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Different Floor Management Systems Affect Soil Properties and Initial Development of Apple Tree (*Malus* × *domestica* Borkh.) in an Orchard

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Abstract: In order to achieve sustainable food production, non-chemical weed management practices need to be developed for fruit growing. Tailor-made floor management systems enable efficient weed regulation, but they also affect the soil quality in an orchard. In this article, the effects of various floor management systems in a 'Red Jonaprince' apple (*Malus* × *domestica* Borkh.) orchard on the soil properties and the trees' nutritional status and initial development during the first two years after the orchard's establishment were assessed. The experiment was set up in the spring of 2017 in the Experimental Orchard of WULS. 'Red Jonaprince' cv. trees grafted on M.9 rootstock were planted with 3.5 × 1 m spacing between them. Different floor management systems were applied to the rows, including the selected organic mulches: *Miscanthus* × *giganteus* straw (MG1 and MG2), spent mushroom substrates (SMS1 and SMS2), herbicide strip (HS), clear mechanical soil cultivation (MC), and synthetic black mulch (BC). The organic mulches affected the soil properties significantly. Spent mushroom substrates (SMS1, SMS2) increased the P and K contents in the soil, increased the salinity 10-fold, and retarded the growth in terms of the trunk cross-section area (TCSA) and its increment compared with other systems. *Miscanthus* × *giganteus* straw mulch (MG1, MG2) was associated with a more vigorous shoot growth compared with other combinations in the first year of the study as it provided a better tree nitrogen nutritional status. The floor management system affected the generative development of the trees. Mulching with a spent mushroom substrate boosted the flower bud formation intensity, but it did not affect the yielding quantity. Moreover, due to the poor fruit set, the trees mulched with a spent mushroom substrate (SMS2) gave a low initial bearing. High crop loads were noted for the trees treated with black synthetic mulch (BC) and the trees mulched with *Miscanthus* × *giganteus* straw (MG1). This was an effect of the tree size rather than the blooming intensity, while there were no differences in the cropping efficiency index (CEI) parameter.

Keywords: floor management system; non-chemical weed control; mulch; soil quality; tree development; initial bearing

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1. Introduction

Orchard floor management can limit the development of the plants that compete with trees for water, nutrients, and space, and it also has direct impacts on the soil structure, temperature, and water relations [1], which may significantly deteriorate during the cultivation of perennial crops [2]. Presently, in most fruit crops that are grown in rows, a so-called mixed system is used to maintain the soil. In alleyways, the turf grass is maintained, and a bare soil herbicide strip is left in rows of trees underneath their canopies [3]. The common use of herbicides is related to their effectiveness, relatively low price, and ease of application [4]. On the other hand, the widespread use of this method may promote the presence of active substance residues in the environment [5] and crops [6] as well as the selection of weed biotypes that develop a resistance to herbicides [7]. Unreasonable use of these pesticides can damage the cultivated plants and disrupt the natural processes taking place in the rhizosphere, e.g., affecting disorders in the uptake of macro- and microelements [8,9]. Therefore, the search for solutions that are primarily focused on replacing the herbicides with other more sustainable methods of floor management in the rows beneath the trees is gaining importance [10–14]. Among the alternative methods to the herbicide strip that may be helpful for decreasing the effects of the weeds and allowing sustainability criteria to be met are mechanical cultivation (black fallow) and the use of synthetic (black foil and agro-textile) or organic (manure, sawdust, straw, wood chips, peat, and spent mushroom substrate) mulches [15].

Mechanical cultivation (black fallow) is a relatively effective way to reduce weed infestation, although its results largely depend on the course of the weather conditions, the intensity of weed infestation, and the weed species composition. Some studies have shown that such methods may be ineffective for perennial weed control [7]. Mechanical cultivation also contributes to the deterioration of the soil structure, and it may accelerate the decomposition of organic matter [16], limit the development of soil fauna and microflora [17], and damage the roots of the trees developing in the subsurface layer of the soil [18,19].

The use of synthetic materials to cover the soil in the rows of plants completely reduces the negative effects of the weeds [20], and it maintains a high level of moisture [21]. However, some scientific research suggests that synthetic mulch may negatively affect other physicochemical properties of the soil, such as the mineral content and humus content [22]. Hence, this system can be perceived as not being fully beneficial from the point of view of agro-technics and the broadly understood concept of biodiversity. Serious problems related to the use of synthetic mulches are the need for the expensive disposal of these materials after the end of the cultivation cycle and the potential for serious environmental contamination [23]. The use of biodegradable materials that decompose naturally may be a solution, but due to their fast rate of degradation, they are currently used primarily for vegetable growth [24].

Mulching with organic litter seems to be a solution that is very similar to the use of synthetic materials without the main disadvantages of them. As some authors have suggested, apart from significantly enriching the soil with organic matter [25] and improving its quality [26], this method may also play a significant role in mitigating the effects of excessive carbon dioxide emissions by increasing its sequestration (binding) in the soil [27]. From a practical point of view, a significant advantage of organic mulches is their beneficial effect on soil moisture, which has the effect of decreasing weed competition [28], and thus reducing the losses related to undesirable transpiration and, above all, reducing the losses associated with direct water evaporation from the soil surface, the level of which can be reduced by up to 35% [29]. Moreover, the research results prove that organic litter can significantly slow down the infiltration of water into the soil profile, keeping it within the root system of plants for a longer period of time [30]. The benefits of using mulches also concern the lowering of the susceptibility to mechanical erosion [31]. Furthermore, the incorporation of a large amount of organic matter into the soil as an effect of crop mulching stimulates the activity of microorganisms, and by increasing their diversity, it enriches the microbiological life of the soil [32]. The layer of mulch stabilizes the soil temperature [33], limiting the adverse effects of low temperatures in winter and high temperatures in summer, thus, positively influencing the functioning of the root system [34]. Despite the many advantages of using organic mulches, there are also some limitations. In the case of organic litter, it is necessary to replenish them continuously, mostly on a yearly basis due to their constant decomposition due to the activity of soil microorganisms [35]. The other disadvantages are the low availability and direct cost of purchasing them as well as the carbon footprint accompanying their long-distance transport.

The ongoing development of sustainable horticulture requires the continuous improvement of the production methods to meet the changing environmental and social conditions. This is fostered by the growing willingness of consumers to use products derived from sustainable crops as well as by decisions made by the European Union board that support the activities aimed at reducing the negative impacts of broadly understood agriculture practices on the natural environment. The currently implemented plan that aims to work toward a sustainable EU economy, the European Green Deal, deals with a reduction in the use of plant protection products and the improvement of sustainability [36]. This is a clear signal that non-chemical agrotechnical methods of horticulture should gain importance, including the use of alternative floor management systems to herbicides in orchards, such as those tested in this study.

The aim of the presented experiment was to investigate the hypothesis that replacing herbicides with non-chemical soil management practices can positively affect the soil quality and tree development in newly established plantations. For this purpose, the impacts of various soil management systems on the main properties of the soil and the growth and initial yield of the apple trees were assessed. Special attention was paid to the use of organic litters, which were carefully selected to overcome potential disadvantages concerning their long transportation and the high cost of purchase. Therefore, *Miscanthus* × *giganteus* straw and spent mushroom substrates were of particular interest. *Miscanthus* × *giganteus* straw, which is known for its rapid growth and high dry matter yield [37], can be obtained from plantations established for this purpose, which are located near the cultivation areas of crops that are grown for mulching. On the other hand, the use of a spent mushroom substrate that is available in large quantities in some areas may be a valuable way to manage this agricultural waste [38]. The use of both of these materials is therefore in line with the broadly understood idea of the circular economy and sustainable horticulture.

2. Materials and Methods

2.1. Experimental Site, Conditions, and Design

The trial was established in the spring of 2017 in an experimental orchard of Warsaw University of Life Sciences. The orchard is located in the suburbs of Warsaw in the central part of Poland (N 52°9′36.1″, E 21°5′58.2″). The weather conditions for the experimental site were monitored using the Davis Vantage Pro 7 field weather station (Davis Instruments, Hayward, CA, USA), which was located near to the experimental plots. The weather data collected during the course of the trial are presented in Figure 1.

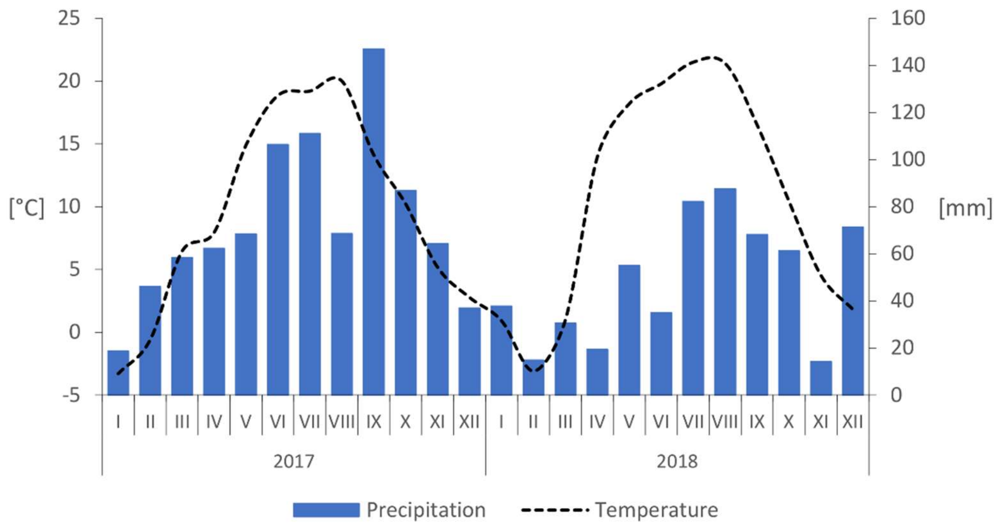

Figure 1. Weather conditions in the 'Red Jonaprince' apple orchard during 2017-2018.

The plant material consisted of well-feathered, uniformly sized maiden apple (*Malus* × *domestica* Borkh.) trees of the 'Red Jonaprince' cultivar that were planted in the spring of 2017 on silty loam alluvial soil with 3.5 × 1 m spacing between them. The trees were trained to form a standard apple spindle bush canopy. In 2017, all of the flowers were removed before full bloom to support tree growth and improve the flower bud formation for the next season. Other agrotechnical treatments were applied in accordance with the local standards for the Integrated Production strategy. No irrigation methods were used on the experimental plots during the experiment.

During the trial, 7 different floor management systems were tested as follows:

(1) a herbicide strip (HS), which was made by applying glyphosate-containing agents twice per season (Roundup 360 SL in 4 L·ha^{-1} dose) at the beginning of June and in October, was used as a control;
(2) mechanical cultivation (MC) was conducted using a rototiller-type tool mounted on a tractor that was run using a hydraulic system, and the soil was tilled depending on demands at least once per 4 weeks from April to October;
(3) synthetic mulch (BC), for which the soil in a tree row was mulched with a black polypropylene cover material at a density of 100 g per m^2;
(4) *Miscanthus* × *giganteus* mulch I (MG1), for which the soil was mulched with straw obtained from shredded *Miscanthus* × *giganteus* plants;
(5) *Miscanthus* × *giganteus* mulch II (MG2), for which the soil in planned tree rows was mulched with straw obtained from shredded *Miscanthus* × *giganteus* plants before tree planting, and it was thoroughly mixed with the soil, which was followed by mulching with the same material after the trees had been planted;
(6) spent mushroom substrate I (SMS1), for which the soil was mulched with a spent mushroom substrate as an agricultural waste material derived from *Agaricus bisporus* production;
(7) spent mushroom substrate II (SMS2), for which the soil in the planned tree rows was mulched with a spent mushroom substrate prior to tree planting, and it was thoroughly mixed with the soil, which was followed by mulching with the same material after the trees had been planted.

All of the described systems were implemented in a soil area, 1 m in width, beneath a tree canopy within a tree row with turfgrass in the alleyways. The doses of organic mulch used in the experiment was approximately 75 L·tree^{-1} when it was used as mulch and 75 L·tree^{-1} when it was used before planting. This was mixed with the soil in the lines of the planned rows of trees, and an additional 75 L·tree^{-1} was used for mulching the soil. The parameters of the organic mulches are presented in Table 1.

Table 1. Physico-chemical properties of mulches used in the experiment.

Mulch Type	Contents of Macro-Elements [% f.w.]			Salinity [g NaCl·L^{-1}]	Organic Matter Content [% d.m.]	Volumetric Mass Density [kg·m^{-3}]
	P	K	Mg			
Spent mushroom substrate	0.36	0.76	0.49	8.49	65.1	341
Miscanthus × *giganteus* straw	<0.1	0.22	<0.1	0.50	2.36	33

Every listed combination was represented by 3 experimental plots, each of them was 5 m^2 in area, where 5 trees were grown. There were 4 buffer trees between each plot. Twenty-one replication plots with a total area of 105 m^2 were distributed in one row of trees within 3 blocks in a randomized block experimental design (Figure 2).

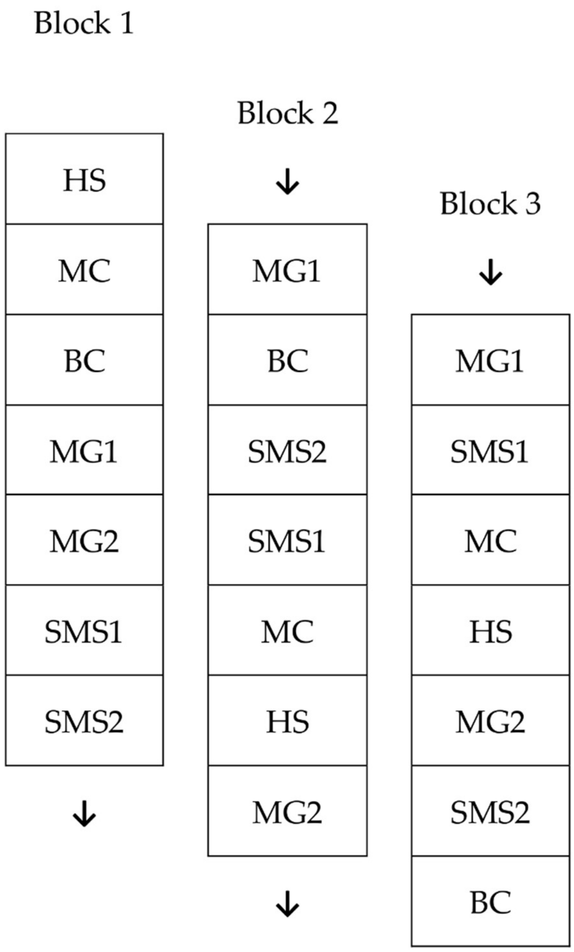

Figure 2. Diagram of the experimental layout used in the presented study, where each rectangle represents experimental plots as follows: HS—herbicide strip; MC—mechanical cultivation; BC—synthetic mulch; MG1—*Miscanthus* × *giganteus* mulch I; MG2—*Miscanthus* × *giganteus* mulch II, SMS1—spent mushroom substrate mulch I; SMS2—spent mushroom substrate mulch II.

2.2. Soil Properties

The soil samples were collected from the experimental site twice during the time covered by the presented results: before the trial set up in the autumn of 2016 (one sample, containing approximately 2000 g, made up with 21 subsamples represented the whole field plot) and at the end of 2018 vegetation season (one sample containing approximately 1500 g per experimental plot, made up of 15 subsamples). This was performed using a gouge auger set for stepwise sampling (Eijkelklamp, Giesbeek, The Netherlands). The samples represented topsoil (0–20 cm) and subsoil (21–40 cm), and they were left at room temperature to dry. The soil pH and salinity were measured in 1 molic KCl solution extract and double-distilled water extract, respectively, using an Elmetron CPC-505 meter (Elmetron, Zabrze, Poland). For each soil layer, 10 g samples were used for examination of the macroelement content which was conducted in accordance with the Egner–Riehm method for P and K and the Schachtschabel one for Mg, as previously described by Komosa and Stafecka [39]. The organic matter content was only measured for the topsoil layer using Tiurin's method, as described by Łądkiewicz et al. [40]. The soil's physico-chemical properties prior to trial establishment are presented in Table 2.

Table 2. Soil parameters of the experimental site measured in autumn 2016 prior to tree planting.

Depth [cm]	pH_{KCl}	Available Macro-Elements in Soil [mg·100 g^{-1}]			K/Mg Ratio	Organic Matter [% d.m.]	Salinity [g NaCl·L^{-1}]
		P	K	Mg			
0–20	5.5	2.76	23.8	15.2	1.57	2.57	0.20
21–40	5.9	2.63	11.2	16.1	0.70	-	0.18

2.3. The Nutrient Content in Leaves

The nutritional status of the trees was assessed using the samples consisting of 50 leaves collected yearly from trial plots directly after the terminal buds formed on year-old shoots. In Polish conditions, this stage of development occurs at the end of July. Fully developed, healthy leaves were taken from annual shoots longer than 20 cm from the middle part of a crown. The collected leaves were taken from the middle parts of the shoots, transferred to the lab, and then dried for 24 h at 70 °C. After the leaves had been dried, they were grounded and tested in terms of the concentrations of the main macro-elements, as follows: nitrogen, which was marked using the Kjeldahl method [41], and P, K, and Mg, which were measured using the ICP-AES technique [42]. P, K, and Mg were marked in samples that had been burnt in a furnace (Czylok, Jatrzębie Zdrój, Poland) at 550 °C. After cooling, 0.5 molic HCl was added to the powder and boiled in a heating block under a condenser for 60 min at 148 °C, which was followed by filtering it through a quartz filter and rinsing it with small portions of acidified water to obtain a volume of 50 mL. The measurements were taken using a Thermo Scientific iCAP 6500 Duo spectrometer (Thermo Fischer Scientific, Waltham, MA, USA) using argon with 99% purity as a carrier gas. The mineral concentration in the leaves is presented as the percentage of dry mass (% d.m.).

2.4. Leaf Area and Tree Growth

In order to assess the leaf area, 50 leaves per plot were harvested using the protocol that was previously described for the tree nutritional status evaluation. The leaves were collected directly after the apple harvest, and then ironed in a paper block before measurement. The Li-3100 Area Meter (Li-Cor, Lincoln, NE, USA) was used for this purpose, and the results are expressed in cm^2. The tree size and growth rate were evaluated using the trunk cross-sectional area (TCSA) and its increment during the study period. These parameters were calculated on a basis of the tree trunk diameter, which was measured at a height of 30 cm above the ground in a permanently marked spot. Trunk diameter measurements were taken on each tree in the spring of 2017 after tree planting and then at the end of every season during the experiment. The results are presented in cm^2. After each season, the one-year-old shoot length and cumulative length of the shoots that appeared during the vegetation period were measured. The results are given in cm and cm·tree^{-1}, respectively.

2.5. Generative Tree Development and Yield Assessment

To assess the generative tree development, the number of flower buds per tree in each plot was counted during the pink bud stage at the end of April 2018. Based on the flower bud number, the flower cluster density (FCD) and blooming efficiency index (BEI) were calculated. The FCD value was computed as a quotient of the flower cluster number for each tree and the cumulative shoot length in 2017. The BEI was calculated as a quotient of the flower cluster numbers for each tree and the TCSA that were measured in autumn 2017. The results are given in pcs·m^{-1} and pcs·cm^{-2} for FCD and BEI, respectively.

The initial yield was assessed in the autumn of 2018 during the harvest period. The results are given in kg·tree^{-1}. The cropping efficiency index (CEI) was determined for all of the tested floor management systems. The CEI value was computed as the quotient of the yield and trunk cross-sectional area measured in autumn 2018, and it is presented in kg·cm^{-2}.

2.6. Statistical Analysis

The data gathered during the course of the trial were analyzed using one-way ANOVA in the Statistica 13.3 software package (StatSoft, Cracow, Poland). The means were separated according to the Newman–Keuls post hoc tests at a significance level of $p \leq 0.05$.

3. Results

3.1. Physico-Chemical Soil Properties

The experiment revealed that the floor management system used significantly affected the orchard soil parameters (Table 3). The soil samples taken from the SMS2 plots showed higher pH values compared to those of the HS and MC combinations in the topsoil, while this parameter was not affected in the subsoil. The mulches affected the mineral concentration in the soil in both of the tested layers. Higher phosphorus contents were noted in the topsoil and subsoil for the SMS2 combination compared with those in the HS, MC, MG1, and MG2 treatments. SMS1 did not differ from any other tested system in terms of the phosphorus concentration in the topsoil, while in the subsoil, there were lower results compared with those obtained with SMS2. In terms of the potassium content, a very clear relationship was found only in the topsoil (0–20 cm). The use of spent mushroom substrate, regardless of the variant used, increased the potassium concentration in the soil in relation to the other combinations. In the subsoil (21–40 cm), there were no differences in the potassium content resulting from the different methods of floor management.

Table 3. Soil parameters measured in two layers depending on floor management systems in the second season of the experiment.

Depth [cm]	System	pH_{KCl}	Available Macro-Elements in Soil [mg·100^{-1} g]			K:Mg Ratio	Salinity [g NaCl·L^{-1}]	Organic Matter Content [% d.m.]
			P	K	Mg			
0–20	HS	5.1 ± 0.5 a	2.80 ± 0.40 a	22.3 ± 4.0 a	14.4 ± 1.6 ab	1.30 ± 0.33 a	0.19 ± 0.01 a	2.77 ± 0.23 a
	MC	5.1 ± 0.3 a	2.63 ± 0.50 a	18.7 ± 3.1 a	15.8 ± 0.5 ab	1.10 ± 0.25 a	0.21 ± 0.03 a	2.79 ± 0.14 a
	BC	5.7 ± 0.3 ab	3.27 ± 0.15 a	20.2 ± 5.8 a	14.0 ± 0.1 a	1.13 ± 0.36 a	0.18 ± 0.02 a	2.32 ± 0.46 a
	MG1	5.5 ± 0.5 ab	3.06 ± 0.50 a	24.3 ± 5.5 a	14.7 ± 0.9 ab	1.33 ± 0.34 a	0.26 ± 0.09 a	2.69 ± 0.29 a
	MG2	5.3 ± 0.7 ab	4.27 ± 0.70 a	25.2 ± 2.9 a	16.0 ± 2.1 ab	1.36 ± 0.28 a	0.23 ± 0.08 a	3.48 ± 0.67 ab
	SMS1	5.7 ± 0.1 ab	14.9 ± 2.95 ab	63.3 ± 4.8 b	15.1 ± 1.5 ab	2.93 ± 0.36 b	1.26 ± 0.37 b	3.52 ± 0.75 ab
	SMS2	6.3 ± 0.3 b	22.6 ± 4.21 b	66.3 ± 6.2 b	18.8 ± 3.2 b	3.46 ± 0.19 b	2.08 ± 0.25 c	4.30 ± 0.25 b
21–40	HS	5.4 ± 0.7 a	3.33 ± 0.90 a	16.1 ± 5.9 a	16.1 ± 2.5 a	0.86 ± 0.53 a	0.19 ± 0.03 a	n.a. *
	MC	5.3 ± 0.4 a	2.97 ± 0.53 a	15.3 ± 3.3 a	15.3 ± 1.5 a	0.76 ± 0.20 a	0.24 ± 0.03 a	
	BC	6.0 ± 0.7 a	1.80 ± 0.50 a	14.9 ± 3.5 a	14.9 ± 0.9 a	0.63 ± 0.31 a	0.17 ± 0.04 a	
	MG1	5.6 ± 0.5 a	3.56 ± 0.87 a	15.9 ± 2.4 a	15.9 ± 0.6 a	1.13 ± 0.62 a	0.23 ± 0.01 a	
	MG2	6.0 ± 0.9 a	3.20 ± 0.98 a	15.6 ± 1.9 a	15.6 ± 1.9 a	0.86 ± 0.66 a	0.26 ± 0.09 a	
	SMS1	5.6 ± 0.2 a	7.80 ± 1.99 a	17.2 ± 4.3 a	17.2 ± 2.0 a	1.33 ± 0.41 a	1.26 ± 0.04 b	
	SMS2	6.3 ± 0.3 a	23.8 ± 2.12 b	18.5 ± 3.6 a	18.5 ± 3.0 a	2.46 ± 0.85 b	2.04 ± 0.25 c	

Note: means followed by the same letter in columns within the same depth do not differ statistically according to the Newman–Keuls post hoc test at $p \leq 0.05$; * data not available.

The SMS2 treatment had a significant effect on the magnesium content. This treatment enriched the soil with magnesium when compared with the effects of the BC combination. The other combinations did not lead to differences in this parameter. The spent mushroom substrate elevated the K:Mg ratio and soil salinity. The K:Mg ratio was affected regardless of the application variant in the topsoil layer, while in the lower layer, increased values were recorded only for SMS2. The effect on soil salinity was significant for both the topsoil and subsoil, and this depended on the amount of substrate used in the treatment. When higher amounts of spent mushroom substrate were used, higher salinity values were noted. There were 6-fold and 10-fold increases in the salt concentration in the soil for SMS1 and SMS2, respectively. A higher organic matter content was observed following the SMS2 treatment compared with the following treatment with the HS, MC, BC, and MG1 combinations.

3.2. Nutritional Tree Status and Growth

According to the results presented in Table 4, the method of floor management used in the rows of trees significantly modified the tree nutritional status as well as the size of the leaves, but the values differed depending on the year of observation. In 2017, there was a higher nitrogen content in the leaves of trees growing in the MG1, MG2, and SMS1 plots compared to those treated with other combinations. The use of SMS2 led to a higher phosphorus leaf content, but only when it was compared to those in MC, BC, and MG1, and there was an elevated potassium concentration for SMS2. In 2018, the lowest leaf nitrogen concentration was recorded for the MG2 combination, while the values for MC were higher, and the highest level was noted for the SMS1 treatment. The nitrogen concentration values in the leaves of trees growing in HS, BC, MG1, and SMS2 did not differ significantly from those treated with MC and SMS1. In terms of phosphorus, as it was the case for potassium, no significant effects were noted. The magnesium content in the leaves was not affected by the treatments in the 2017 and 2018 seasons. The analysis of the leaf area showed a significant impact of soil management systems on this parameter. The leaves from trees growing in MC, MG1, and MG2 were significantly larger than those harvested from trees growing in the SMS1 and SMS2 plots. The other treatments did not lead to differences in the leaf area.

Table 4. Macro-nutrient contents in the leaves and leaf areas of tested apple trees with different floor management systems in 2017–2018.

Year	System	Macroelement Concentrations in Leaves [% d.m.]				Leaf Area [cm^2]
		N	P	K	Mg	
2017	HS	2.31 ± 0.11 a	0.16 ± 0.01 ab	2.13 ± 0.24 a	0.20 ± 0.01 a	36.9 ± 3.76 ab
	MC	2.35 ± 0.01 a	0.14 ± 0.01 a	2.02 ± 0.09 a	0.20 ± 0.02 a	43.6 ± 1.59 b
	BC	2.47 ± 0.20 a	0.15 ± 0.01 a	1.92 ± 0.19 a	0.19 ± 0.01 a	35.9 ± 2.35 ab
	MG1	2.83 ± 0.12 b	0.14 ± 0.01 a	2.05 ± 0.07 a	0.19 ± 0.02 a	41.3 ± 3.79 b
	MG2	2.87 ± 0.09 b	0.16 ± 0.01 ab	2.13 ± 0.15 a	0.19 ± 0.01 a	42.6 ± 3.41 b
	SMS1	2.97 ± 0.10 b	0.16 ± 0.01 ab	2.10 ± 0.04 a	0.18 ± 0.01 a	32.4 ± 1.79 a
	SMS2	2.46 ± 0.03 a	0.20 ± 0.01 b	2.58 ± 0.06 b	0.19 ± 0.01 a	31.5 ± 4.01 a
2018	HS	2.46 ± 0.03 bc	0.17 ± 0.02 a	1.12 ± 0.05 a	0.27 ± 0.03 a	36.4 ± 3.70 ab
	MC	2.36 ± 0.08 b	0.18 ± 0.02 a	1.27 ± 0.15 a	0.22 ± 0.01 a	43.8 ± 1.76 b
	BC	2.47 ± 0.37 bc	0.17 ± 0.01 a	1.08 ± 0.16 a	0.29 ± 0.03 a	36.0 ± 2.43 ab
	MG1	2.45 ± 0.26 bc	0.16 ± 0.01 a	1.39 ± 0.06 a	0.22 ± 0.04 a	41.0 ± 5.51 ab
	MG2	2.21 ± 0.11 a	0.18 ± 0.01 a	1.28 ± 0.22 a	0.22 ± 0.05 a	42.5 ± 3.52 b
	SMS1	2.51 ± 0.09 c	0.16 ± 0.01 a	1.48 ± 0.18 a	0.22 ± 0.02 a	32.2 ± 2.26 a
	SMS2	2.47 ± 0.14 bc	0.16 ± 0.01 a	1.45 ± 0.06 a	0.22 ± 0.01 a	31.7 ± 4.19 a

Note: means followed by the same letter in column within the same depth do not differ statistically according to the Newman–Keuls post hoc test at $p \leq 0.05$.

While the nitrogen concentration in apple leaves seems to be one of the most affected nutritional status parameters by the floor management systems for the trees in our experiment, we also observed some variation in the ratio of nitrogen to the other main nutrients (Figure 3). Using spent mushroom substrate as a mulch elevated the N:P ratio, and this was clearly shown in both seasons of observation. The N:K ratio was not affected by the main experiment factor, but its values seem to be dependent on the season, and in 2018, they were relatively higher than those in 2017. Additionally, the N:Mg ratio was season dependent. In 2017, higher values of this parameter were noted for the MC, BC, MG1 treatment groups compared to in the trees treated with the SMS2 combination, while in 2018, the trees exposed to the MG1, MG2, SMS1, and SMS2 treatments had higher N:Mg ratios than those treated with the HS and MC combinations did. The ratio of nitrogen to the sum of all of the nutrients for which the contents were determined in the leaves was significantly affected in the first year of our study only. A higher N:(N+P+K+Mg) ratio was recorded for the MC treatment in comparison with that of the SMS2 plot, while the values for HS, BC, MG1, MG2, and SMS1 did not differ from any other groups.

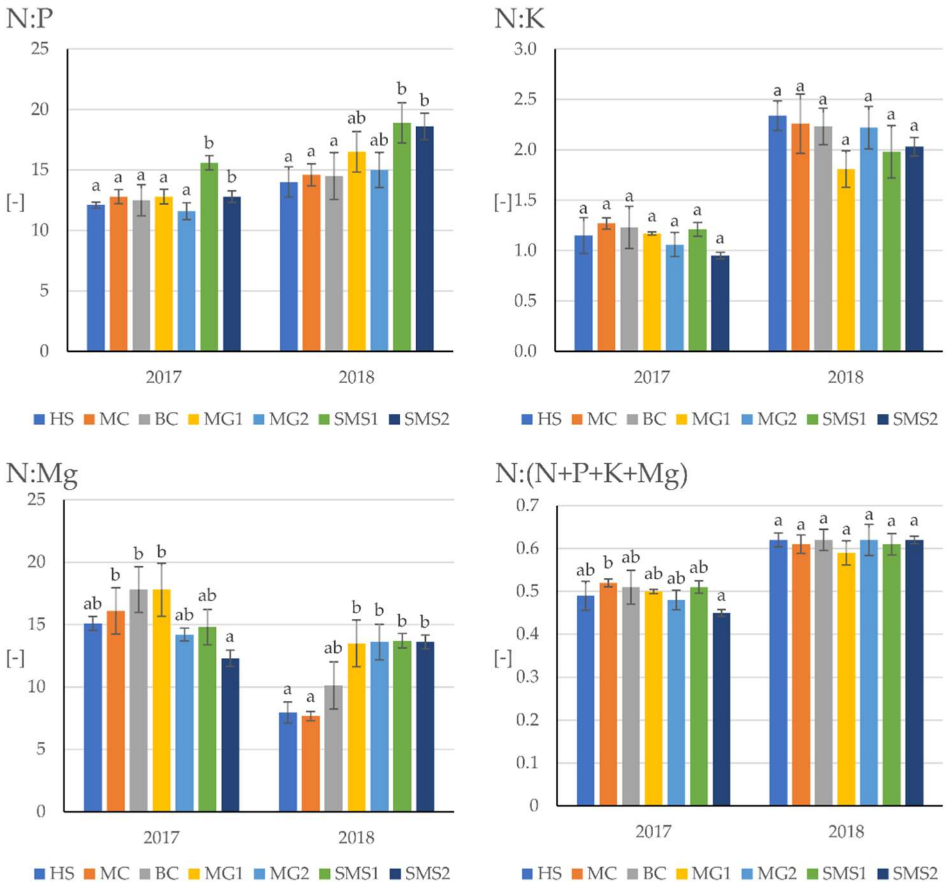

Figure 3. Macro-nutrient ratios in 'Red Jonaprince' apple leaves calculated for elements chosen depending on the floor management system used. Letters over bars indicate significant differences between treatments within a year according to the Newman–Keuls post hoc test at $p \leq 0.05$.

The floor management systems affected the growth of the trees in the seasons covered by the experiment, as shown in Table 5. The measurements of the trunk diameters just after setting up the experiment showed that the planting materials used for the trials were homogenous in size. In the first year of the study, we noted more vigorous growth of the trees with larger trunk cross-section areas (TCSA) were recorded for the trees grown in the BC combination plots compared those exposed to the SMS1 and SMS2 treatments.

Table 5. TCSA and its growth and the shoot lengths of tested apple trees depended on the floor management system used during the trial.

System	Initial TCSA [cm^2]	Autumn 2017			Autumn 2018			TCSA Increment 2017–2018 [cm^2]	Cumulative Shoot Length 2017–2018 [cm]
		TCSA [cm^2]	Mean Shoot Length [cm]	Cumulative Shoot Length [cm]	TCSA [cm^2]	Mean Shoot Length [cm]	Cumulative Shoot Length [cm]		
HS	1.15 ± 0.08 a	2.78 ± 0.12 bc	20.7 ± 0.8 b	428 ± 33 c	4.39 ± 0.22 b	25.6 ± 1.1 a	802 ± 79 c	3.25 ± 0.24 b	1230 ± 104 c
MC	1.17 ± 0.12 a	2.67 ± 0.13 bc	18.9 ± 1.9 ab	600 ± 96 d	4.89 ± 0.19 b	27.4 ± 3.5 a	915 ± 47 d	3.61 ± 0.14 b	1515 ± 144 d
BC	1.28 ± 0.05 a	3.09 ± 0.28 c	24.3 ± 2.4 b	532 ± 59 cd	4.19 ± 0.51 b	26.7 ± 2.6 a	609 ± 48 b	3.02 ± 0.46 b	1142 ± 86 c
MG1	1.17 ± 0.18 a	2.88 ± 0.39 bc	29.1 ± 3.9 c	526 ± 34 cd	4.58 ± 0.55 b	25.8 ± 2.5 a	744 ± 55 c	3.41 ± 0.37 b	1269 ± 54 c
MG2	1.16 ± 0.07 a	2.81 ± 0.02 bc	37.9 ± 2.8 d	495 ± 67 cd	4.46 ± 0.07 b	33.0 ± 1.8 b	1077 ± 59 d	3.30 ± 0.14 b	1573 ± 104 d
SMS1	1.30 ± 0.20 a	2.37 ± 0.31 ab	15.0 ± 2.6 ab	272 ± 21 b	3.47 ± 0.49 a	23.9 ± 3.6 a	567 ± 35 ab	2.16 ± 0.40 a	838.9 ± 35 b
SMS2	1.11 ± 0.09 a	2.03 ± 0.08 a	11.4 ± 2.2 a	153 ± 19 a	3.02 ± 0.11 a	23.6 ± 0.6 a	480 ± 46 a	1.91 ± 0.04 a	633.4 ± 60 a

Note: means followed by the same letter in a column do not differs statistically according to the Newman–Keuls post hoc test at $p \leq 0.05$.

After the second year of tree growth, the plants that were grown in the combinations in which a spent mushroom substrate was applied, regardless of the amount used, showed significantly lower TCSA values compared to the trees growing in the other tested systems.

The choice of floor management system affected the average length of the one-year-old shoots. The MG1 and MG2 systems were shown to have significant impacts on the mean shoot length. The shoots in the mentioned combination were longer than those in the other treatment groups, while the values for the MG1 group were lower than those recorded for MG2, and SMS2 decreased the shoot length the most. In 2018, only the MG2 combination showed longer one-year-old shoots. The soil management practices used in the orchard also affected the cumulative shoot length in both of the years of the experiment and during the trial on the whole. The highest values of this parameter were recorded for trees grown in the MG2 and MC combinations. Significantly lower cumulative shoot length values were recorded for the HS, BC, and MG1 treatment groups. In general, the spent mushroom substrate decreased shoot vigor the most, but SMS2 inhibited it more strongly than SMS1 did.

3.3. Generative Tree Development

The blooming of the trees depended on the soil management system used in the orchard (Table 6). The values of all of the parameters describing flowering were modified by the experimental factor. The number of flower buds per tree was higher for the trees growing in SMS2 and BC compared to those growing in HS, MG1, and MG2. The highest flower cluster density (FCD) values were recorded for the plots where the spent mushroom substrate was used. Significantly lower values were calculated for BC, and the lowest values were recorded for HS, MC, MG1, and MG2. The trees grown in the SMS1 and SMS2 treatment plots also showed the highest values for the blooming efficiency index (BEI), while MG1 and MG2 decreased the value of this parameter in the same way as for FCD. The highest fruit set value was recorded for the MG1 combination. Significantly lower values were noted for the MG2, MC, and HS combinations, and the lowest values were recorded for the SMS2, SMS1, and BC treatment groups. The floor management system affected the initial cropping of the trees. The highest yield was obtained from the trees growing in the MG1 and BC systems. Significantly lower yields were noted for all of the other combinations, among which the SMS2 treatment particularly decreased the yield. The soil management systems have not been shown to affect the cropping efficiency index (CEI), but the level of variation among the values was relatively high.

Table 6. The blooming intensity, fruit set, and initial bearing of the tested apple trees depended on the floor management system used during the trial.

System	No. of Flower Clusters [pcs·Tree^{-1}]	Flower Cluster Density [pcs·m^{-1}]	Blooming Efficiency Index (BEI) [pcs·cm^{-2}]	Fruit Set [pcs·100^{-1} Flower Buds]	Initial Yield [kg·tree^{-1}]	Cropping Efficiency Index (CEI) [kg·cm^{-2}]
HS	47.7 ± 3.2 a	3.82 ± 0.55 a	17.2 ± 2.2 ab	75.0 ± 1.9 b	7.44 ± 0.77 b	1.70 ± 0.19 a
MC	51.0 ± 5.7 ab	2.93 ± 0.35 a	19.0 ± 1.7 b	68.5 ± 5.7 b	6.21 ± 0.78 ab	1.48 ± 0.15 a
BC	61.3 ± 8.8 b	5.97 ± 0.80 b	19.9 ± 0.8 b	60.4 ± 1.7 a	8.90 ± 0.48 c	1.84 ± 0.29 a
MG1	47.3 ± 6.3 a	3.73 ± 0.65 a	16.4 ± 0.8 ab	86.7 ± 13.3 c	9.12 ± 0.40 c	2.00 ± 0.16 a
MG2	37.7 ± 3.2 a	2.41 ± 0.35 a	13.4 ± 1.2 a	74.2 ± 6.8 b	7.48 ± 0.24 b	1.68 ± 0.03 a
SMS1	51.0 ± 5.1 ab	7.37 ± 0.85 c	26.2 ± 2.2 c	52.7 ± 6.3 a	6.73 ± 0.73 ab	1.97 ± 0.41 a
SMS2	61.7 ± 3.6 b	8.11 ± 1.01 c	25.2 ± 2.8 c	53.0 ± 2.7 a	5.65 ± 0.53 a	2.00 ± 0.24 a

Note: means followed by the same letter in a column do not differs statistically according to the Newman–Keuls post hoc test at $p \leq 0.05$.

4. Discussion

Many published studies show that the floor management system significantly affects soil properties such as the pH, the nutrient concentration, and the organic matter content [25,43–49]. The results of these works indicate that the nature and dynamics of these changes depend on the method used. The use of mulch may have no effect or it may increase the content of minerals in the soil or limit their availability [30,50,51]. The use of organic litter as a mulch has a particularly large impact on the soil properties, although its effect can be very diverse, and it depends on the origin, composition, and physico-chemical properties of the material used. According to [29,47,52], the use of organic litter generally leads to an increase in the content of organic matter in the soil, which was also been observed in the presented experiment for the SMS2 combination. During our two-year trial, the use of the spent mushroom substrate led to an increase in the pH as well as in the contents of P, K, and Mg, and this effect was mostly observed in topsoil as a result of the high contents of these components in the used litter. Miscanthus straw, in turn, was a much poorer source of the mentioned macro-nutrients, although it should be emphasized that in the cases of both P and K, their contents in the soil in the plots where this mulch was used were relatively high in comparison to the treatments where no organic litter was used at all.

The presented results suggest that the floor management system affected the nutritional status of the trees, which was also observed by other authors [25]. In general, the trees mulched with organic material in the experiment showed relatively high nitrogen contents in the leaves. However, the proven influence of organic litter was only observed in the first season of research when it was relatively humid due to a large amount of precipitation. After analyzing the results obtained in the presented study, it can be assumed that the observed variability was an indirect result of mulching, and it probably was primarily dependent on the soil moisture and temperature [53]. The soil in the experimental orchard in Wilanów is well known for its high organic matter content. Thus, mineralization can provide a rich source of nitrogen which is easily available to plants, as has been documented in several studies [54–57]. Mulching the soil helps to retain moisture and stabilize the soil temperature, which could positively affect the dynamics and efficiency of inorganic nitrogen release into the bulk soil [58]. This may explain why the nitrogen leaf content differs between the years, and the higher concentrations seem to be correlated with periods of higher soil moisture as an effect of higher rates of precipitation, especially for the mulched plots. In turn, the relatively low nitrogen content in the leaves of the trees growing in the MG2 plots in the second year of the study can be explained as an effect of using a large amount of shredded straw with a high C:N ratio. The small amount of rainfall and the accompanying low soil moisture did not favor natural nitrogen release [53], and the increased C:N ratio additionally could have caused microbial nitrogen immobilization [59]. In this situation, it should be assumed that a similar mechanism of nitrogen circulation in the soil also took place in 2017, but the net balance in the inverse soil moisture conditions at that time covered the needs of trees as well as the microrganisms.

For P and K, the very high P and K contents in the soil mulched with the spent mushroom substrate led to significantly increased concentrations of these macro-nutrients in the tree leaves. As in the case of nitrogen, a significant differentiation of the effect was visible only in the first season of study, which seems to confirm the significant influence of the weather conditions. The relatively high potassium content in the leaves in the first year of observation was probably also influenced by the flower removal, which was performed to prevent fruit bearing in the first year of the tree's growth. This is strongly supported by the finding of Mészáros et al. [60] which state that the mineral balance of apple tree is strongly dependent on the yield level.

The quality, growth, and development of the trees in the first season after the orchard establishment is crucial from the point of view of maintaining appropriate vigor in the plants and allowing the early initiation of fruiting [61–63]. The two-year research period covered by the presented experiment allowed us to assess the impact of the floor management systems on the initial growth and development of the trees. It has been shown that the use of mulches can modify the growth of trees in an orchard, and the effect depends on the material used and its quantity. The spent mushroom substrate greatly limited the growth of the trees in both the first and second seasons of their growth. In 2017, in the SMS2 combination, the trunk cross-section area (TCSA), the mean shoot length, and the cumulative shoot length values were lower by 27%, 45%, and 64%, respectively, compared to those of the control combination (HS), and in 2018, they were lower by 31%, 8%, and 40%, respectively. The use of miscanthus litter led to an improvement in the trees' vigor, although this effect was not as clear, and it concerned the increase in the one-year-old shoots length in 2017. This seems to be correlated with the observed better nitrogen nutrition of the trees. In turn, the described impact of the spent mushroom substrate in the experiment which resulted in the excessive P and K content in the soil did not affect the trees' growth and yield positively. This results are similarly to Łysiak and Pacholak's [64] finding. They proved that in certain conditions, fertilisation had no effect on the growth and fruit set in apple growing. Moreover, as stated by Brunetto et al. [65], a mineral content above the upper threshold may even lead to some negative impacts. This was also identified in the presented study as high soil salinity, which increased by up to 10-fold in the combinations where the spent mushroom substrate was used. As Zhao et al. [66] and Singh et al. [67] reported, salinity is a strong stress factor for plants which reduces their growth but also increases their flowering intensity. The results of the experiment confirm this. The trees that were mulched with the substrate had relatively high numbers of inflorescences. The recorded numbers of flower buds in relation to the length of the shoots and the trunk cross section area (TCSA) suggest that the observed variation was also due to vegetative growth acting as a limiting factor, as this is a factor that is well known to affect flower bud development [68,69]. The potentially beneficial effect, however, did not affect the yield, which was the result of the poor fruit set observed for the trees mulched with the spent mushroom substrate, and this led to a low yield level, especially when they were compared to the other combinations. The high initial yield was favored by the mulching trees with *Miscanthus* × *giganteus* straw and black fabric, although the mulching effect was highly dependent on the amount of litter used. It seems that relatively high bearing that the trees mulched with black synthetic material (BC) and *Miscanthus* × *giganteus* straw (MG1) demonstrated was rather the effect of the tree size rather than the blooming intensity, because there were no differences in the cropping efficiency index (CEI) parameter.

5. Conclusions

The presented results provide a complete summary of the first step of the experiment, which ended with the initial cropping of the trees. The experiment results prove that organic mulches can be used as alternatives for the more common soil management methods in rows of trees. The mulching trees with *Miscanthus* × *giganteus* straw appeared to be one of the most productive system in terms of the initial yield, and among the other tested systems, it lacks the serious downsides, especially in terms of the environmental issues. *Miscanthus* × *giganteus* straw, which was used as mulch, has an indirect beneficial effect on the growth and development of young trees in orchards grown on soil rich with organic matter. Due to its potentially large and easy availability, it is an interesting alternative to the other mulches obtained from the plants. The presented results also show that the spent mushroom substrate can be a valuable source of potassium and phosphorus in the soil. On the other hand, the significant impact of using the litter to increase the level of soil salinity limits its use in practice to doses lower than those used in the experiment. The next step of our research will be to continue to evaluate the effects of different floor management systems on soil properties as well as the regularity and level of yielding trees and the quality of the fruit.

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