental ridges

tration was measured with an O_2 sensor. The following data were obtained with implement No. 1 and the data obtained with implement No. 2 tended to be the same.

The soil in the experimental fields consisted of Typic Epiaquepts (Mottled Gley Lowland soil). Liquid limit of fresh soil was about 75%, plastic limit about 37% and clay content about 38%.

Results and discussion

Both implements could till and make ridges simultaneously and easily. The use of implement No. 1 (the larger of the two) showed that ridges could be made by using an implement with a width larger than the ridge itself. However, the ridge was tilled in only one direction. The use of implement No. 2, with a minimum size rotary, showed that the ridge could be tilled in two directions.

1) Depth of tillage and ridge shape

The depth of deep tillage under the ridges was about 14–15 cm, and that in the inter-ridge spaces was about 7–8 cm. The depth of standard tillage was about 11–13 cm. The depth of shallow tillage under the ridges was about 4–5 cm and that of tillage in the inter-ridge spaces was about 11–12 cm. Simultaneous tillage and ridge-making were possible for all the types of ridges. Also the ridge height after ridge-making was about 20 cm, while the ridge depth, from the ridge surface to the bottom of the cultivated ridge, was about 30 cm in deep tillage, about 20–25 cm in standard tillage and about 15 cm in shallow tillage (Tables 1, 2). The lower end ridge width was about 90 cm and the upper end ridge width was about 65 cm.

2) Rate of soil pulverization

The implements could till the soil and make ridge simultaneously. An up-cut rotary system was used in which the small soil clods were collected in the surface layers of the ridge. The soil pulverization rate of the ridge surface layers was high compared with about 20% for the non-simultaneous process (Fig. 8). Although the ridge-making operation was carried out after tillage by the up-cut rotary using a different process, the surface layers of soil with fine clods, were mixed with the lower layers of soil. The soil clods became larger and the rate of soil pulverization in the ridge surface layers decreased compared with the simultaneous operation performed with the developed implements. In addition, even when the tillage depth of the ridges was deeper than in the case of standard tillage, the soil pulverization rate did not decrease compared with the standard ridge, since the small soil clods at the surface between ridges were moved to the ridge surface (Fig. 9).

In general, when the rotary leveling flat plate is

Table 1. Depth of 3 types of ridges

	Deep ridge	Standard ridge	Shallow ridge
Height of ridge (cm)	18–21	18–21	17–21
Depth of rooting zone (cm)	28–30	19–24	15–16

Table 2. Power requirement and tillage depth of 3 types of ridges

	Deep ridge	Standard ridge	Shallow ridge
Power requirement (kW)	31–32	33–34	18–20
Tillage depth			
shallow part (cm)	7–8	11–13	4–5
deep part (cm)	14–15	11–13	11–12

Travelling speed : 0.16 m/s.

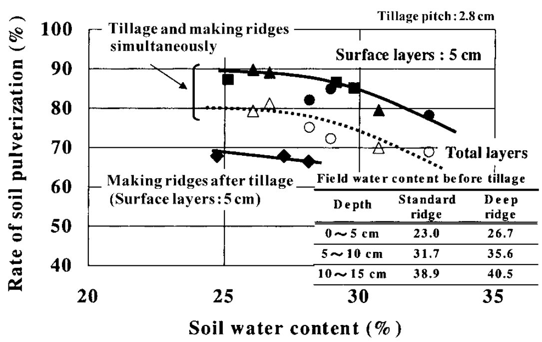

Fig. 8. Effect of simultaneous work on soil pulverization rate

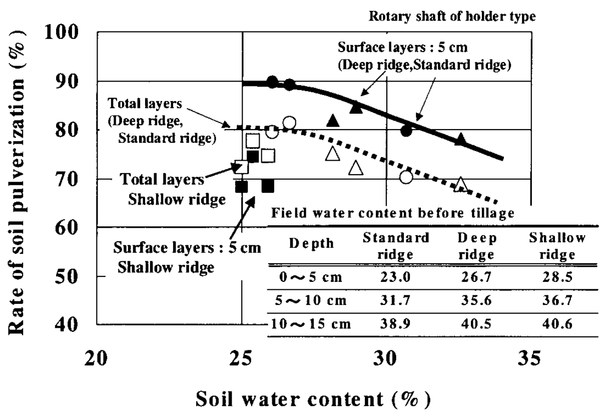

Fig. 9. Soil pulverization rate of ridges differing in tillage depth

raised, the rate of soil pulverization decreases. However, with the implements, the soil pulverization rate did not decrease because the tine was attached to collect the soil in the rotary center.

3) Power requirement and working efficiency

The power requirement was proportional to the tillage depth (Table 2). Average depth of tillage through the deep tillage ridge and standard tillage ridge was 11–13 cm and 8–9 cm for the shallow tillage ridge. The power for the deep tillage ridge (30 kW) was almost equivalent to that for the standard tillage ridge. The increase of power required for deep tillage was thus negligible.

The travelling speed of the developed implements was about 0.16 m/s, and the working efficiency was very high, about 1.5–2 h/10 a, a value 2 or 3 times as high as that in other processes of tillage and ridge-making.

4) Penetration depth through the use of rectangular plate between ridges

When heavy clay soil has been tilled and become soft, the water content in the soil increases during and after rainfall. Trafficability also decreases because the other implements travel between the ridges. After being tilled by the developed implements, the soil between the ridges was moved by the tillage tine to the ridge area, the untilled layers were exposed, the soil water content decreased, the penetration depth by the rectangular plate decreased, and the trafficability of the implements was improved (Fig. 10).

5) Matric potential of soil and underground oxygen concentration

Figs. 11 and 12 show the data in a rainy year, 1998. Soil matric potential of the deep tillage ridge decreased compared with the standard tillage ridge at depths of 20 and 30 cm (Fig. 11). Also, the oxygen concentration inside the deep tillage ridge was high at depths of 20 and 30 cm, compared with the standard ridge (Fig. 12).

The year 1999 was characterized by a low rainfall and from the beginning onward, the matric potential of soil under deep tillage was low at all depths and the oxygen concentration was always 20%. Only a few days after rainfall, the matric potential of soil was high but the oxygen content was low. This deep ridge was well suited to the cultivation of cabbage and other crops compared with the standard ridge.

In the Hokuriku region, the soil water content increases over a long period of time due to winter snow, and it was anticipated that excess water remained in the deep tillage area under the ridge. In mid-April, the water content of each type of ridge was almost identical. Therefore the amount of stored water in the deep tillage area was negligible (Fig. 13).

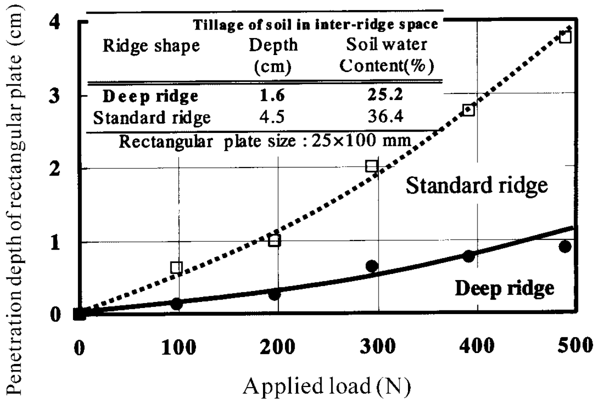

Fig. 10 Penetration depth of rectangular plate in different ridges

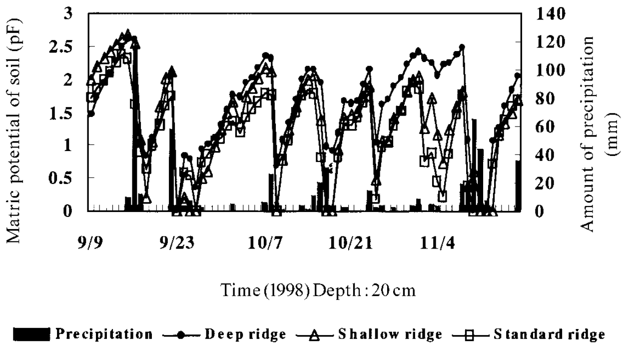

Fig. 11. Changes in soil matric potential in 3 types of ridges

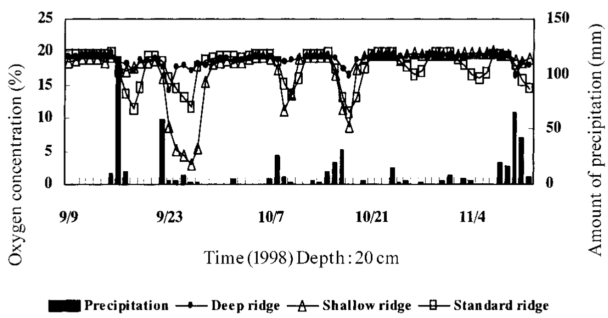

Fig. 12. Changes in oxygen concentration in 3 types of ridges

6) Cabbage yield

Yield of cabbage grown in deep tillage ridges increased by 10% compared with that of the cabbage grown in standard ridges, due to rainfall in 1998 and 1999. Especially, in 1999, the yield of cabbage grown in the deep tillage ridges was about 5.7 t/10 a (Table 3). Also the average weight of one cabbage was about 1.67

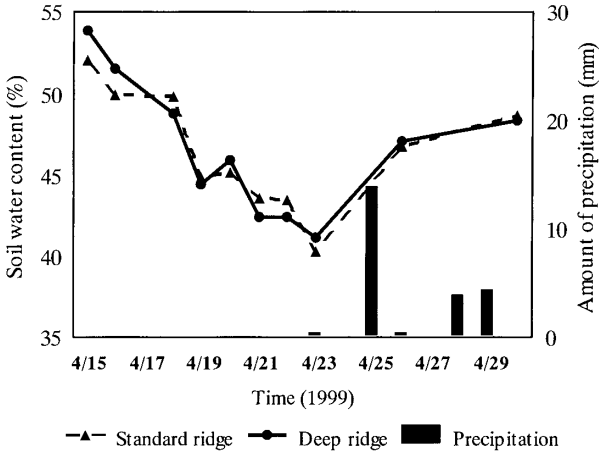

Fig. 13. Soil water content of 2 types of ridges after snow

kg and the harvest rate in the deep tillage ridges was 82%. Both the weight and harvest rate were higher than those of cabbage grown in standard ridges.

Conclusion

The developed implements enabled to perform deep tillage in heavy clay soil where the rate of soil pulverization was low due to deep tillage. Fine clods of soil were concentrated on the ridge surface layers and the ridge was suitable for the transplanting of vegetable seedlings. With the implements, soil tillage and ridge construction could be performed simultaneously. As a result, the working efficiency was 2–3 times higher than that by other methods. Also, the operation of the worker and the trafficability of the implements in the inter-ridge spaces were improved. Soil clods in the inter-ridge spaces did not remain and the spaces between the ridges hardened.

The developed implements enabled to perform tillage in heavy clay upland fields converted from wet rice fields. For the maintenance of the soil water content, the developed implements were found to be as effective as the up-cup rotary machine. The type of tractor used should also be considered because the working time and power requirement differ depending on the soil type and water content.

Basically, the pulverization rate in heavy clay soil is low when the soil water content is high. Therefore, it is important to use soil with fine clods effectively. In the future, tillage technology will continue to be applied in areas where the soil shows a low pulverization rate and high water content. Through this technology, the pulverization rate of heavy clay soil could be raised. Finally, the implements may require further development to (1) cover the ridges with a vinyl sheet, (2) raise the height of the ridges, and (3) extend the depth of tillage.

Table 3. Yield of cabbage cultivated in 3 types of ridges

1999 (1998)	Deep ridge	Standard ridge	Shallow ridge
Yield* (kg/10 a)	5,730 (1,950)	5,050 (1,760)	4,350 (735)
Rate of harvest* (%)	82.1 (59.5)	76.1 (54.4)	68.8 (24.5)
Average weight* (g/cabbage)	1,676	1,594	1,506

*: over 1 kg/cabbage (1999), Variety: YR-Seisho, Planting date: 5,6 Aug. 1999 (18,19 Aug. 1998), Harvest date: 5 Nov. 1999 (5 Nov. 1998).

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