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Studies on the sod culture and the management of soil moisture for the improvement of waxapple quality

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In Taiwan, Kaohsiung and Pingtung districts are the main cultivating areas of waxapple in Taiwan. The quality of waxapple is commonly involved in appropriate fertilization. Therefore, the demonstration orchards were established in Kaohsiung and Pingtung districts. This research was conducted to the effects of sod culture and management of soil moisture on the improvement of waxapple quality. The results showed that soil properties in the districts of two kinds of sod culture (*Alternanthera philoxeroidex* Mart. and *Wedelia chinensis* Merr.) were excellent than that of non-sod culture, and the harvesting fruit quality were higher for two areas of sod culture than non-sod cultivature. The treatment of moisture control by tensiometer (TM) on soil available elements, the concentration of leaf elements and fruit color were all highest, and fruits cracking percentage were lowest than other treatments in shallow soil. On the other hand, the effect of furrowed and immersed (FI) on soil available elements, the concentration of leaf elements and fruit color were all highest, and the fruit cracking percentage was lowest than other treatments in alluvial soil. The results showed that the quality of waxapple could be improved by treating with sod culture and the management of soil moisture.

Key words: Soil properties, tensiometer, furrow, immerse.

INTRODUCTION

Waxapple is one of the important fruits in Taiwan, they are cultivated mainly at the farmlands of Kaohsiung and Pingtung. High quality waxapples like" Black Pearl" and "Black Diamond" have been well known for more than a decade. However, the factors including climate (temperature, sunlight, and rainfall etc.), cultivation and management (pruning, flower and fruit thinning etc.), and appropriate fertilization significantly influence the growth and development, sugar content, color, and even abscission and cracking of the waxapple fruit (Kuo et al., 2004). In addition, sod culture influence the quality of waxapple fruit, it includes the soil properties and fruit weight, sugar degree, and so on (Lin, 2012, 2014). In the quality of waxapple, besides color and sugar degree, fruit cracking is another reference index for the quality of waxapple. Sugar content and color have been notably

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improved in the past years. However, fruit cracking is always a quality defects. High ratio of fruit cracking has a negative impact on the marketing of waxapple (Lai, 2005). Therefore, the problem needs to be solved urgently. There are a large number of achievements in fighting against fruit cracking for other fruits. For example, GA3 50 ppm + NAA 50 ppm is great for loquat in preventing fruit cracking (Yen, 1989). Calcium fertilizer improves the fruit cracking and malformed fruits of tomato as a result of calcium deficiency (Asen, 1976). For Fuyu sweet persimmon, an appropriate rates of N- and K-Fertilizer ($N:K_2O$=300:300 g/year/tree) is better than the high N- and K-Fertilizer rates ($N:K_2O$=450:300 g/year/tree), for increasing the quality of fruits and reducing the fruit cracking for 25% (Lai, 2001). The control of moisture content also has its impacts on fruit cracking. Markakis (1974) showed that it was possible to control the fruit cracking of pineapple by controlling the moisture content of the soil. During the period of fruit growing, instant rainfalls and bad management of moisture content in the soil may result in severe fruit cracking for Murcott Orange (Garcia-Luis et al., 1994). Soil should be kept from being excessively dry and with appropriate water content (Chang et al., 2005). For waxapple, most of the studies on the fruit quality are based on the utilization of nutritional agents and the cultivation management of the parts above ground in the past. For example, Lai (2005) showed that the fruit string at the outside of the crown demonstrated the highest fruit cracking ratio on a horizontal basis. Spraying 0.3% $CaCl_2$ or $CaSO_4$ on the surface of leaves had a remarkable effect against fruit cracking. Yen et al. (2004) believed that spraying Chung-Hsin 100 (plant extract) 1000X solution in the winter helped to reduce the fruit cracking ratio by 25%. Another reason that rainfalls in the mature stage of waxapple result in significant fruit cracking. This is because of the fast alternation between dryness and moisture at the roots (Lai, 2005). In this study, the effect of appropriate fertilization, sod culture and the moisture of soil are evaluated on the quality of waxapple (e.g. sugar content, size, weight, and fruit cracking ratio).

MATERIALS AND METHODS

Effect of sod culture on waxapple quality

The experimental design

The experiments of sod culture was proceeded at the waxapple orchards of Chianjhih, county, Pingtung. By evaluating, the two kinds of grass species (*Alternanthera philoxeroidex* Mart. and *Wedelia chinensis* Merr.) were excellent for the experiments of sod culture. The experiment was preceded in the vegetative growth period. Before experiment, other weeds were controlled by herbicide. After two weeks, two specific grass species were planted beside waxapple trees. By spreading of specific grasses, the rate of coverage grasses was high-density. The soil properties, the concentration of nutrients in leaves and fruit quality (e.g. fruit weight, width, length and sugar degree) were estimated and compared between the different areas of treatments.

Fourier-transform infrared spectroscopy (FTIR) analysis for the root surface of two kind of grass species

The root apice of two kind of grass species were sampled and oven-dried, and then powdered, and then 200 mg KBr after pre-dried at 110°C that was added and mixed for KBr pellet preparation by a die at 10,000~15,000 lb/in^2 pressure for 3 min. The KBr pellet was measured by Shinazu (Japan) FTIR spectrophotometer for its light transmission at wave member between 4000 and 400 cm^{-1}.

Efffects of the management of soil moisture on waxapple fruit quality

The soil properties of experimental orchards

The experimental orchards were located at Kaosu and Nantzu, Pingtung, Taiwan. The soil series in Kaosu is among Shashuipu series. It is shallow soil with very perfect drainage properties. This area can be characterized by rock layer or stone block layer beneath the surface soil. The soil in Nantzu belongs to Lantau series which is alluvial soil with limited drainage capability, based on duripan of iron and manganese accumulated by the ancient alluvial deposits of clay slates, which are alkalescent.

Experiments of soil moisture control for soil

During fruit setting stage, the experiment was treated accordingly, (1) FI: Digging a channel which is 20 cm in depth on the soil around the tree. Keep the water level in this channel as 5 cm in depth. (2) TM: The moisture of the root rhizophere at 30 cm under the ground is monitored with a tensionmeter as a reference for irrigation. If the value of tensionmeter is greater than 25 cbar, the irrigation was initiated. If the value is smaller than 15 cbar, the irrigation was stopped. (3) DR: There is no any irrigation after the fruit setting stage. (4) CK: The orchard was irrigated every 4 to 5 days to keep soil moist. Before the experiment and during the fruit setting stage, soil is sampled for different treatments. And the leaves from the branch of non-fruit branch were sampled for analysis. Sugar degree, average fruit length, average fruit width, average fruit weight, and cracking ratio at the harvested stage were investigated.

PRETREATMENT AND ANALYSIS OF SOIL AND PLANTS

Pretreatment and analysis of soil

After soils sampled, they were air dried and grinded. And then shaked the grinded soils through 2 mm sieve. The soil properties were analyzed as below, (1)The pH of soils were pretreated by water : soil = 1:1, and then measured by a pH meter (McLean, 1982). (2) Organic matter (OM) was measured by wet-oxidation method described by Nelson and Sommer (1982). (3) potassium (K), calcium (Ca), magnesium (Mg) were extracted from the soils by 0.1N HCl. And then the content of K, Ca and Mg were measured by an induced coupled plasma (ICP) spectrophotometer (Baker and Suhr, 1982). (4) phosphorus (P) was measured by molybdenum-blue method (Bray No.1) (Murphy and Riley, 1962). (5) iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) were extracted from the soils by 0.1 N HCl. And then were measured by an induced coupled plasma (ICP) spectrophotometer (Cope and Evans, 1985).

Pretreatment and analysis of leaves

At first, the dusts and chemical residues on the leaves were cleaned

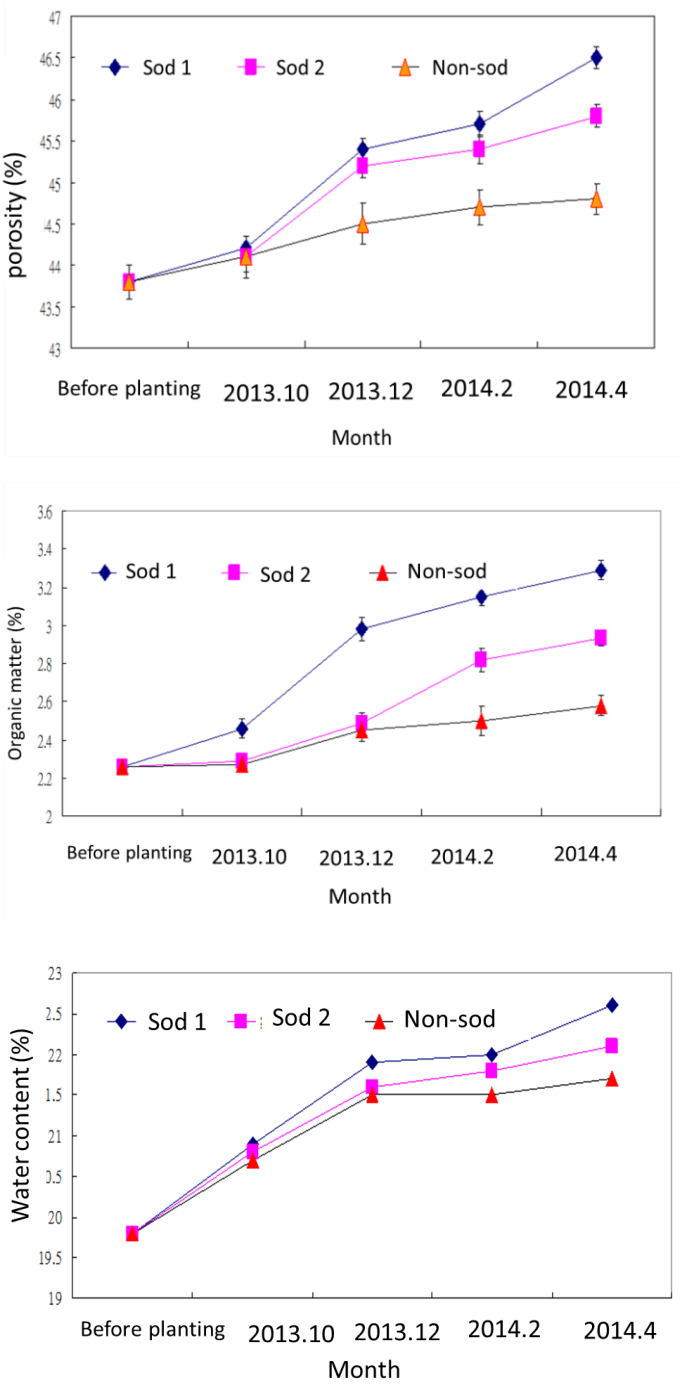

Figure 1. Effect of sod culture on soil properties in waxapple orchards (sod 1: *Wedelia chinensis* Merr. sod 2: *Alternanthera philoxeroidex* Mart.).

by distilled water. And then put the cleaned leaves were put into an oven (70-75°C). After 2 to 3 days, the dried leaves were grinded and put into decomposition tube. The leaves were then dissolved by concentrated sulphuric acid in high temperature and analyzed by the following methods. (1)N was measured by Kjeldahl method. (2) P was measured by molybdenum-yellow method (Bray No.1). (3) K, Ca, Mg, Fe and Mn were extracted from the soils by 0.1 N HCl. And then were measured by an induced coupled plasma (ICP) spectrophotometer (Cope and Evans, 1985; Chang, 1981).

Determination of fruits quality

In the mature stage of fruits, 20 fruits in similar size and are selected for determination of fruit length, width, weight and sugar content. Color of fruit peel was measured by the values of L (lightness), a (red representation), and b (yellow representation) via randomed selection for 20 fruits. 60 mature fruit samples were randomly selected from every treatment for the estimation of cracking ratio.

RESULTS AND DISCUSSION

Effect of sod culture on waxapple quality

The soil properties, nutrient concentration in leaves and fruit quality were shown in Figures 1 to 3. The results showed that soil porosity, organic matter and soil moisture were all higher at the area of two kinds of sod culture than non-sod culture. The average fruit weight was highest at the area of *A. philoxeroidex* Mart. Is highest between different treatments, and the sugar degree is highest in the area of *W. chinensis* Merr.. The fruit cracking is lowest in the area of *W. chinensis* Merr.. The concentration of potassium, calcium and maganisium is higher in waxapple leaves of sod culture is higher than that of non-sod culture. The results showed that the soil properties and fruit quality were improved by sod culturing of two specific grass species. Zou et al. (2016) showed that sod culture with white clover significantly increased the concentrations of easily extractable glomalin-related soil proteins (EE-GRSP), total GRSP (T-GRSP), and soil organic carbon (SOC), the distribution of water-stable aggregates in the size of 2-4, 1-2,and 0.5-1 mm, and the activity of soil peroxidase and phosphatase. They concluded that sod culture potentially improved soil properties in orchards (Zou et al., 2016). Wu et al. (2015) showed that sod culture can increase the activities of soil enzyme.

Based on FTIR spectroscopic analysis, the kind and intensity of functional groups from the roots of five specific grass species are shown in Figure 4. The main absorption zones of the spectrum include those located around 3300-3400 cm^{-1} (H bonds, OH group), 2850-2930 cm^{-1} (C-H asymmetric, C-H stretch of CH), 1690-1735 cm^{-1} (stretching mainly carboxyl-C or traces of ketones and esters C=O), 1595-1660 cm^{-1} (C=C in aromatic ring), 1510-1515 cm^{-1} (amide II bonds), 1420-1440 cm^{-1} (C-H deformation of CH_2 or CH_3 groups), 1372 cm^{-1} (COOH,CH_3), 1243 cm^{-1} (aromatic C, C-O stretch), 1157 cm^{-1} (aliphatic CH_2, OH or C-O stretch of various groups) and 1030-1145 cm^{-1} (C-O stretch of polysaccharite, Si-O stretch).

Inbar et al. (1989) compared some major spectroscopic intensities such as 1720 cm^{-1} (COOH with C=O bond), 1410 cm^{-1} (CH_2 and COO^-) and 1230 cm^{-1} (aromatic C

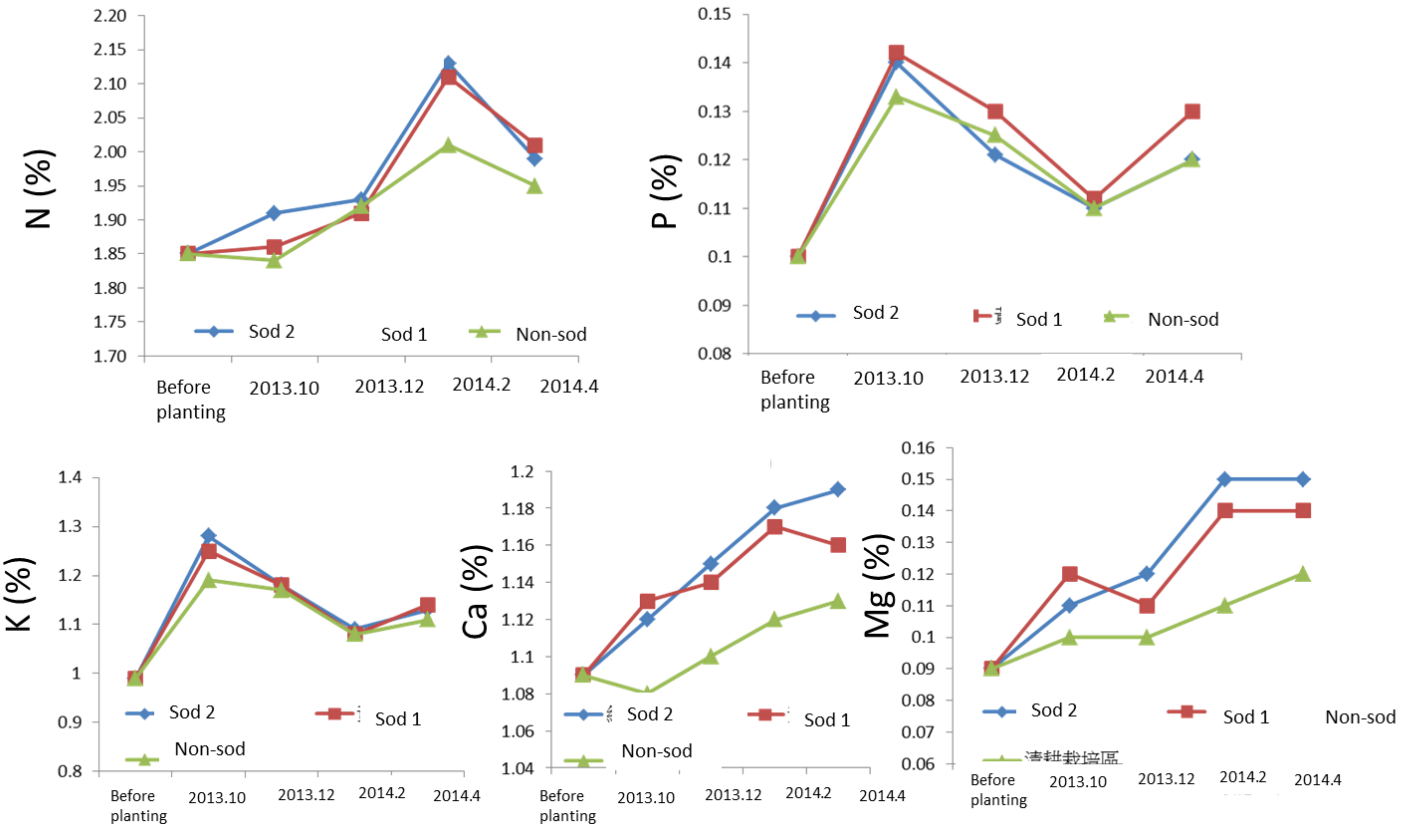

Figure 2. Effect of sod culture on nutrient elements (%) in leaves (sod 1: *Wedelia chinensis* Merr., sod 2:*Alternanthera philoxeroidex* Mart.).

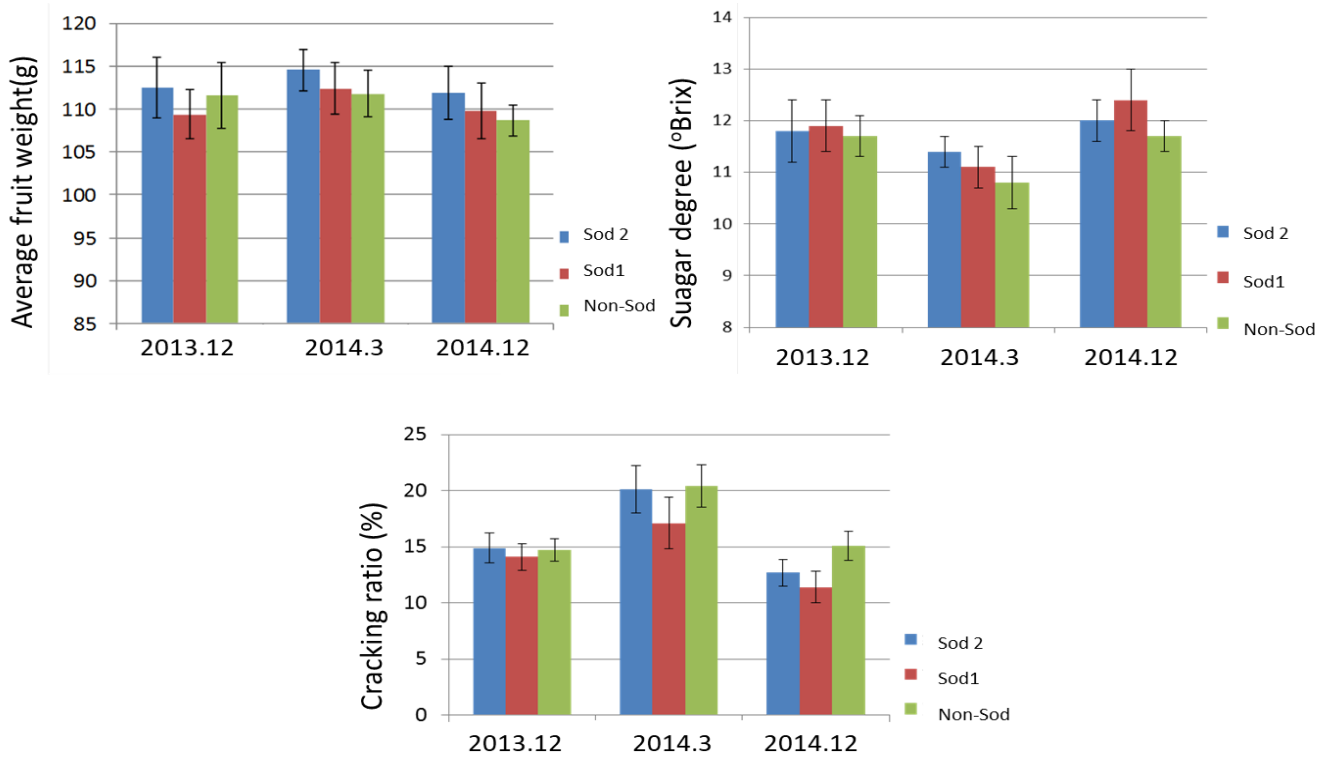

Figure 3. Effect of two different sod culture on fruit quality (sod 1:*Wedelia chinensis* Merr.,sod 2:*Alternanthera philoxeroidex* Mart.).

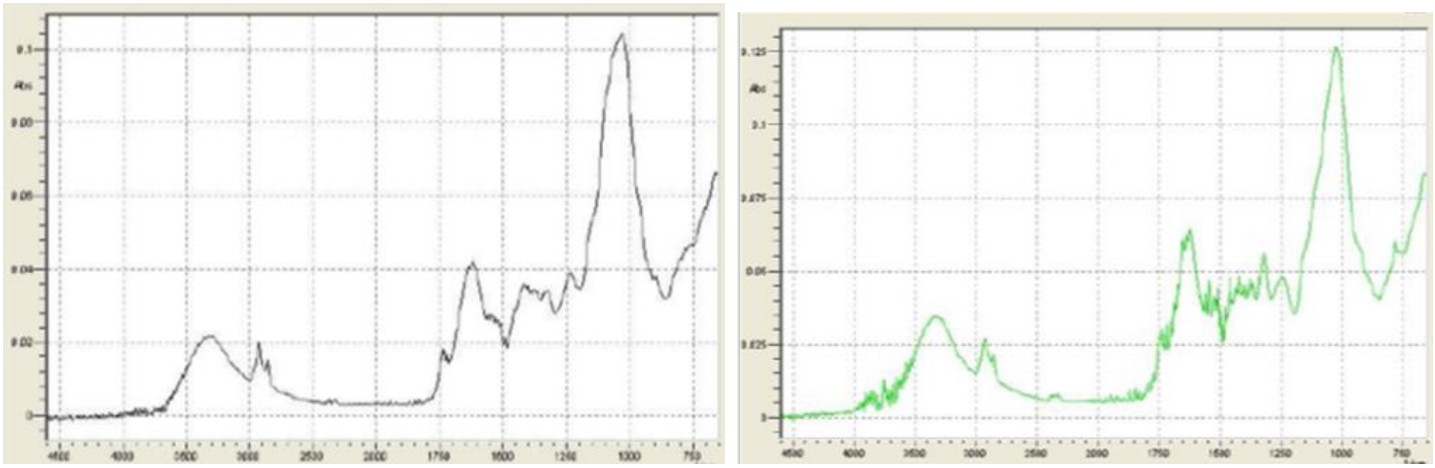

Figure 4. FTIR graphs of two kind of grasses on root surface (sod 1:*Wedelia chinensis* Merr., sod 2: *Alternanthera philoxeroidex* Mart.).

Table 1. The influence of different soil moisture managements on waxapple quality in Kaosu, Pingtung.

Treatments	Sugar degee (^{o}Brix)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g/granule)	Cracking percentage (%)	Color		
						L	a	b
FI	8.8^{a}	62.3^{a}	72.1^{a}	134.1^{a}	38.3^{b}	29.9^{a}	12.6^{ab}	5.2^{a}
TM	9.0^{a}	63.2^{a}	67.5^{a}	115.4^{a}	35.0^{b}	29.9^{a}	15.5^{a}	6.3^{a}
DR	8.1^{b}	65.4^{a}	68.8^{a}	117.6^{a}	46.7^{a}	30.4^{a}	10.9^{b}	5.2^{a}
FU	9.2^{a}	62.0^{a}	68.2^{a}	123.9^{a}	43.3^{a}	31.9^{a}	13.0^{ab}	5.4^{a}

FI: Furrowing and Immersing, TM: Tensiometer monitoring, DR: Drought, FU: Farmer usage.

and C-O bond), and suggested that these spectroscopic intensities might represent the functional groups such as carboxylic group (-COOH) and hydroxyl group (-OH). In general, these carboxylic and hydroxlic groups may bond with metalic ions (Chang-Chien and Wang, 2003). In this study, the root of specific grass species were detected to have spectroscopic intensities at 1731 cm^{-1} (represent COOH with C=O bond), 1420 cm^{-1} (represent CH_2 and COO^{-}) and 1243 cm^{-1} (represent aromatic C and C-O bond), indicating existence of functional groups such as carboxyl and hydroxyl in the cell wall of their root apices. As dissociation of H^{+} from carboxyl and hydroxyl may increase negatively charged ions, the chance for bonding with nutrient ions is increased.

The influence of moisture management on fruit quality of waxapple in Kaosu

When *pomegranate* fruit was 14 day irrigative interval, it will resulted in significantly more cracking in pomegranate than 7 day interval (standard irrigation) (Ghanbarpour et al., 2019). These experiments were preceded during late-spring, the fruit cracking ratio of waxapple was higher season. In addition to fruit cracking, we investigated the other fruit quality, too. Table 1 showed that the treatment of TM and CK that had the highest sugar degree in the fruit at the harvested stage. That of DR was the lowest. For fruit length, DR showed the highest value than other treatments, and FI had the higher value in fruit width, however, the lowest value was found TM. But the narrowest value is from group TM. For average fruit weight, group FI has the heaviest value, but group TM is the lightest. For cracking ratio, the highest value was found in DR and the lowest value was found in TM. Based on the datas, the treatment drought result in insufficient water supply and therefore caused a negative impact on the photosynthesis in the leaves where carbohydrates were produced. As a result, the sugar degree in the treatment of drought was lowest than that of others. In the treatment of TM, the moisture in the soil was always sufficient. Therefore, the sugar higher was highest than other treatments. Although the fruits weight and length in DR were higher than other treatments, however, the fruit density may be lower. For cracking ratio, DR has a high value. Highest fruit cracking is probably dramatic variation of soil moisture by the suddenly rainfall before the fruits being harvested. Among all treatments, TM showed the

Table 2. The influence of different soil moisture managements on waxapple quality in Nantzu, Pingtung.

Treatments	Sugar degree (^{o}Brix)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g/granule)	Cracking percentage (%)	Color		
						L	a	b
FI	10.5^{a}	66.8^{a}	74.5^{a}	136.2^{a}	10.3^{c}	30.2^{a}	14.3^{a}	4.8^{a}
TM	8.4^{b}	65.4^{a}	71.0^{a}	130.7^{a}	25.2^{b}	33.3^{a}	10.5^{b}	5.2^{a}
DR	8.0^{b}	64.5^{a}	68.3^{a}	127.3^{a}	33.3^{a}	31.4^{a}	11.3^{b}	4.2^{a}
FU	9.4^{a}	66.6^{a}	73.1^{a}	131.9^{a}	30.0^{a}	32.3^{a}	12.5^{ab}	5.1^{a}

FI: Furrowing and Immersing, TM: Tensiometer monitoring, DR: Drought, FU: Farmer usage.

lowest cracking ratio. It indicates that TM method may be the best method for controlling cracking ratio of waxapple in Kaosu. The control of soil moisture in the kind of soil texture may have increase the absorption of nutrients by waxapple. Advancely, the fruit quality was improved. Although the expression in the treatment of TM was not good performance in fruit length, width, and weight, however, the improving of sugar degree and the reduction of cracking ratio were significant. For the L value of fruit peel, CK had the highest value, however, that of FI and TM were low. For a value, TM is the highest and DR is the lowest. Similar condition can be found for b value. It indicates that although TM may not be the best method for fruit lightness, it was the perfect method for the improvement of red and yellow expression on fruit peel. Rain cracking of soft, fleshy fruits is thought to result from excessive water uptake through the wetted fruit surface and also through the vascular systems of the fruit pedicel (Winkler et al., 2016). In this experiment, the soil texture of Kaosu is sandy. When the irrigated interval was long period, the soil moisture will be dried easily. Hence, when the soil moisture was monitored by the tensiometer, and maintaining the soil moisture in the soil frequently, the fruit quality will be increased and the fruit cracking will be decreased.

The influence of moisture management on fruit quality of waxapple in Nantzu

Table 2 showed the comparison of fruit quality of waxapple fruit quality by different treatments of soil moisture. In the treatments of soil moisture in Nantzu, FI showed that the highest in sugar content, however DR was the lowest. Either for fruit size and weight. On the other hand, FI showed the lowest (10.3%) and group DR shows the highest (33.3%). Fruit cracking as shown in Figure 1, high fruit cracking may be the dramatic variation of soil moisture by the suddenly rainfall before fruits being harvested. The fruit cracking happened very serious in DR. The L value of fruit peel was highest in TM and lowest in FI. The “a” value was highest in FI and lowest in TM. The “b” value was highest in TM and lowest in DR. The results showed that although the perfect method for the lightness and “b” value on fruit peel, however, FI had highest performance for “a” value which was beneficial for red color on fruit peel. Yang et al., (2017) showed the fruit anthocyanin content was significantly positively correlated with irrigative frequency and pH of the irrigation water, so for maintaining higher anthocyanin content, fruit trees should be cultivated with soil moisture content between 60 and 90%, and the irrigation water should be neutral or alkaline. Rehman et al. (2019) showed that when cherry adapting certain management practices, of which irrigation management and mineral supplements, the fruit cracking will be decreased. In this experiment, we showed that when waxapple was planted on the clayey soil, the treatment of furrowing and immersing (FI) was excellent for increasing waxapple quality and decreasing fruit cracking.

Conclusion

In these researches, the management of sod culture on the orchards can increase the soil properties and the quality of waxapple that was found. On the other hand, the proper management of soil moisture in different soil texture during fruit-setting stage is important for waxapple, for example, the increase of sugar degree of fruit and color of fruit peel, the decrease of fruit cracking.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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