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Assessment of the variability of loess soil moisture in pear orchards in different use zones

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Abstract: Soil moisture is one of the most important factors determining crop development, growth and yield. Moisture variability is primarily related to the precipitation, soil texture and vegetation cover. The aim of the study was to assess the impact of soil maintenance systems on moisture content in brown soil formed from loess. The study was conducted during the summer season in 2019–2021 at the Fruit Growing Experimental Station in Garlica Murowana near Krakow operating as part of the Faculty of Biotechnology and Horticulture of the University of Agriculture in Krakow. Soil moisture content was measured at two measuring points in a pear orchard (under the tree crowns and between the rows of trees) and one at the agrometeorological station located next to the orchard. The results showed that the topsoil (0–20 cm) was most susceptible to meteorological conditions. The impact of the soil surface maintenance system in the orchard determined the soil moisture content. The greater the coverage of the soil surface by tree crowns, the higher the moisture content in the soil and the smaller the differences in the soil profile. The key role of soil retention associated with granulometric composition, consisting silt loam, has been confirmed as well as.

Keywords: loess soil, orchard, soil maintenance, soil moisture content

INTRODUCTION

Soil moisture is the basic source of water for crops, regulating many processes, such as nutrient uptake, photosynthesis and soil structure maintenance (Dobriyal *et al.*, 2012). That is why investigation of this factor and its temporal and spatial variability is essential for studies on meteorological and hydrological processes, water resources and climate change (Koster *et al.*, 2004; Ford *et al.*, 2014). Soil moisture is created by such natural agent as climate, plant cover and soil properties (Schulz *et al.*, 2021; Ye *et al.*, 2023; Lin *et al.*, 2024). The main climate parameter influencing soil moisture is precipitation in terms of the amount, intensity and temporal distribution (Treder *et al.*, 2022). In general, at a local scale, the structure of precipitation can be modified to a large extent by relief and land use, resulting in varying crop-growing conditions (Bokwa and Skowera, 2008). Zarzycki *et al.* (2020) found that tall vegetation has a significant impact on soil moisture conditions. As a result of advanced secondary forest succession, trees attenuate evaporation from the soil and thus soil water levels stabilise. Based on studies conducted in a forest in a tropical, semiarid climate, Rascón-Ramos *et al.* (2021) showed the influence of precipitation and land cover on soil moisture in forests. In microcatchments with different forest densities during the rainy season, high evapotranspiration and interception rates did not significantly increase soil moisture after low rainfall. The accumulation of 10 mm of rain in the first 30 minutes represented a threshold of rainfall that caused a drastic increase in soil moisture. In contrast, low rainfall (<10 mm) significantly increased soil moisture in the catchment where tree pruning or post-thinning was applied.

Li *et al.* (2024) found that soil texture is an important factor affecting soil moisture. They determined the correlation between soil moisture in the 0–10 cm layer, surface soil moisture and soil moisture in seven layers up to 120 cm (at depths of 20, 40, 60, 80, 100 and 120 cm) in soils of different textures and climates in the USA. The initial moisture content of the soil, i.e. before the onset of precipitation, has a significant impact on the changes in water content in the different layers of the soil profile. Irrespective of the thickness of the soil layer, the lower the initial moisture content of the soil, the more precipitation water it is able to store (Treder *et al.*, 2022). In addition to the amount of precipitation, the physical properties of the soil, which determine the soil's water retention capacity, are of fundamental importance for soil water resources. For plants, water resources in the subsurface soil layer (0–40 cm) are particularly important (Walczak and Usowicz, 1994; Biniak-Pieróg *et al.*, 2011). In order to better understand biogeochemical processes as well as surface and subsurface lateral flows, knowledge of soil moisture dynamics at the local scale and its spatial variability is essential (Vereecken *et al.*, 2014).

In the context of the multifactoral determinants of soil moisture, this issue is particularly important for the safety of food production in relation to the global warming and its consequences. The increase in air temperature (Sulikowska and Wypych, 2021), precipitation variability (on a global scale entails an increase in the dryness of climates, and locally the occurrence of increasingly severe economic droughts, from atmospheric, through soil, agricultural to hydrogeological ones (Ziernicka-Wojtaszek and Kopcińska, 2020; Bartoszek *et al.*, 2021; Wałęga *et al.*, 2024). Ecological practices are part of climate change adaptation strategies and improving retention through appropriate soil use is particularly noteworthy. Nagy *et al.* (2020) observed soil dependencies on land use: pastures and orchards (especially tree rows), were identified as sites with high retention capacity. Tang *et al.* (2019), based on a study conducted on loess soils, demonstrated the influence of land use on soil water retention. They found that under meteorological drought conditions in orchards, areas covered with natural vegetation or green mulches improved soil moisture by 14–18% compared with arable land. The pear tree is a thermophilic species and sensitive to moisture deficiencies in the soil. Research on the determinants of soil moisture in fruit cultivation in Poland is fragmentary and most often focuses on the impact of precipitation on soil moisture content. Research on water retention in the soil through proper care is becoming increasingly important. The aim of the study was to determine the impact of the methods of loess soil cultivation in pear orchards on the dynamics of soil moisture variability.

STUDY MATERIALS AND METHODS

STUDY AREA

The investigation was conducted in Garlica Murowana near Krakow, which, according to the physical geographical division of Poland, belongs to the south-eastern part of the Olkusz Upland, which is part of the macroregion of the Krakow-Czestochowa Upland.

In order to determine the impact of soil maintenance on the moisture content of loess soil, a field experiment was set up in the central part of a pear orchard located on the plateau in Garlica Murowana at the site of the Fruit Growing Experimental Station operating as part of the Faculty of Biotechnology and Horticulture of the University of Agriculture in Krakow and at the site of the Agrometeorological Station belonging to the Department of Ecology, Climatology and Air Protection of the Faculty of Environmental Engineering and Geodesy. The garden of the Agrometeorological Station is located at an altitude of 270.00 m a.s.l. (φ = 50°09'N, λ = 19°55'E) (Bokwa and Skowera, 2008).

Figure 1 shows the location of the pear orchard where the investigation was conducted and the agrometeorological station, which, in addition to measuring soil moisture, provided meteorological data to characterise the study period.

CLIMATIC CONDITIONS OF THE STUDY AREA

The most favourable thermal conditions in the study area occur on the plateaus where the average annual temperature is 7.0°C. On north-facing slopes it is 6.6°C and in the valley bottoms, it is 6.2°C, i.e. the coldest (Kondracki, 2000). Garlica Murowana is located in a rain shadow, in agricultural land. Compared with the Krakow Botanical Garden and Krakow Balice stations, there is less precipitation here, but it is characterised by greater variability. The average annual precipitation in Garlica was 595–600 mm (Bokwa and Skowera, 2008).

The analysis of soil moisture in the period May–September 2019–2021 is presented against the background of meteorological conditions. The weather characteristics are presented on the basis of the 10-day average air temperature, precipitation totals, number of days with precipitation and the calculated values of the hydrothermal coefficient (*HTC*) developed by Selyaninov, calculated according to the equation:

$$HTC = \frac{10P}{\sum T} \tag{1}$$

where: P = total daily precipitation (mm) in the 10-day period; ΣT = total of average daily air temperature (°C) in the 10-day period.

Meteorological data were obtained from the agrometeorological station in Experimental Station in Garlica Murowana (point 1 in Fig. 1). The values of the *HTC* were classified according to the criteria specified in the study Skowera *et al.* (2014), which enabled an objective assessment of the pluvial and thermal conditions in the study seasons.

FIELD STUDY METHODOLOGY

The investigation was conducted in an orchard established in 2005 where 'Conference' pear trees were grown on S1 quince rootstock. The row spacing in the orchard was 4.0 m, and the

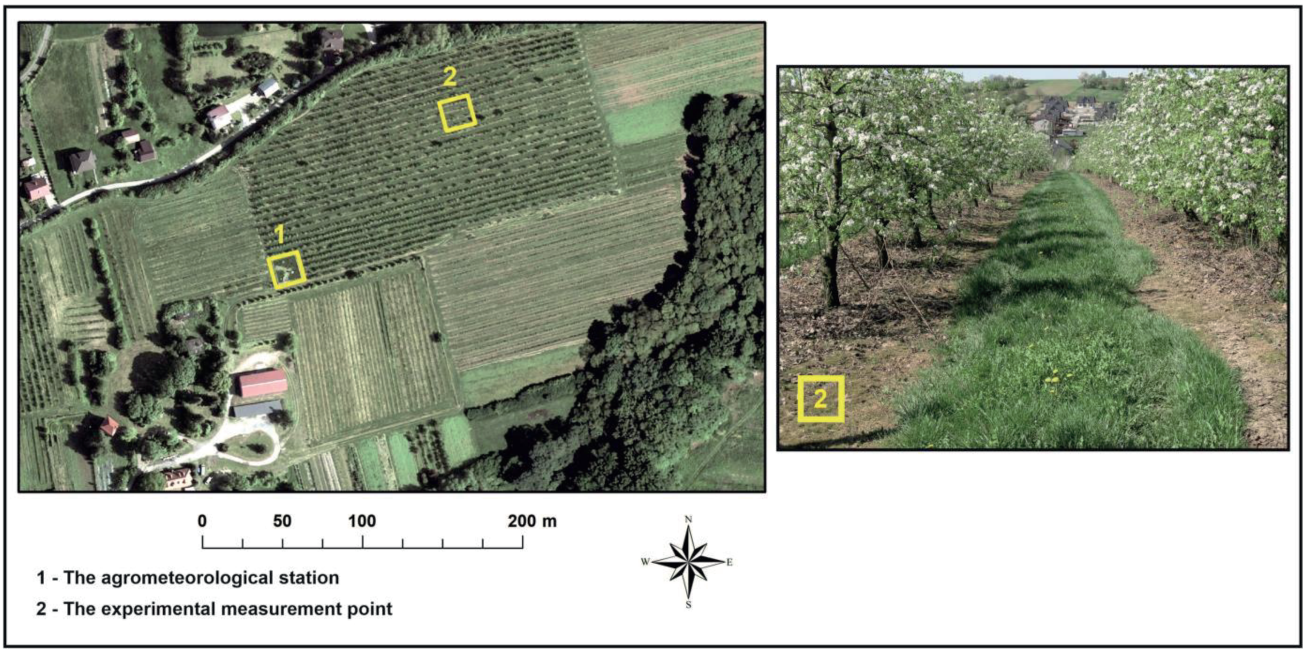


Fig. 1. Study area; pear orchard at the Fruit Growing Experimental Station of the Faculty of Biotechnology and Horticulture in Garlica Murowana; source: own elaboration

distance between trees in a row was approx. 1.5 m (Fig. 1). Soil maintenance in the orchard consisted of maintaining the inter-row turf, which included moving it 3–4 times during the growing season. In the tree rows herbicide fallow treatment was applied within a strip with a width of approx. 1.5 m. The area of the agrometeorological station garden adjacent to the orchard (Fig. 1) and the inter-row space in the pear orchard were covered with self-seeded turf which was maintained in a similar way as the turf between the rows of trees.

The objective of the study was accomplished in 2019, 2020 and 2021, in three stages, i.e. field measurements, statistical analysis of the results, and analysis of a selected case (year) in which a meteorological drought occurred (SMSR, no date). The field stage involved the selection of measurement sites where scheduled measurements of soil moisture were taken at the locations marked in Figure 1.

These were the following measurement sites: point 1 (agrometeorological station adjacent to the orchard) and point 2 located in the central part of the pear orchard. In the centre of the pear orchard (point 2), two measuring stations were selected, in a row of trees, i.e. on the herbicide fallow area (area without plants); in the study this place is referred to as a 'row of trees'. Perpendicular to the row of trees, at a distance of 2 m, a site referred to as the 'between rows' site was established (the soil in the strip between the rows of trees was covered with self-seeded grass). Next, two shields were installed at the aforementioned sites in the orchard (in the row of trees and between the rows) and one at the Agrometeorological Station. These shields are included in the PR2/6 profile probe set and enable the measurement of soil volumetric moisture (%vol.) at depths of 10, 20, 30, 40, 60 and 100 cm. Soil moisture measurements were performed using a Delta-T PR2 profile probe and an HH2 moisture meter on days without precipitation at approximately weekly intervals. Soil moisture measurements were performed in the following periods: in 2019 from 25th June to 24th September, in 2020 from 11th May to 29th September and in 2021 from 5th June to 24th September. Due to the unequal length of the measurement periods in the individual years resulting from equipment and logistical problems, the same period was used for statistical analysis in all three years, i.e. from 25th June to 15th September.

DETERMINATION OF SOIL PROPERTIES

The soil at the Experimental Station in Garlica Murowana is loess with high agricultural suitability (soil valuation class IIIa 'good arable land'). The texture was determined using the Casagrande method acc. PN-R-04032 (Polski Komitet Normalizacyjny, 1998) while a pedotransfer function was used to map soil bulk density (*BD*) (Abdelbaki, 2016):

$$BD = 1.228 - 0.155\log(\mathrm{OC}) + 0.008\mathrm{S} \tag{2}$$

where: *BD* = bulk density (Mg·m^{-3}), OC = organic carbon content (%), S = sand content (%).

The physical properties of the soil in the 0–100 cm profile are presented in Table 1. According to the classification proposed by the Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), this soil was classified as category 3 in terms of drought resistance.

Retention properties of the soil were determined based on the parametrised soil-water characteristic curve (the van Genuchten model (Genuchten van, 1980)):

$$\theta_v = \theta_r + \frac{\theta_s - \theta_r}{(1 + (\alpha \cdot h)^n)^{1-\frac{1}{n}}} \tag{3}$$

where: θ_v = volumetric water content (cm^3·cm^{-3}), θ_r = residual volumetric water content (cm^3·cm^{-3}), θ_s = saturated volumetric water content (cm^3·cm^{-3}), α (cm^{-1}) and n = parameters of the model, h = suction pressure (cm).

Parameters of the model were determined using pedotransfer functions (Liao *et al.*, 2011):

Table 1. Basic physical properties of the soil

Layer (cm)	Organic carbon (%)	Fractions content (%)			Granular group	Acronym	Bulk density ($Mg{\cdot}m^{-3}$)
		sand 2–0.05 mm	silt 0.05–0.002 mm	clay <0.002 mm			
0–30	7.05	35	59	6	silt loam	SiL	1.38
30–51	1.75	41	54	5	silt loam	SiL	1.52
51–73	0.99	46	53	1	silt loam	SiL	1.60
73–100	0.39	47	51	2	silt loam	SiL	1.67

Source: own elaboration.

$$\theta_r = 0.015 + 0.0056\mathrm{C} + 0.014\mathrm{OC} \tag{4}$$

$$\theta_s = 0.810 - 0.283BD + 0.001\mathrm{C} \tag{5}$$

$$\ln(\propto) = -2.486 + 0.025\mathrm{S} - 0.351\mathrm{C} \tag{6}$$

$$\ln(n-1) = 0.053 - 0.009\mathrm{S} - 0.013\mathrm{C} + 0.00015\mathrm{S}^2 \tag{7}$$

where: C = clay content (%), OC = organic carbon content (%), *BD* = bulk density ($Mg{\cdot}m^{-3}$), S = sand content (%).

Based on the determined soil water characteristic curve, the volumetric water content for the field water capacity (θ_{FWC}), and the permanent wilting point (θ_{PWP}) were calculated.

STATISTICAL ANALYSIS

The hypothesis of the occurrence of differences in soil moisture at depths of 10, 20, 30, 40, 60 and 100 cm and between the study years (i.e. 2019, 2020 and 2021), and also at the sites with different soil maintenance methods was checked using a non-parametric Kruskal-Wallis test of variance. Statistical inference was performed at a significance level of $\alpha = 0.05$.

In the final stage of the study the results of the moisture measurements taken in 2019 were presented graphically as an example of the dynamics of soil moisture changes in the 0–100 cm profile depending on the method of soil maintenance in the orchard. In that year a meteorological and agricultural drought occurred over a significant area of Poland during the summer months (SMSR, no date). Deviations of the soil moisture results from the median were also calculated for the particular measurement dates and presented in graphs for the longest, anomalously warm rainless period.

RESULTS AND DISCUSSION

METEOROLOGICAL CHARACTERISTICS OF THE STUDY PERIOD

The values of air temperature and precipitation in the study years 2019–2021 varied relative to the long-term averages (1991–2020) (Fig. 2). According to the Polish Climate Monitoring Bulletin (IMGW-PIB, no date), 2019 was exceptionally warm with the lowest number of days with precipitation in the summer months, the following year 2020 was classified as warm with higher and more frequent precipitation while 2021 was normal in terms of temperature and wet in terms of precipitation. The temporal variation in meteorological conditions is shown by the changes in the 10-day values of temperature and precipitation in the period between May and September (2019–2021) (Fig. 2) and the values of hydrothermal coefficient (*HTC*) together with the number of days with precipitation (Tab. 2). In each year of the study hydrothermal conditions ranged from extremely dry to extremely wet. In 2019 the longest dry period was observed in late June and early July, with the lowest values of the *HTC* and the lowest number of days with precipitation (Tab. 2).

Despite such a wide variation in thermal and precipitation conditions during the study period in the area of Garlica Murowana, where the soil moisture study was conducted, no agricultural drought was observed.

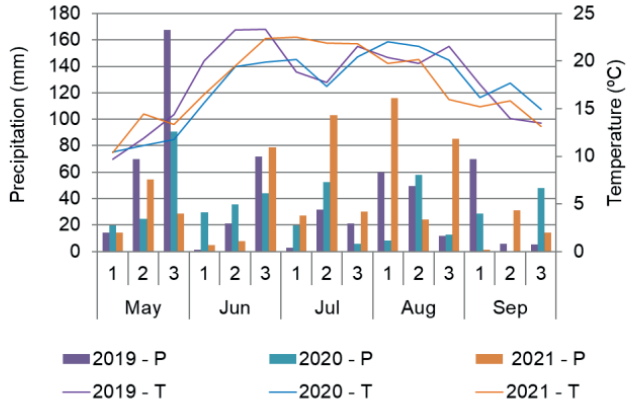


Fig. 2. Ten-day mean values of air temperature and precipitation totals during the study years (2019–2021); data from the agrometeorological station in Experimental Station in Garlica Murowana – see Fig. 1); source: own study

ANALYSIS OF SOIL MOISTURE

Based on the results of the non-parametric Kruskal-Wallis median test, statistically significant differences in loess soil moisture were found between the measurement sites, i.e. depending on the method of soil maintenance (Fig. 3). In each year of the study, the lowest moisture content was found at the site between the tree rows, ranging from 28 to 30% vol. At this site, soil moisture was characterised by the smallest range of variation, i.e. 20–40% vol. in 2019, 19–40% vol. in 2020 and 15–42% vol. in 2021. In contrast, at the agrometeorological station adjacent to the orchard, soil moisture ranged from 33 to 34% and was characterised by the greatest range of variation, i.e. 9–58% vol. in

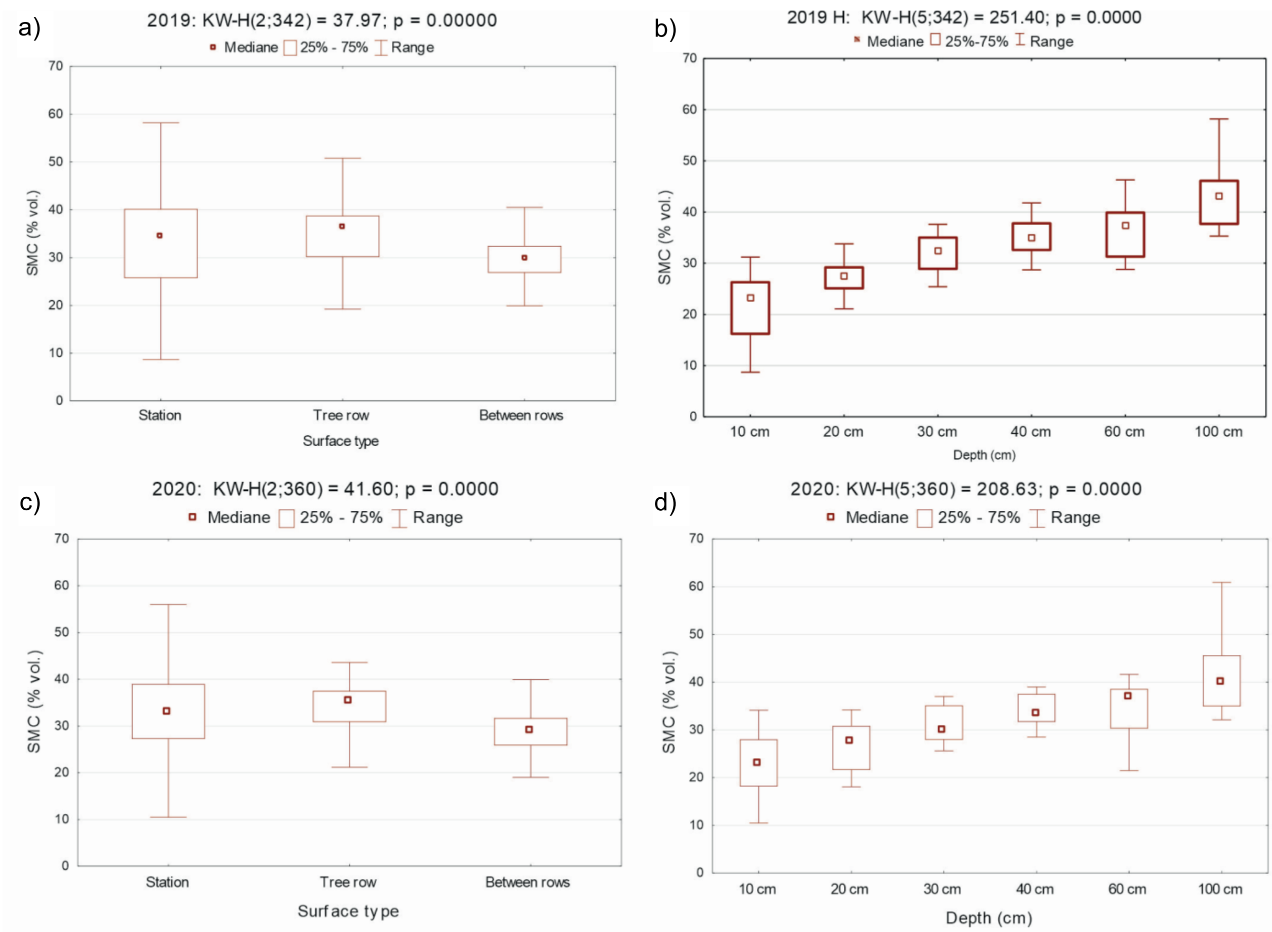
Table 2. Ten-day mean values of hydrothermal coefficient (*HTC*) and number of days with precipitation (PREC) during the study years (2019–2021)

Year	Parameter	Mean value in month														
		May			June			July			August			September		
		10-day period														
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
2019	*HTC*	1.5	5.8	10.6	0.1	0.9	3.1	0.2	1.8	0.9	2.9	2.5	0.5	4.0	0.4	0.4
	PREC	3	6	9	1	4	1	1	4	2	5	5	1	5	2	3
2020	*HTC*	1.9	2.2	7.0	1.9	1.8	2.2	1.0	3.0	0.3	0.4	2.7	0.6	1.8	0.0	3.2
	PREC	6	6	9	6	8	5	4	6	3	2	3	3	6	0	6
2021	*HTC*	1.4	3.8	2.0	0.3	0.4	3.5	1.2	4.7	1.2	5.9	1.2	4.9	0.1	2.0	1.1
	PREC	5	6	7	3	1	5	2	9	5	7	3	9	1	4	3

Explanations: $HTC \leq 0.4$ extremely dry, $0.4 < HTC \leq 0.7$ very dry, $0.7 < HTC \leq 1.0$ dry, $1.0 < HTC \leq 1.3$ relatively dry, $1.3 < HTC \leq 1.6$ optimal, $1.6 < HTC \leq 2.0$ relatively humid, $2.0 < HTC \leq 2.5$ humid, $2.5 < HTC \leq 3.0$ very humid, $HTC > 3.0$ extremely humid (Skowera *et al.*, 2014).
Source: own study.

2019, 10–56% vol. in 2020 and 13–50% vol. in 2021. The row of trees had more stable and higher moisture content than the other sites, i.e. between 34 and 37% vol., and the moisture range was 19–51% vol. in 2019, 21–43% vol. in 2020 and 25–45% vol. in 2021.

The lowest soil moisture content (*SMC*) and the greatest range of variation in all years were found at a depth of 10 cm, 23–26% vol.; the range of values during the study years varied between 9.5–31% vol. in 2019, 10–34% vol. in 2020 and 10–50% vol. 2021 while moisture increased with increasing soil depth to



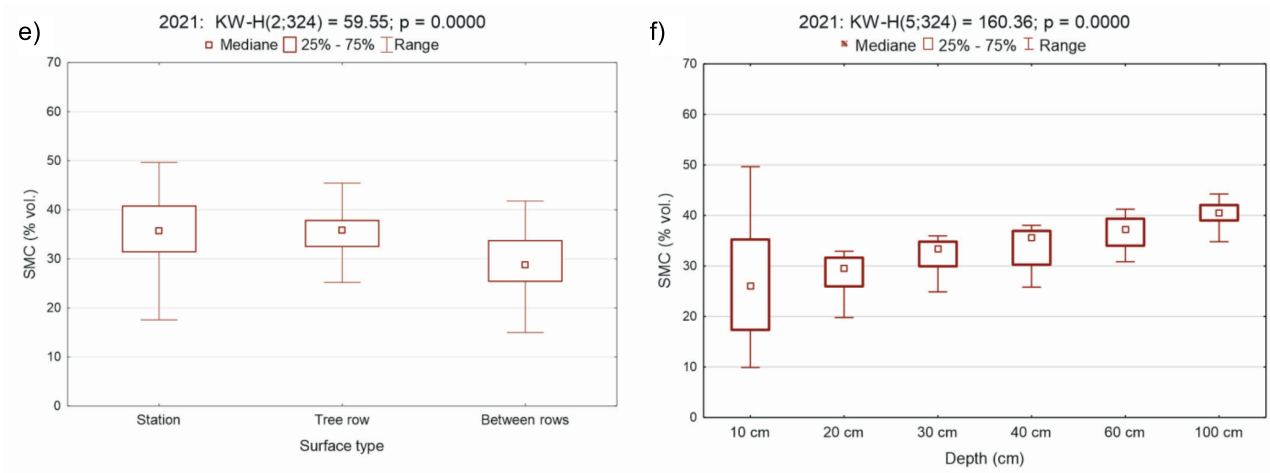


Fig. 3. Variation in soil moisture (%vol.) depending on soil maintenance (a, c, e) and at different levels of the profile (0–100 cm) (b, d, e) in 2019, 2020 and 2021; KW-H = Kruskal-Wallis test, p = probability (p > 0.05 not statistically significant, $p \leq 0.05$ statistical significance), *SMC* = soil moisture content; source: own study

over 40% vol. (Fig. 3). Attention should be paid to the variation in soil moisture between the depths of 20 cm and 100 cm in 2021; the range of moisture variation was the smallest compared with the other years of the study. During that year of the study period precipitation was frequent and intense; the weather was wetter than in previous years, which is confirmed by the 10-day values of the *HTC* (Fig. 2, Tab. 2).

Considering the variability of moisture at each level (10, 20, 30, 40, 60 and 100 cm) between years, statistically significant differences occurred only in the topsoil (10 cm) regardless of the method of surface maintenance (Tab. 3). Statistically significant differences at depths of 60 and 100 cm are difficult to explain in an unambiguous manner. It should be mentioned that this is below the range of the root system of the 'Conference' pear tree (40–60 cm) grafted onto a quince rootstock. On the other hand, it could have been a technical reason related to the appearance of water in the covers at a depth of 100 cm. When comparing moisture contents at different levels depending on the method of soil maintenance, statistically significant differences in soil moisture contents were found throughout the profile. The highest soil moisture content, ranging from 27.3 to 39.6% vol. in the 0–100 cm profile, was found in the row of trees (Tab. 3).

Figure 4a, b, c shows an example of soil moisture levels at depths of 10, 20, 30, 40, 60 and 100 cm as a function of precipitation intensity levels in 2019. This year was selected for analysis due to the longest dry period during the study (2019–2021), the occurrence of extremely high air temperatures and, consequently, extremely low hydrothermal coefficients (Figs. 2 and 4, Tab. 2) (Ziernicka-Wojtaszek, 2021; IMGW-PIB, no date).

In 2019, soil moisture content varied at the individual measurement dates. At all the sites, the lowest soil moisture content was observed at a depth of 10 cm, especially during the dry periods, while it increased after the rainy periods (Fig. 4). It was observed that the differences in soil moisture levels at depths of 10 and 20 cm were smaller in the tree row and between tree rows than at the agrometeorological station. At all the sites, soil moisture levels (%vol.) showed less variability between 30 and 100 cm, with the highest values occurring at the deeper levels,

Table 3. Comparison of soil water content (%vol.) in the 0–100 cm layer

Soil depth (cm)	Soil water content (% vol.)			Kruskal-Wallis statistic		Soil water content (% vol.)			Kruskal-Wallis statistic	
	2019	2020	2021	H	$p \leq$	station	tree row	between rows	H	$p \leq$
10	23.2	22.4	26.0	6.90*	0.03	19.4	27.3	20.6	32.67*	0.001
20	27.5	27.3	29.3	4.76	0.09	26.2	30.7	25.4	53.99*	0.001
30	32.4	30.0	33.5	2.58	0.28	32.5	35.0	28.2	89.81*	0.001
40	35.0	33.5	35.6	4.50	0.10	35.1	37.5	30.5	107.50*	0.001
60	37.4	36.9	37.2	6.20*	0.05	39.4	37.0	30.9	132.42*	0.001
100	43.1	39.7	40.5	6.11*	0.05	45.1	39.6	38.0	90.64*	0.001

Explanation: H = Kruskal-Wallis test statistic, p = least significance level, * = values statistically significant at $\alpha \leq 0.05$.
Source: own study.

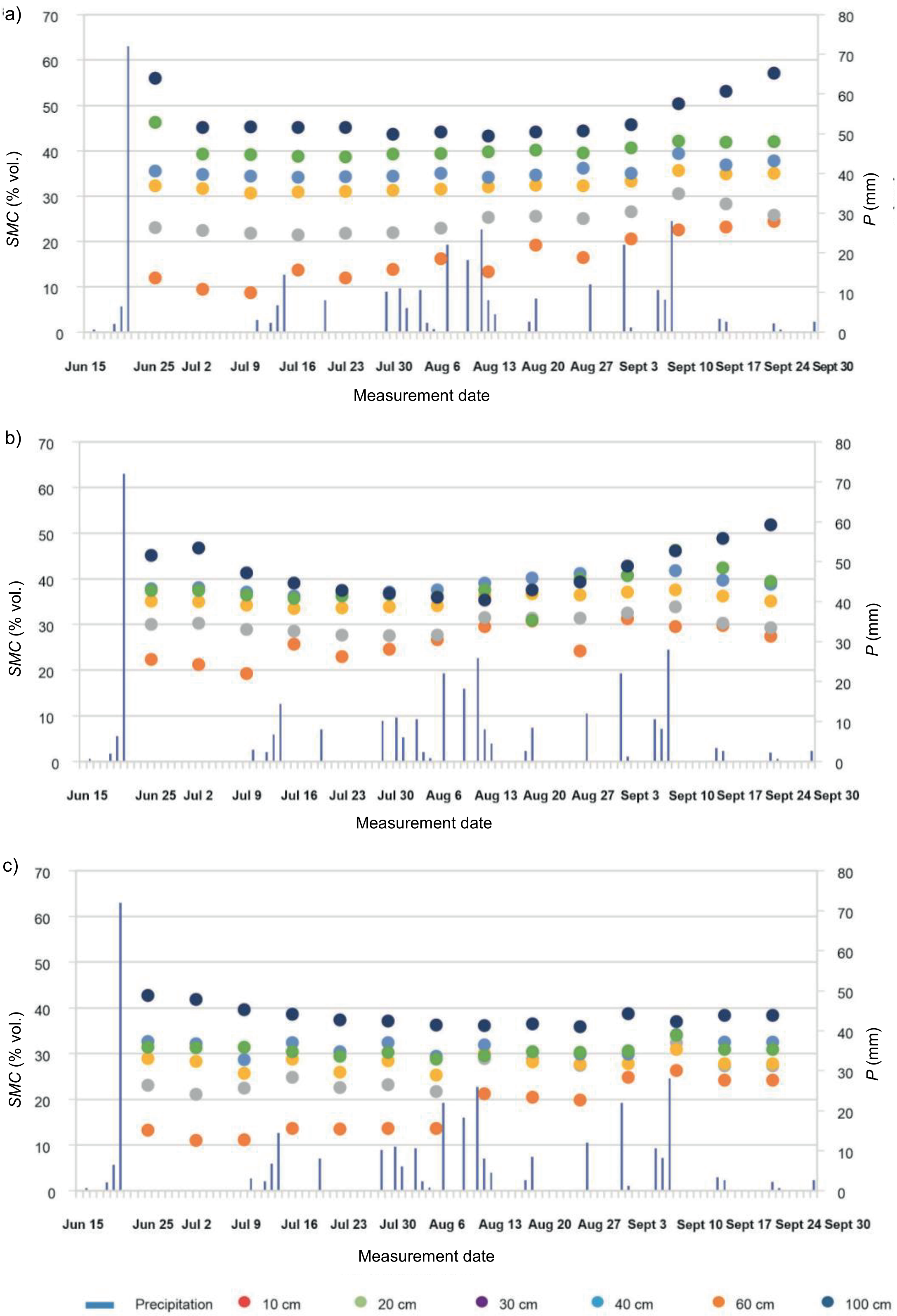


Fig. 4. Volumetric soil moisture content (*SMC*) at depths of 10, 20, 30, 40, 60 and 100 cm and daily precipitation (*P*) in 2019 in the orchard: a) in the row under the tree crowns, b) between the tree rows, c) at the agrometeorological station; source: own study

i.e. 60 and 100 cm (Fig. 4a, b, c). This was due to the response of the soil to the changing meteorological conditions (Biniak-Pieróg *et al.*, 2011; Mostowik *et al.*, 2023) and the hydraulic properties of the soil (Li *et al.*, 2024). Based on studies assessing precipitation efficiency in an apple orchard in 2010–2013, Treder *et al.* (2022) concluded that the initial soil moisture content, i.e. before the onset of precipitation, had a significant impact on changes in the water content of the soil profile, which is consistent with the results of studies obtained in the pear orchard in Garlica Murowana. Based on the analysis of soil moisture contents at different levels, the smallest range of variability was recorded in the orchard, under the tree crowns, and the largest at the agrometeorological station. During periods of precipitation (e.g. in the wettest year of 2021), soil moisture fluctuations were the smallest in the tree row (Figs. 3a, c, e; 4a). These points to the conclusion that proper soil maintenance in the orchard (herbicide fallow in the row of trees) and properly maintained turf between the rows affected the soil moisture levels. At the site where the soil was sheltered by the crowns of the trees (herbicide fallow) soil moisture was higher and characterised by less variability throughout the soil profile than between the tree rows (turf) and at the agrometeorological station (turf).

The final stage of the study analysed the dynamics of the changes in soil moisture during the longest rain-free period in the study period 2019–2021, lasting from 22nd June to 9th July 2019. In that year a meteorological drought of varying degrees of severity, locally transforming into agricultural and hydrological drought, was observed throughout Poland in the summer months (Ziernicka-Wojtaszek, 2021). Atmospheric drought is caused by a prolonged period of below-average rainfall or lack of rainfall, and its intensity increases when the air temperature is high. In 2019 this situation occurred over a significant area of Poland (Ziernicka-Wojtaszek, 2021). The study period was extremely warm at the beginning and slightly warm in the second half of the period (IMGW-PIB, no date). Figure 5 shows an example of deviations in soil moisture contents during the dry period on 25th June, and 2nd and 9th July.

After the last rainfall, which occurred on 21st June, negative deviations in the moisture content increased with each subsequent measurement and varied between the measurement points depending on the method of soil cultivation.

The impact of land cover on soil water content is confirmed by a study by Rascoń-Ramos *et al.* (2021) conducted in a forest in a semi-arid climate. These authors paid attention to the impact of rainfall intensity and volume as well as tree density on soil moisture in the forest. They found that after crown thinning, only low rainfall (<10 mm) significantly increases soil moisture. In the case of heavy rainfall (>30 mm), tree thinning had no effect on soil moisture. Chudecki *et al.* (1971) found that changes in moisture content at different depths of the soil profile depend mainly on the amount of precipitation and the soil moisture level before it occurs. The authors found that 2.5 mm of rainfall per day has no significant effect on soil moisture.

Our study also confirmed the impact of precipitation on soil moisture; this can be seen in Figure 4. Soil moisture (%vol.) in the row of trees, between the rows and at the agrometeorological station next to the orchard differed (Figs. 4 a, b, c, and 5).

The results were consistent with those obtained by other authors. On the basis of research conducted in the Bieszczady Mountains, Mostowik *et al.* (2023) also confirm that the higher the precipitation sum, the higher the soil moisture content, but this correlation is not very strong.

Tables 4 and 5 show the calculated parameters of the soil-water characteristic curve for the loess soil found in the pear orchard. In Garlica Murowana, the soil moisture content and volumetric moisture content (SMC_{FWC} and SMC_{PWP}) for the field water capacity (θ_{FWC}) in the layer up to 30 cm was 26.5% while that for the permanent wilting point (θ_{PWP}) was 14.6%. Deeper into the soil profile the values decreased.

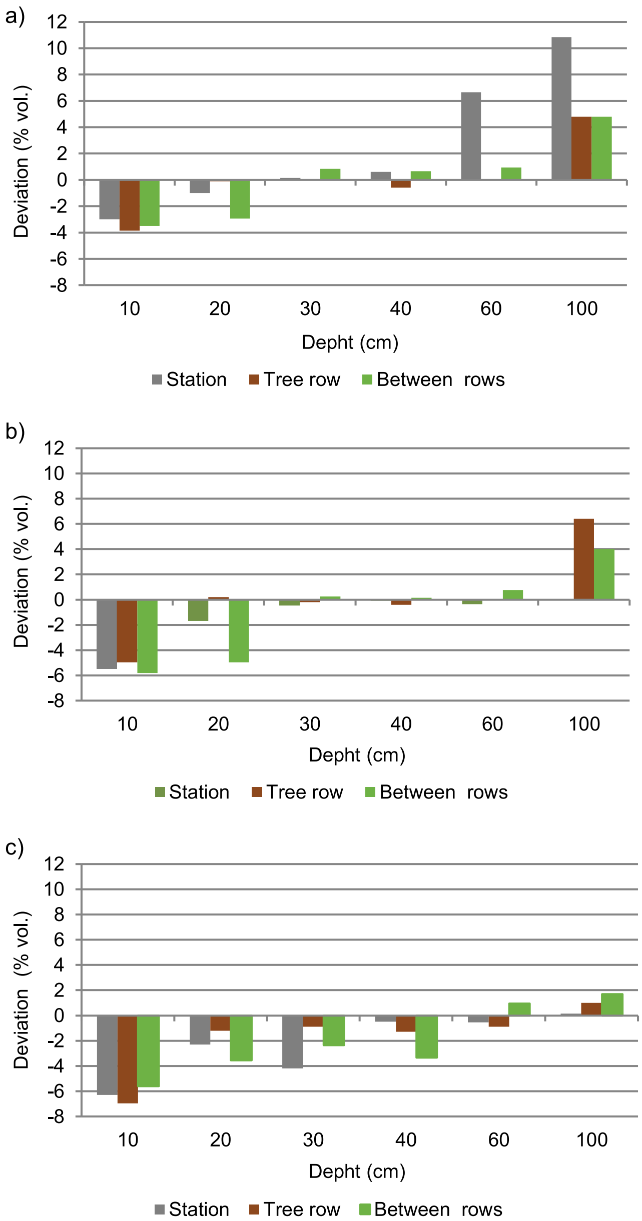


Fig. 5. Example of deviations in soil moisture contents (%vol.) during the rain-free period in 2019: a) 25th June, b) 2nd July, c) 9th July (for the days on which measurements were taken, the soil moisture deviations at each level were calculated in relation to the entire study period in 2019); source: own study

Table 4. Calculated parameters of the van Genuchten function

Layer (cm)	Parameter			
	α (cm^{-1})	n (–)	θ_s	θ_r
			(cm^3·cm^{-3})	
0–30	0.02431	1.855	0.426	0.144
30–51	0.04012	1.879	0.385	0.065
51–73	0.18507	1.945	0.359	0.034
73–100	0.13359	1.937	0.340	0.030

Explanations: α and n = parameters of the model, θ_r = residual volumetric water content, θ_s = saturated volumetric water content.
Source: own study.

Table 5. Volumetric water contents at characteristic points of the soil-water characteristic curve determined from the van Genuchten model (Genuchten van, 1980)

Level (cm)	Moisture content at the characteristic points			
	θ_{FWC} ($cm^3 \cdot cm^{-3}$)	SMC_{FWC} (%vol.)	θ_{PWP} ($cm^3 \cdot cm^{-3}$)	SMC_{PWP} (%vol.)
0–30	0.265	26.5	0.146	14.6
30–51	0.156	15.6	0.066	6.6
51–73	0.058	5.8	0.036	3.6
73–100	0.057	5.7	0.030	3.0

Explanations: θ_{FWC} = volumetric water content at the field water capacity point, θ_{PWP} = volumetric water content at the permanent wilting point, SMC_{FWC} = soil moisture content at the field water capacity point, SMC_{PWP} = soil moisture content at the permanent wilting point.
Source: own study.

Based on the soil moisture contents recorded in 2019 (Figs. 4 and 5) and the range of moisture in the years of the study, soil moisture fell below the level of the permanent wilting point (Tab. 5) of the SMC_{PWP} only in the top layer (10 cm) between the rows at the Agrometeorological Station. In the deeper layers, soil moisture was always above the permanent wilting point. No agricultural drought was observed in fruit tree cultivation in the study area in the years 2019–2021 (SMSR, no date).

The progressive warming of the climate and the increased precipitation variability make the adverse conditions for agriculture/horticulture even worse, and crops are increasingly exposed to water shortages during vegetation (Skowera *et al.*, 2023; Wałęga *et al.*, 2024; SMSR, no date).

The investigation presented in our work is an example of the importance of applying good agricultural practices in mitigating the effects of drought, in this case in orchards. Similar studies should be carried out on soils with poorer retention properties, which dominate in central and central-eastern Poland, where fruit growing accounts for a significant share in agricultural production.

CONCLUSIONS

Based on the studies on the impact of soil cultivation on loess soil moisture content, conducted between 2019 and 2021 in a pear orchard, the key role of soil retention associated with granulometric composition has been confirmed. The quantitative impact of orchard maintenance on soil moisture has been confirmed. The topsoil layer (0–20 cm) was most sensitive to meteorological conditions. As the rainless period lengthened, soil moisture decreased; then, after the onset of rainfall again, moisture increased and stabilised in the soil profile. The impact of the manner of orchard maintenance determined the soil moisture level. The shielding of the soil surface with tree crowns resulted in increased soil moisture levels and less variation in soil moisture throughout the profile. The results proved that the right choice of cultivation site (i.e. with favourable soil retention properties) and proper crop/orchard management can significantly reduce crop losses in conditions of climate warming and the associated increase in the risk of drought for agricultural/orchard crops.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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