Effects of high water table conditions on sunflower growth and quality

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ABSTRACT

Sunflower is one of the major crops for edible oil, which is widely known as a high quality and healthy oil. Recently it was reported that the oil of high oleic acid cultivars had higher oxidation stability and better dietary properties than that of the standard linoleic cultivars. In Japan, sunflower is frequently cultivated as an upland-crop component in rice-based cropping systems. Therefore, an understanding of the effects of water conditions on the growth and oil quality is important. The aims of this paper are to evaluate the effects of water conditions on plant growth, seed yield and oil quality, and to obtain physiological information for increasing yield of sunflower in rice-based upland fields in the central region in Japan. Seed yield and the major yield components, as well as the oil content, were negatively affected by the shallower water table and lower temperature conditions. Regarding their fatty acid composition, the percentage of oleic acid was decreased, and that of linoleic acid was increased with the higher water table. In the next step, the physiological mechanisms behind the effect of higher water table should be elucidated to develop improved management practices for increasing the seed yield and improving the oil quality of sunflower in rice-based cropping systems.

Key words: fatty acid – rotational upland paddy field – sunflower – water table level.

INTRODUCTION

Regarding the effects of short-term waterlogging on sunflower, Orchard and Jessop (1984) reported that the yield was most affected by the waterlogging at anthesis. They also reported that waterlogging at the vegetative and floral initiation stages inhibited the leaf expansion (Orchard and Jessop, 1984). Regarding the soil conditions affected by waterlogging, Orchard and So (1985) reported that availability of oxygen concentration was reduced and ethylene concentration was increased. Hunt et al. (1981) reported that this increased ethylene concentration affected plant growth and reduced root growth in tobacco. Grassini et al. (2007) reported that waterlogging during grain filling caused direct and adverse physiological responses: leaf area, leaf capacity to fix carbon, water absorption, and grain yield were all decreased.

As mentioned above, there are some reports about the effect of waterlogging on sunflower growth, but there are few reports about the effect on oil quality. In the case of soybean, Shimada et al. (1995) reported that the depth of the water table affected chlorophyll contents and yield. The effects on chlorophyll contents varied with the leaf position on the main stem. When the plants were grown with a shallower water table, the lower leaves contained less chlorophyll, and the ripened pod number and 100-seed weight were decreased.

Regarding the fatty acids, there were some reports on the factors changing their compositions. Since waterlogging conditions usually delay the growth stages, the air temperature during the grain filling would be different among the treatments, so that the temperature condition was widely reported as being one of those factors. Nagao and Yamazaki (1984), Sobrino et al. (2003) reported that the oleic/linoleic acid ratio was increased with higher temperature during grain filling. Izquierdo et al. (2006) reported that night minimum temperature during grain filling was better related to oleic acid concentration and its linear increase increased oleic acid concentration. Flagella et al. (2002) reported that oleic acid and stearic acid were decreased and linoleic and palmitic acid were increased under irrigation. But not many papers have been published regarding the change in quality under high water table conditions.

In Japan, the cultivation of sunflower on rice-based upland fields for the purpose of human consumption, and for the use of bio-diesel fuel is increasing. Therefore, the objective of this paper is to elucidate the effects of a shallow water table on the growth, yield and quality of sunflower.

MATERIALS AND METHODS

Field experiments

Experiment I was conducted in 2005 in two farmers' upland fields after irrigated rice at Tsukubamirai city in Ibaraki prefecture. Soil moisture conditions were different between the two fields (Fig. 1). One field (F7) was wetter than the other (E7). Twenty-one hybrid varieties of sunflower were cultivated in them. In 21 cultivars, 9 were linoleic type, 11 were middle oleic type and one was high oleic type. They were sown on May 30 and 31 at 30 x 60cm or 30 x 80cm spacing. A compound fertilizer was applied at the rate of N-P_2O_5-K_2O = 8.4-8.4-8.4 g/m^2.

Stem length, disk diameter, number of seeds in a disk, flowering date, and maturing date were measured. Soil moisture content was measured by a soil moisture probe (Profile Probe PR2, Daiki Rika Kogyo Co. Ltd., Tokyo) at depths of 10, 20, and 30cm. Yield of each plot was determined from harvest of 1.44m2 . All treatments were replicated two or three times depending on the varieties.

Experiment II was conducted in 2007 on an artificially sloped plot at Ibaraki Agriculture Institute at Ryugasaki city in Ibaraki prefecture. The slope, 8.3 m in length and 86 cm in height at one end gave a set of 10 rows with different water-tables. The ditch surrounding the sloped plot was constantly filled with water after June 7. Two hybrid varieties were used. One was traditional type; Hybridsunflower (Kaneko Seeds Ltd. Gunma), and the other was NuSun type, 63M80 (Pioneer Hi-Bred International, Inc., USA). These varieties were sown on June 7 and June 26, 2007. The sowing space was at 20 x 86cm. The ditches around the sloping plot were filled with water from June 7 until the end of the experiment. Soil moisture contents were measured as in Exp. I at a depth of 20, 40, 60 and 80 cm. Fertilization and observed parameters were the same as in Exp. I.

Sample and data analysis

Sampled seeds were air-dried. Two g seeds from each sample were crushed and the oil was extracted with *n*-butyl alcohol. The measurement of oil content and fatty acids composition in total fatty acid were determined by the Caviezel method (Pendl et al., 1998) using a gas chromatograph (B-820, Nihon Büch Co. Ltd., Tokyo). The content of fatty acids was calculated from the peak areas and calculated as the percentage of the total fatty acid content.

Statistical analysis

The results were analyzed by ANOVA. All statistical analyses were performed with SPSS 11.0 for Windows (SPSS, 2001). All values are expressed as mean values. Significant statistical differences between treatments were established by the Tukey's test at $P<0.05$. A correlation was calculated with the values of the different parameters. The significance levels ($P<0.01$) are based on the Pearson coefficients.

RESULTS

Exp. I.

Soil moisture conditions in the sloping plot

The first flowering date was July19. and the last maturing date was Sept. 13. During this period, soil water content was always higher in F7 than in E7. The largest differences were observed in the row with the water-table of 20cm in depth (Fig. 1).

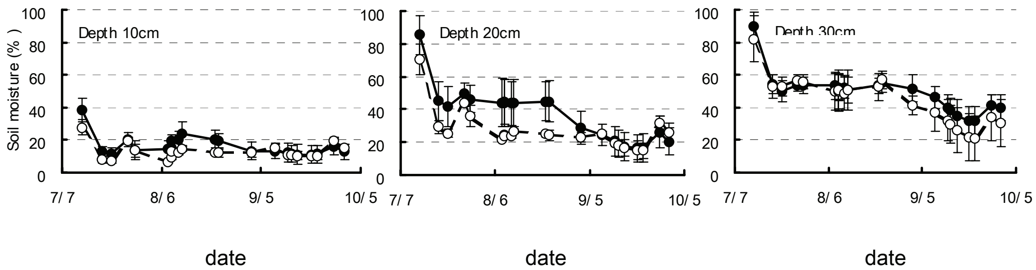

Fig. 1. Soil moisture conditions in the two fields. F7 ● , E7 ○

Effects of soil moisture conditions on growth, yield and quality

The differences in growth and yield between the two fields are shown in Fig. 2. The reductions in stem length in F7 (higher soil moisture condition) were measured in all cultivars. The responses of numbers of seeds in a disk were different depending on the cultivars: that of Hybridsunflower increased and that of 63M02was decreased in F7 field. Their yields in F7 field (higher soil moisture condition) were almost always lower than those in E7 (lower soil moisture condition) (Fig. 2). In this study, the decrease in oil content and oleic acid composition and the increase in linoleic acid composition were observed at the harvest in higher soil moisture conditions. But the order of high or low oil content and oleic acid and linoleic acid composition in cultivars was unchanged in two water table conditions. Regarding the correlations of some traits with the yields, numbers of seeds in a disk had a significant correlation with the yields in both fields (data not shown).

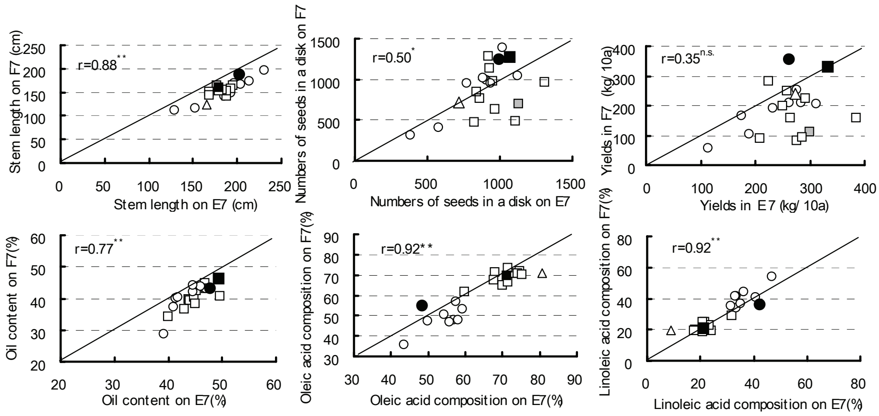

Fig. 2. Growth, yield and harvest quality in the two fields.
○:Trad. (●:Hybridsunflower),□:NuSun (■:63M80, ▩63M02),△:High oleic

Exp. II.

Effects of soil moisture conditions on growth, yield and quality.

Soil moisture contents at different depths in the sloping plot are shown in Fig. 3. The largest difference in soil moisture content was found at the depth of water table of 40 cm. The mean air temperature during the ripening period of each treatment (water-table depth) is shown in Fig. 4. Except for the cases at depths of 0 cm and 9.2 cm, there were no large differences in mean temperature and accumulated temperature (data not shown) between the treatments of the same sowing date (Fig. 4).

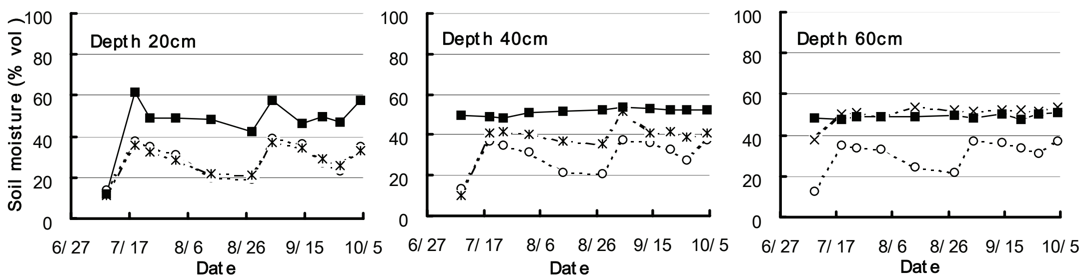

Fig. 3. Soil moisture conditions on the sloping field. Depth to water table; ○:86cm, ×:47.6cm, ■:9.2cm

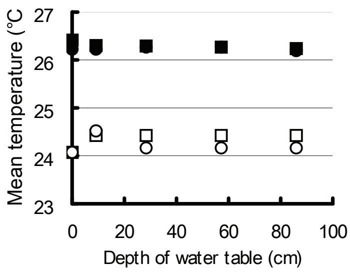

Fig. 4. Mean temperature during ripening period.
Sown on June 7.●Hybrid. (Trad.) ■63M80 (NuSun)
Sown on June 26.○Hybrid. (Trad.) □ 63M80 (NuSun)

The effect of different water table conditions on the growth of sunflower is shown in Fig. 5. Stem elongation, diameter of a disk and yields were significantly reduced with shallower water table. The stronger response to the water table rise was seen when the depth of water table was shallower than about 30 cm (Fig. 5). The growth stage when the water treatment started was different between the plants sown on June 7 and those sown on June 26. The decrease in oleic acid composition ratio and the increase in linoleic acid composition ratio with a rising water table were somewhat clearer for the plants sown on June 7 (Fig. 5).

These experiments demonstrated that the shallow water table affected not only the growth and yield but also the quality of the harvest even under the same temperature conditions.

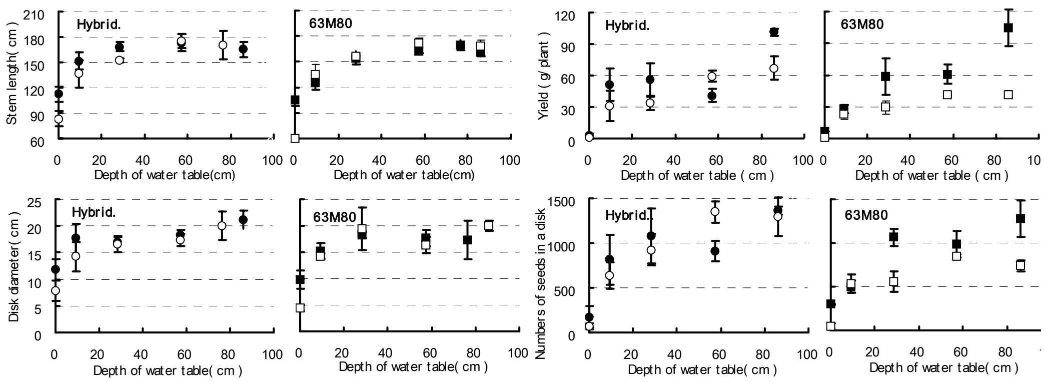

Fig. 5. Growth and yields on the sloping field.
Sown on June 7.●Hybrid. (Trad.) ■63M80 (NuSun)
Sown on June 26.○Hybrid. (Trad.) □ 63M80 (NuSun)

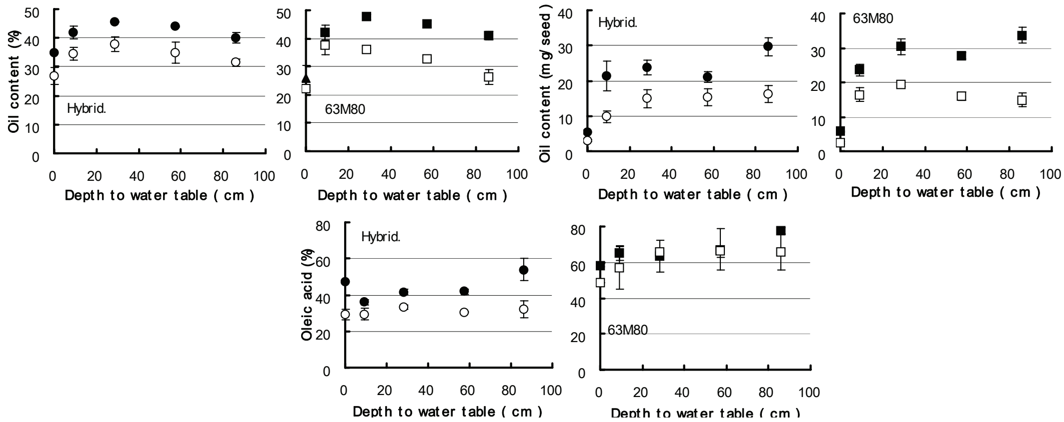

Fig. 6. Harvest quality on the sloping field.
Sown on June 7.●Hybrid. (Trad.) ■63M80 (NuSun)
Sown on June 26.○Hybrid. (Trad.) □ 63M80 (NuSun)

DISCUSSION

The increase in oleic/linoleic acid ratio and the decrease in oil content with increasing temperatures during grain filling have been widely reported. Izquierdo et al. (2006) reported that increasing night temperature resulted in higher oleic acid concentration, and Flagella et al. (2002) reported that a decrease in the oleic/linoleic acid composition ratio was observed in early sowing treatments (lower mean temperature) and under irrigation. In this study, a similar tendency was shown so that the decrease in oleic acid composition and the increase in linoleic acid composition were observed at lower temperature conditions and rise of water table. The oil content (%) was highest at the water table of 30 cm. With a deeper water-table the oil content was decreased. Oil content per one-gram seeds reached the highest at the same water-table depth. After that it remained unchanged. The oil accumulation in seed was presumably most active at around 30cm depth of water table, a comparatively shallow depth. In the case of soybean, Shimada et al. (1995) reported that the fluctuation of the water table reduced the yield. In this experiment, the water table condition was constant, which might have affected the results that even when the water table was shallow, around 30cm in depth, the oil content was the highest.

As a further step, it is necessary to gain a deeper insight into the physiological mechanisms behind the effect of excess moisture in order to increase seed yield and improve the harvest quality.

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