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Evaluation of the Effectiveness of Loose and Compressed Wood Chip Mulch in Field-Grown Blueberries—A Preliminary Study

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Abstract: Blueberry production in the field faces several challenges, including competition from weeds and soil suitability. Different mulch types are widely used in blueberry cultivation to control weeds, conserve moisture, and mitigate soil erosion. However, the comparative effects of loose and compressed wood chips on fruit quality and weed control in blueberry production systems have not been studied. Many farmers use expensive imported peat moss as soil covers, while others apply organic mulches such as chips or chaff, which can be easily washed away by runoff. This study aimed to evaluate the effects of compressed mulching boards (MB) fabricated without the use of chemical adhesives using pressurized steam and compression technologies in blueberry cultivation. During the two growing seasons, the effectiveness of compressed MB on soil moisture retention, fruit quality, and weed biomass was compared to that of wood chip (WC) and control treatments in a blueberry field. Although a significant difference was observed in the fruit fresh weight, no significant differences were observed in the other fruit growth parameters for all the treatments. Generally, the compressed MB significantly improved soil moisture retention capacity compared to WC and control during the two-year study. The compressed MB showed effective weed suppression ability by significantly reducing the weed biomass at all sampling times.

Keywords: mulching effectiveness; blueberry fruit quality; weed control; compressed mulching boards; field-grown blueberry

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1. Introduction

Despite concerted efforts over the last decade to increase blueberry (*Vaccinium corymbosium* L.) production in Japan, the level of production remains lower than consumer demand. Due to low production levels, blueberry fruits are imported from neighbouring countries to supplement the shortfall in production [1]. As a result, it is essential to increase the production of quality blueberry fruits grown in the domestic environment. Even with the increase in blueberry cultivation areas in the country, some constraints obstruct the production of high-quality blueberries for the local market. Tamada [2] stated that among the useful research interests in blueberry production in Japan are breeding early maturing and high-yielding cultivars, poor soil drainage and aeration, and pest management. Furthermore, in the United States and Chile, mulching and weed management are important considerations for successful field-grown blueberry production [3,4].

In Japan, blueberry growers are increasingly utilizing greenhouse technology or plant factories. While these methods are important for ensuring a year-round supply of blueberries, the management and production costs are extremely high. Field-grown blueberry production, which is gaining popularity in Japan, is hindered by the lack of suitable soils for cultivation. For example, most of the soils in Japan are characterized by poor drainage and aeration [2]. Meanwhile, soil moisture can significantly affect blueberry fruit yield and quality [4–6].

Mulching is usually done to cover the soil with any solid material to reduce the soil surface exposed to environmental conditions (especially rainfall and wind). Mulching is a sustainable practice for managing agricultural water in crop production, particularly during drought seasons [7,8]. Mulches can prevent soil moisture loss due to evaporation, protect plant roots from extreme temperatures, improve soil structure, increase soil organic matter content, and improve soil hydraulic conductivity [9–11]. Soil mulching has particularly gained attention in crop production, largely due to its effectiveness in controlling weed growth [12]. The two main sources of mulch material are synthetic sources (polythene sheets) and organic sources (biomass residues) [13]. Farmers in Japan use a variety of strategies to improve drainage and retain soil moisture, including the use of live mulch, cover crops, chaff, and compost materials such as peat moss. Soil moisture, in particular, may have a tremendous effect on blueberry fruit yield [14,15]. Although these methods improve soil productivity to a large extent, their ability to retain soil moisture is often compromised after heavy storms or winds, which usually remove large amounts of soil surface cover from one point to another. The use of synthetic materials (especially polythene sheets) as mulch has also posed some environmental challenges. Gao et al. [16] reported that an increase in the amount of residual plastic film would seriously affect crop yields over time. Additionally, agricultural soils are contaminated by plastic mulching, which adds to the global problem of plastic pollution [17]. Irrespective of the type of plastic mulch, its increased adoption in modern agriculture threatens the natural ecosystem primarily due to residual deposits in aquatic and terrestrial habitats [18].

Although the global generation of biomass residues has increased [19], a significant proportion of organic materials when applied as mulch often decompose in one growing season [20–22], thus limiting the influence on soil moisture regulation in humid environments. These crop residues could also be wiped off the soil surface by runoff or strong winds, exposing the topsoil to erosion. In this regard, the transformation of biomass residues into solid layers to form bulk boards may result in a more durable and sustainable mulch material. The compression of wood waste in the form of chippings, chaff and compost materials in mulch boards [23,24] presents an alternative to maintain soil moisture on farmlands for a prolonged period. Given the large forest resources of Japan, compressed mulching boards (MBs) could provide a means of converting commonly utilized forest biomass resources into useful products. Previous research in Japan has found that urea-impregnated boards improved crop growth by increasing soil moisture retention capacity, releasing nitrogen to crops on time and suppressing weeds [25]. Additionally, Ito et al. [23] showed the potential of substituting these boards for pavement blocks as a surface cover against surface runoff. However, there is little information on the effectiveness of these MBs in retaining soil moisture under field-grown blueberries. Other biomass boards were produced from crop residues including corn [26], sorghum [27], and sugarcane [28,29]. In this study, the effectiveness of the continuous application of different mulch forms of Japanese red cedar (*Cryptomeria japonica* D. Don) on soil properties, especially soil moisture dynamics, weed suppression and fruit quality indices of field-grown blueberries over two years were assessed.

2. Materials and Methods

2.1. Chip Collection and Board Fabrication

Chip materials (<10 mm) were obtained from the waste of Japanese red cedar (*C. japonica*) which was sampled from the forest areas in Gifu prefecture, Japan. The chips were initially air-dried for several days to attain a constant weight. Using a high-pressure steam and compression method, the dry chips were initially placed in a metallic frame and compressed to a target thickness of 2 cm. The dry chips were then placed in an autoclave, where steam at 180°C was injected for 30 minutes. This process allowed the mulches to be turned into dimensionally stable boards in about thirty minutes (detailed description in [25]).

2.2. Site Description

Two-year consecutive field studies were carried out in the experimental field of Tokyo University of Agriculture and Technology (TUAT), Japan, from April 2013 to December 2014. The campus is in Fuchu, along the Tama River (35°41′ N, 139°29′ E; 65 m above sea level (a.s.l.)) and has an annual rainfall amount of 1500 mm. The mean annual temperature in the area during the experimental period was 28°C. The soil at the site, characterized by high organic matter, is defined as Haplic andosol [30]. Some physical and chemical properties of the soil used are provided in Table 1.

Table 1. Physicochemical properties of the experimental site.

Parameter (Unit)	Value/Concentration
Total carbon (g kg^{-1})	42.4 ± 2.6
Total nitrogen (g kg^{-1})	4.41 ± 5.2
Carbon: Nitrogen ratio	9.61
TOC (mg kg^{-1})	610 ± 21.1
NH_4^+ (mg kg^{-1})	116 ± 6.1
NO_3^- (mg kg^{-1})	289 ± 58.3
Available phosphorus (mg kg^{-1})	42.4 ± 6.9
Available potassium (mg kg^{-1})	8.32 ± 1.1
Soil organic matter (%)	4.91
Sand (%)	32.4
Silt (%)	29.4
Clay (%)	38.2
pH (H_2O)	6.32

TOC: total organic carbon.

2.3. Treatments, Experimental Procedure, and Management

Three treatments were tested in this study. The treatments comprised a compressed mulching board (MB), with dimensions of 100 cm by 30 cm and a thickness of 2 cm, a waste wood chip (WC), and no input control (Figure 1). Treatments were randomly assigned to four-year-old previously established blueberry plants (Tifblue variety) in April 2013. A randomized complete block design with three replications was used for the study. Each plot, measuring 2 m by 0.9 m, was cleared of weeds and debris and tilled with a hand fork before treatment. Buffer plots of 0.5 m were left in between the blocks to minimize cross-border effects. At the onset of the dry seasons of 2013 and 2014, treatments were applied to the respective plots. In the case of the MB treatment, several pieces of board were laid as mulch to cover the respective plots.

Figure 1. Mulching boards from wood chips.

In the WC treatment, the equivalent amount of wood chips was evenly spread at 1 Mg plot^{-1} and levelled with a rake to completely cover the surface. Control treatment did not receive resource inputs. In 2014, while fresh wood chips were added to the plots in the WC treatment, the boards in the MB were maintained. Two months before treatment addition, each plot received a blanket N, P, and K fertilizer as NPK 15:15:15 at 30 kg ha^{-1}. Additionally, the top dressing with $(NH_4)_2SO_4$ at 20 kg ha^{-1} was done one month before flower initiation. The weeds were manually handpicked at monthly intervals from June to December of each year. Dead blueberry branches were pruned off during the off-season.

2.4. Fruit Yield and Quality Analyses

The physiologically mature blueberry fruits were harvested from all plants in each plot at two weeks intervals from July to August in both cultivation years. Only mature fruits were handpicked and sorted at both harvest times. A subsample of approximately 30 fruits was randomly selected from each plot harvest and weighed with a weighing balance. The same individual fruits were used to determine the fruit diameter, firmness, epicarp, and mesocarp amounts. The firmness of the fruit was determined by measuring the force required to penetrate (with 2 mm Φ) the berries positioned on their side with a rheometer (RT-3005 D; Rheotech Co., Ltd., Tokyo, Japan). The maximum peak of the recorded force-time curve, measured in kilogram-force (kgf), was taken as the firmness of blueberry [31]. Fruit diameter was determined using vernier callipers (Fisher Scientific, Memphis, TN, USA).

2.5. Weed Dry Weight and Soil Characteristics

The effect of the various treatments on weed biomass was estimated by collecting weeds on each plot from June to December of each growing season. Weeds on each plot were handpicked, thoroughly washed with water, and oven-dried at 60 °C for 72 h to achieve constant weights. Weed dry weights were determined using a weighing balance at each sampling time. Soil surface hardness was measured on each plot with a handy push-cone penetrometer (Daiki Rika Kogyo, Japan) in 2013, before treatment application, and in 2014, immediately after the last blueberry fruit harvest. Ten random penetrometer readings were recorded on each plot. Soil moisture and temperature monitoring were performed in May and August 2014 using the Em50 data collection system (Decagon Devices, Inc., Pullman, WA, USA).

2.6. Statistical Analyses

All statistical analyses were performed using SPSS (Statistical Package for the Social Sciences, Version 16.0) software program. A one-way analysis of variance (ANOVA) was used to compute the mean differences among the treatments. The weight, diameter, firmness, epicarp, and mesocarp data of the fruits were analyzed each year. Replicates were considered random effects, and treatments were considered fixed effects. The statistical significance of all effects was compared using the least significant difference (LSD) test at $p < 0.05$.

3. Results

3.1. Fruit Quality Characteristics as Affected by Different Mulching Materials

Although there was no significant difference between WC and control in 2014, treatment application increased blueberry fruit weight in both cultivation years (Figure 2a). The weight of blueberries increased in 2014 for all treatments. Fruit weights ranged from 1.1 kg to 1.3 kg in 2013 and from 1.3 kg to 1.5 kg in 2014. While treatment applications increased the diameter of the fruit in 2014 compared to 2013, no significant differences were observed between treatments in both years (Figure 2b). Furthermore, there were no statistical differences in fruit firmness between the two cultivation years (Figure 2c). Even though the second season treatment increased the mesocarp tissues of the berries, no significant differences were observed between treatments in both years (Figure 2d). While epicarp content differed between the years 2013 and 2014, no statistical differences were detected among the three treatments (Figure 2e).

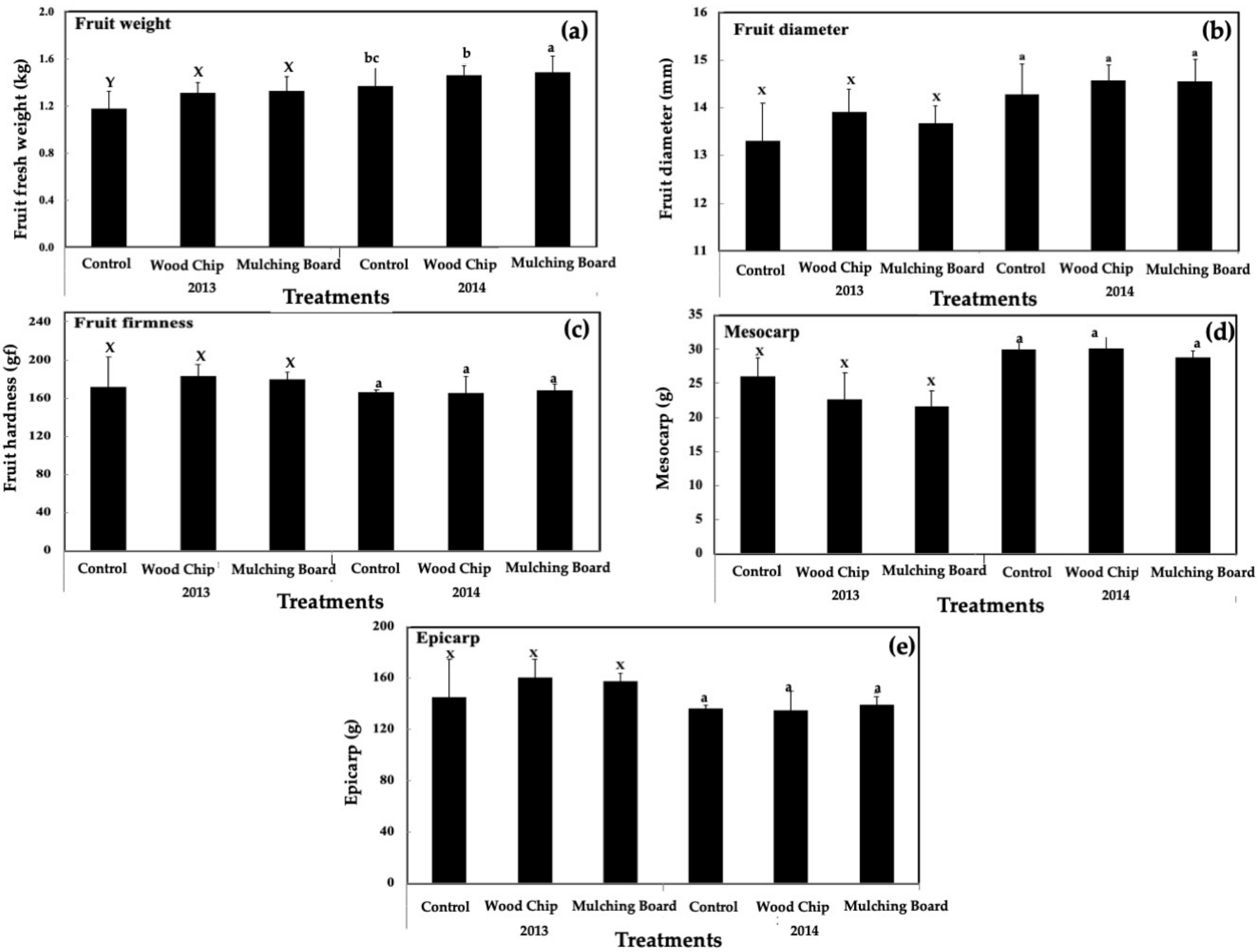

Figure 2. The effects of the different mulching treatments on (**a**) fruit weight, (**b**) diameter, (**c**) firmness, (**d**) mesocarp, and (**e**) epicarp (**e**) of blueberries in both growing seasons. Different letters (a–c) and (x–z) above the bars in each year indicate significant differences among treatments ($p < 0.05$).

3.2. Effects of Different Mulch Treatments on Weed Suppression

The mulch treatments evaluated in this study had effects on weed growth during the experimental period. Compared to 2014, weed growth was nearly twice as high as in 2013 (Figure 3). The highest weed growth in 2013 occurred in August, whereas the lowest occurred in December, irrespective of the treatment (Figure 3a). In August 2013, the control and the WC showed the highest dry-weight values of the weed biomass. The total weed dry weight in the 2013 cultivation year varied from 674.6 g in the WC to 727.1 g in the control. MB treatment showed the highest weed suppression effect with a weed biomass dry weight of 176.7 g. However, in 2014, the highest weed biomass dry weight was found in December, regardless of the treatment application, and it was four times greater than the lowest values observed in June (Figure 3b). Furthermore, unlike in 2013, the WC treatment resulted in the highest total weed dry weight of 418.1 g, compared to 388.6 g in the control. The mulch board treatment showed the highest weed suppression effect at all sampling times.

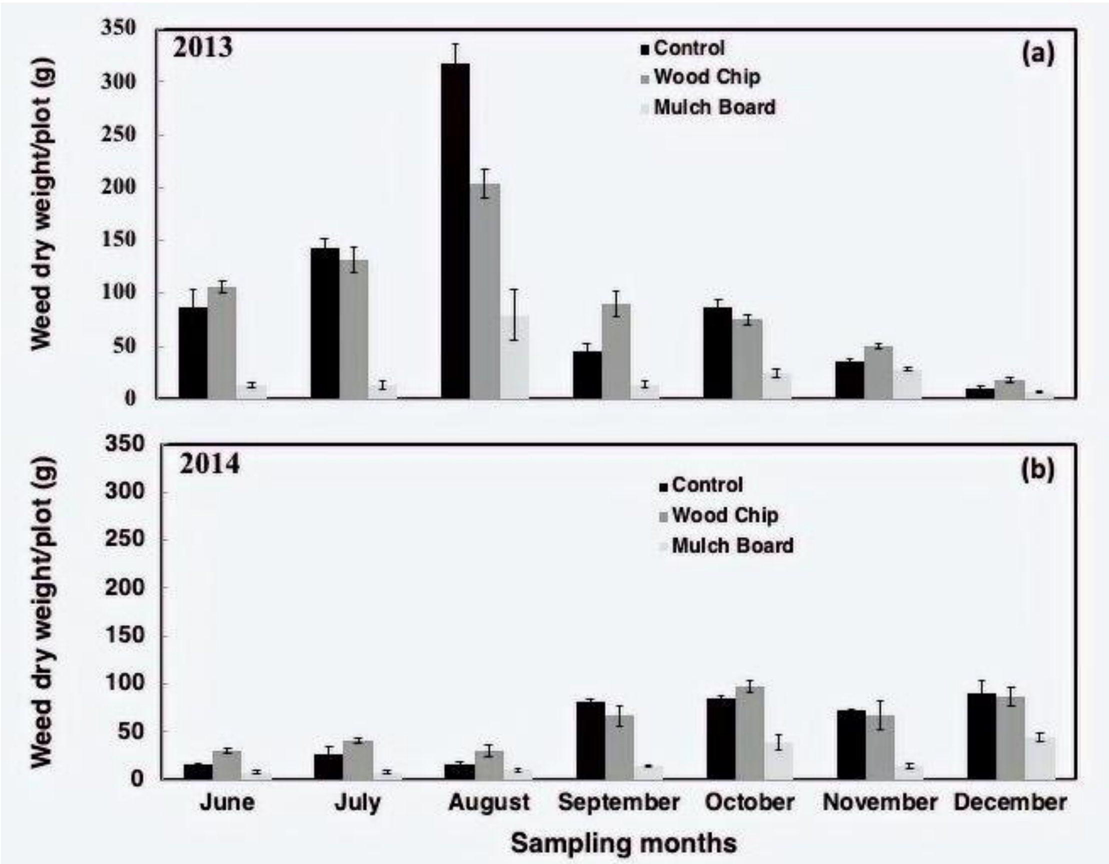

Figure 3. Oven-dried weight of weeds in the (**a**) 2013 and (**b**) 2014 growing seasons. The error bars represent the standard deviation of three replications.

3.3. Impact of Mulch Treatments on Soil Properties

The application of mulch treatments reduced soil surface hardness in the WC and MB treatments (Figure 4) during the repeated two-year study. Soil surface hardness decreased from 0.7 to 0.2 kg cm^{-2} in the WC treatment compared to 1.5 to 1.0 kg cm^{-2} in the MB treatment. This is equivalent to a 68% and 35% reduction in surface hardness in WC and MB treatments, respectively. In contrast, soil surface hardness in control increased from 0.3 to 0.7 kg cm^{-2} in 2013 and 2014, respectively. This corresponds to a 60% increment in soil surface hardness at the end of the study.

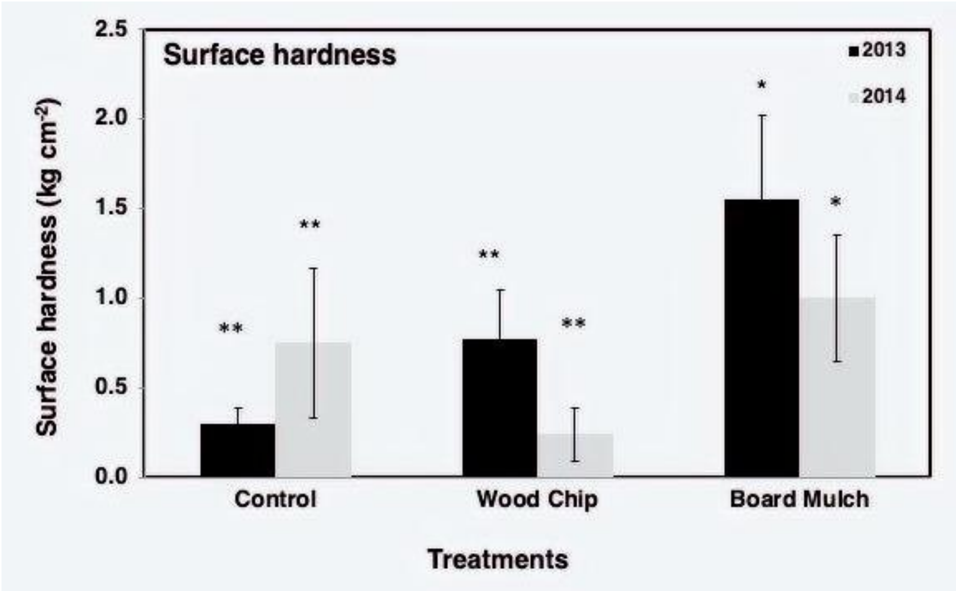

Figure 4. Surface hardness in both growing seasons. The error bars represent the standard deviation of three replications. Significance levels: *: $p < 0.05$, **: $p < 0.01$.

The mulch treatments tested did not significantly affect soil temperature (Figure 5a). Although the WC treatment resulted in higher soil temperatures from May to July, there were no statistical differences when compared to the MB. Furthermore, among the treatments tested, the MB treatment resulted in the highest soil moisture content (Figure 5b). From May to July, the average soil moisture content in the MB treatment ranged from 35 to 39%, while the control ranged from 26 to 30%.

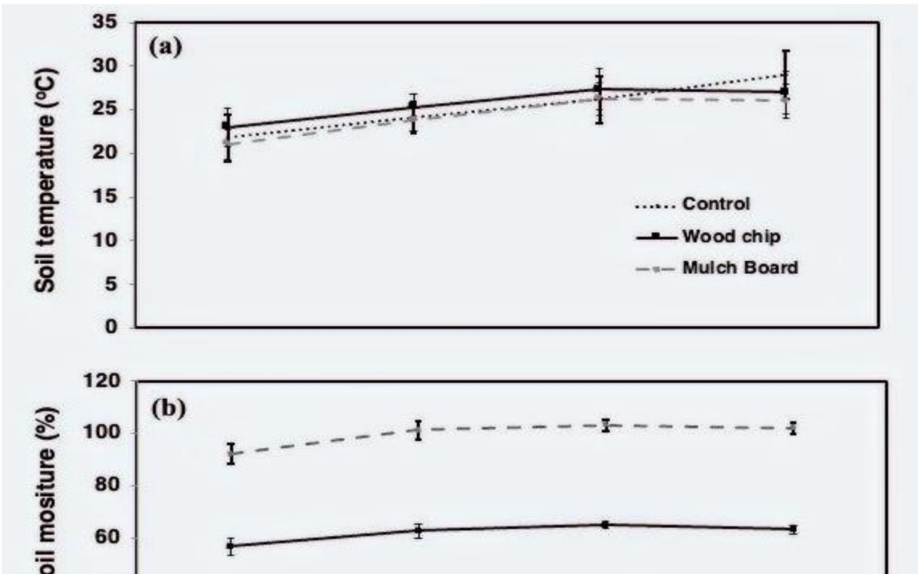

Figure 5. Soil properties (**a**) soil temperature and (**b**) soil moisture content in both growing seasons. The error bars represent the standard deviation of three replications.

4. Discussion

4.1. Mulching Effects on Fruit Yield and Quality

Fruit yield and quality characteristics were generally higher in 2014 than in 2013, most likely as a result of the former receiving more rainfall than the latter. Strik and Davis [32] also reported that the yield of blueberries increased from the second through fourth growing seasons. In both cultivation years, fruit weight was significantly higher in the MB and WC treatments compared to the control. Strik et al. [33] attributed the increase in blueberry yield (measured in terms of fruit weight) to the increase in plant biomass and nutrient accumulation after the mulch treatment. Schindelbeck et al. [34] reported that soil conditions become favorable after the application of organic mulch. Consequently, vegetative growth and fruit development increased significantly in both mulch amendments compared to the control. Spiers [35], however, attributed the improvement in blueberry yield to the root rhizosphere's cooling effects after mulch application to the soil. Although the WC application decomposed and likely increased the nitrogen input to the soil, the fruit yield and quality parameters did not improve significantly. While previous studies have shown significant impacts of surface mulches on blueberry yield [5,36], the significantly higher soil moisture content in MB treatment did not necessarily translate into superior fruit yield gains compared to WC treatment.

Although there were differences in the mesocarp and epicarp contents in both years, none of the mulch treatments tested in the present study showed any significant effect on the observed values. Similar to the results of this study, Strike and Davis [32] reported that blueberry diameter and firmness were unaffected by the mulch type. Retamal-Salgado et al. [37] also reported that the use of pine bark and geotextiles as mulch in blueberries only increased fruit yield without affecting fruit firmness and other fruit qualities. Whilst Pliszka et al. [38] observed significant influences of mulches on the growth and yield of blueberry fruits, a study by Krewer et al. [39] showed minimal impacts of mulch application in the first year. Meanwhile, continuous mulching for eleven to twelve months significantly increased blueberry growth [39]. Strik and Davis [32] reported that some mulching materials usually had little consistent effects on soil and leaf nutrients or soil organic matter during the first few years of application in blueberry cultivation and this may have little effects on yield and some fruit quality parameters. Therefore, long-term evaluations may be necessary to unravel the full impact of these mulching materials on the quality parameters of the fruit of field-grown blueberries.

4.2. Weed Suppression Effects of Different Mulch Materials

Although there was higher rainfall in 2014 than in 2013, the dry weight of the weeds collected in the former was significantly lower than in the latter (Figure 3). The hand-picking of weeds from each plot every month, most of which had not yet blossomed, dramatically reduced the density of the weeds in each treatment. This weed control method probably decreased the likelihood that weed seeds would be dispersed in the soil, which led to a decrease in weed biomass in 2014. Hand weeding on arable farms also successfully decreased the density and population of weeds [40,41]. In both trials, weed dry weight in the MB treatment was the least in all samplings. Compared to WC and control, the MB treatment resulted in a 64–75% reduction in weed dry weight in both cultivation years. This is due to robust soil surface coverage, which denied weeds and weed seeds access to air and water, preventing them from growing effectively. Furthermore, the absence of mulching material in the control plots allowed the weeds to grow physically unrestricted, resulting in increased weed biomass. Even though the amount of wood chip residue remaining in WC was not measured at the end of the experiment, more than half had disappeared by the end of the experiment. However, the MB remained intact throughout the experiment, while some weeds emerged through gaps between the boards. A similar observation was made when a sugarcane bagasse board was used in the production of carrots [42]. Applying MB to the soil in other trials significantly increased radish yields largely due to its higher weed suppression capacity and soil moisture retention [25]. In 2014, the WC treatment showed a total weed dry weight of 418.1 g as opposed to 388.6 g in the control. This increase could be a result of the nutrient inputs from the partially decomposed chip materials from the WC treatment. As more chip components break down and provide nutrients to the soil, the growth of weeds in the WC could likely increase. The MB mulch was recommended over WC mulch as a mulching material due to its significant weed suppression ability, resistance to degradation, and ability to withstand running water.

4.3. Impact of Different Mulching Materials on Soil Properties

Although surface mulching has significant effects on soil temperature dynamics [38,43], minimal effects were observed in this study using the present materials. The MB and WC treatments showed similar potentials in maintaining soil temperature. Similar to the results of this study, sugarcane bagasse board and chips used as mulch in carrot production did not show significant variations in soil temperature [42]. On the contrary, significant differences in soil moisture content were observed between the three treatments during the sampled periods. Among the treatments tested, the soil moisture was significantly higher in the MB treatment followed by the WC (Figure 5b). Furthermore, the MB and WC treatments reduced soil hardness, resulting in better drainage and aeration [34], ensuring effective root growth and development in both treatments. The complete coverage offered by the MB treatment and its 2 cm thickness proved to be the most effective method for retaining soil moisture in this study. Gumbrewicz and Calderwood [44] did not observe any significant change in soil moisture after the variation in the particle size of white pine mulch used for blueberry cultivation. Moreover, the MB treatment retained more moisture after the rainfall event, which subsequently drained the soil by capillary action. Similar results were obtained when the MBs were compared with plastic sheets in radish cultivation [25]. The reduction in soil hardness after treatment with WC was two times higher than after treatment with MB. This is explained by the rapid decomposition of the chip materials, which improved the soil tilth and further increased soil microbial biomass pools, whose activities improved soil drainage and aeration [45–47].

5. Conclusions

The present results showed the positive effect of surface mulches on the cultivation of blueberry plants in the field. Although the compressed mulching biomass board did not significantly influence the fruit quality of blueberry, it significantly improved weed control, making it a desirable material to reduce nutrient competition between weeds and the crop. The mulching board showed the highest weed suppression effect during the two growing seasons in all sampling periods. Furthermore, minimal effects in soil temperature were observed between the WC and MB treatments. Although the mulching materials showed weed suppression effects during the two growing seasons, a long-term study of the MB materials is required to fully investigate the effects of the material on the yield and fruit quality of field-grown blueberries.

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