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Impact of Water Holding Capacity and Moisture Content of Soil Substrates on the Moisture Content of Wood in Terrestrial Microcosms

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Abstract: Terrestrial microcosms (TMCs) are frequently used for testing the durability of wood and wood-based materials, as well as the protective effectiveness of wood preservatives. In contrary to experiments in soil ecology sciences, the experimental setup is usually rather simple. However, for service life prediction of wood exposed in ground, it is of imminent interest to better understand the different parameters defining the boundary conditions in TMCs. This study focused, therefore, on soil–wood–moisture interactions. Terrestrial microcosms were prepared from the same compost substrate with varying water holding capacities (WHCs) and soil moisture contents (MC_{soil}). Wood specimens were exposed to 48 TMCs with varying WHCs and MC_{soil}. The wood moisture content (MC_{wood}) was studied as well as its distribution within the specimens. For this purpose, the compost substrate was mixed with sand and peat and its WHC was determined using two methods in comparison, i.e., the "droplet counting method" and the "cylinder sand bath method" in which the latter turned out advantageous over the other. The MC_{wood} increased generally with rising MC_{soil}, but WHC was often negatively correlated with MC_{wood}. The distance to water saturation S_{soil} from which MC_{wood} increased most intensively was found to be wood-species specific and might, therefore, require further consideration in soil-bed durability-testing and service life modelling of wood in soil contact.

Keywords: decay; ENV 807; soft rot test; soil moisture content; use class 4 (UC4)

1. Introduction

For determining the durability of wood or the protective effectiveness of wood preservatives against soft rot fungi and other soil-inhabiting micro-organisms, terrestrial microcosms (TMCs) can be used. For this purpose, natural top soil or a fertile loam-based horticultural soil should be used and various requirements need to be fulfilled with respect to the soil substrate.

It is well known that many parameters affect the decay activity of soils [1–5]. Therefore, it is recommended to consider more than one in-ground field test site for durability testing of wood and more than one soil substrate for laboratory studies using TMCs [2,6–9].

Consequently, for standardized test protocols several parameters are more or less strictly defined. For instance, according to the European standard CEN/TS 15083-2 [10], the following soil-related boundary conditions need to be assured:

- pH 6–8
- no added agrochemical
- water holding capacity (WHC): 25%–60%
- natural soils: peat or top 50 mm removed and not taken from a depth below 200 mm

- soil collected in moist conditions
- soil passed through a sieve of nominal aperture size 12.5 mm
- storage of soil prior to use only in closed moisture proof containers
- thorough mixing of soil before use
- horticultural soil which was sterilized during its preparation needs to be replenished with 20% natural soil
- soil not used before

Finally, a moisture content of the soil (MC_{soil}) equivalent to 95% of its WHC is required and the TMC should be stored at 27 °C ± 2 °C and 70% ± 5% relative humidity (RH) during the whole period of exposure in a dark room.

A previous study by Wälchli [11] showed that MC_{wood} decreased with both decreasing MC_{soil} and WHC as determined for two different soils and five different MC_{soil}. However, mass loss (ML) by decay of untreated and differently copper–chromium–boron (CCB)-treated Scots pine sapwood was neither correlated with MC_{wood} nor with MC_{soil}. Similarly, Mieß [12] found an increase in MC_{wood} with rising MC_{soil} in three different soil types and for different untreated and modified timbers. Furthermore, she found a gradient of MC_{wood} in untreated wood from the highest MC_{wood} in the bottom part and lowest MC_{soil} in the top part of the buried test stakes. In contrast, a remarkable 20% of the Scots pine sapwood specimens showed the highest MC_{wood} in the top or central part of the specimens. Mieß [12] suggested that the MC_{wood} gradients were the consequence of vertical gradients of MC_{soil}, which were differently severe due to the different soil wetting and re-drying regimes. It is further likely that the gradients were the consequence of ML gradients along the stake-shaped specimens, because the MC_{wood} of the different specimen segments had been determined not before the end of the test after 17 weeks of incubation when significant ML had already occurred.

Gray [13] performed durability tests in TMCs using different soils at different MC_{soil} and found that the highest ML occurred at an MC_{soil} between 108% and 148% of the WHC of the respective soil. The highest MC_{wood} after harvesting was found at an MC_{soil} between 120% and 218% of its WHC referring to an MC_{soil} at approximately 40% in all soil types used. Thus, ML increased with increasing MC_{soil}, but found an optimum, which was, however, far beyond the recommended 95% WHC. Again, MC_{wood} data are needed to obtain a set perspective, since they refer to the different severely decayed specimens after harvesting.

In summary, it becomes evident that both WHC and MC_{soil} influence MC_{wood} and ML through fungal decay, and do seemingly interact. Clear relationships between the three moisture-related parameters have not yet been established.

Others [6,12,14,15] previously demonstrated that all three rot types, i.e., brown, white, and soft rot, occur in TMCs complemented by tunneling, erosion, and cavity bacteria. However, neither MC_{wood} nor MC_{soil} seemed to limit their occurrence. Solely, soft rot apparently copes better with very high moisture contents, which are not favorable for brown and white rot fungi. Nevertheless, soft rot fungi can degrade wood in a rather large moisture range. They are early colonizers, so-called "ruderal organisms" [16], which, in contrast to basidiomycetes ('combative organisms'), are rarely able to take over a substrate [17].

The WHC of soil substrates can vary remarkably, and therefore, it needs to be determined before each test. In both standards, CEN/TS 15083–2 [10] as well as ENV 807 [18], a suitable method for determining the WHC of soil is described: the so-called "droplet counting method". The method is based on determining the ability of a sample of a test substrate to retain water against the pull of a vacuum pump, as a measure of its WHC. However, the method is rather laborious and time consuming. Furthermore, the standards lack a definition of the vacuum that needs to be applied, wherefore one might question the reproducibility of the test results.

Within this study, we conducted comparative WHC measurements on a series of different mixtures of compost and silica sand using the "droplet counting method" and an alternative method according to ISO 11268-2 [19], where wet soil samples are allowed to drain on a sand bath. Based on this comparison of methods, TMCs should be prepared representing soil substrates of varying WHCs and MC_{soil}. The overall objective of this study was to establish relationships between WHC, MC_{soil}, and the resulting MC_{wood} of different wood species after exposure in the TMC.

2. Materials and Methods

2.1. Soil Substrates

Three soil substrates were used to prepare TMCs of defined water holding capacities (WHCs). The basis substrate was a compost produced by the University of Goettingen from horticultural waste (i.e., leaf litter, grass, cut softwoods, and hardwoods, sand). To lower its WHC, silica sand (grain size > 0.2 mm) was added; to increase its WHC, peat (moderately-to-severely decomposed high-moor peat (H3–H8), total nitrogen 0.35%, magnesium 0.15%, organic substance 30%) was added. Both peat and compost were passed through a sieve of a nominal aperture size 8.5 mm. The soil moisture content (MC_{soil}) and the WHC were determined according to the "droplet counting method" and the "cylinder sand bath method".

2.2. Determination of the soil Moisture Content (MC_{soil})

Soil samples of 7–64 g (depending on the soil density) were taken for determining the soil moisture content (MC_{soil}). Three replicate samples were taken, weighed to the nearest 0.01 g, oven-dried at 103 °C, and weighed again. MC_{soil} was calculated as follows:

$$MC_{soil} = \frac{m_{soil,\ wet} - m_{soil,0}}{m_{soil,0}} \times 100\ [\%] \quad (1)$$

where MC_{soil} is the soil moisture content, in %; $m_{soil,wet}$ is the wet soil mass, in g; $m_{soil,0}$ is the oven-dry soil mass, in g.

2.3. Determination of the Water Holding Capacity (WHC) of Soil

2.3.1. "Droplet Counting Method"

A small quantity of water was added to soil samples of 200 g, the substrate was mixed well, and the operation was repeated until the soil particles stuck to another (crumb structure). Further, 25 mL water were added, mixed well, and allowed to stand for 2 h. A coarse filter paper was placed in the bottom of a Buchner funnel (100 mm diameter) and moistened to seal the filter paper to the funnel. The prepared test sample was transferred into the funnel and spread evenly. The bottom of the Buchner funnel was covered by soil substrate to a height of at least 10 mm. Suction was applied using a vacuum pump until no more than five drops of water per minute were being withdrawn from the sample, increasing the suction slowly to avoid perforation of the filter paper. The sample was transferred to an aluminum container of known mass and weighed. The container was oven-dried at 103 °C ± 2 °C and weighed again. The *WHC* of $n = 5$ peat samples and $n = 3$ sand and compost samples was determined and calculated as follows:

$$WHC = \frac{m_{soil,\ saturated} - m_{soil,0}}{m_{soil,0}} \times 100\ [\%] \quad (2)$$

where *WHC* is the water holding capacity, in %; $m_{soil,saturated}$ is the soil mass at saturation, in g; $m_{soil,0}$ is the oven-dry soil mass, in g.

2.3.2. "Cylinder Sand Bath Method"

Soil was inserted into polyethylene cylinders with 4 cm diameters. The bottoms of the cylinders were covered with a fine polymer grid and filter paper (MN 640 W 70 mm). All cylinders were placed in a vat for 3 h, which was filled with water to a height 1 cm above the soil filling height of 7 cm. After soaking the soil in water, the cylinders were placed on a water-saturated sand bath for 2 h to allow the unbound water to drain. The soil samples were then weighed wet, oven-dried at 103 °C ± 2 °C, and the WHC of the soil was calculated according to Equation (2) analogously to the “droplet counting method”.

2.4. Preparation of Mixed Soil Substrates

For a comparison of the “Droplet counting method” and the “cylinder sand bath method” and for establishing a regression between mixing ratios of the different soil substrates and their resulting WHC, a total of 22 soil substrate mixtures were prepared as summarized in Table 1.

Table 1. Mixing ratios of soil substrates for water holding capacity (WHC) tests. Percentage is based on the oven-dried mass.

Percentage Compost (%)	**100**	**95**	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**
Percentage silica sand/peat (%)	0	5	10	20	30	40	50	60	70	80	90

For preparing mixed soil substrates, the following equation was used:

$$m_{soil\ x,target,\ wet} = m_{target,\ total,\ 0} \times \left(\frac{a_{target,0}}{100}\right) \times \left(\frac{100}{100 - MC_{soil\ x}}\right)\ (\mathrm{g}) \quad (3)$$

where $m_{soil\ x,target,\ wet}$ is the target mass of the wet substrate x, in g; $m_{target,\ total,\ 0}$ is the target oven-dry mass of the total mix, in g; $a_{target,0}$ is the target percentage of substrate x based on the oven-dry mass, in %. $MC_{soil\ x}$, is the soil moisture content of substrate x, in %.

2.5. Terrestrial Microcosms (TMCs)

Miniature terrestrial microcosms were prepared in polypropylene containers of 110 (height) × 110 × 80 mm^3 and a volume of 500 mL. In total, 48 different substrates were filled in the containers each to a height of 100 mm. The combinations of the parameters WHC and MC_{soil} are summarized in Table 2, where the latter is expressed as (%WHC). The containers were weighed to the nearest 0.01 g, closed with a lid, and their total mass maintained over a period of three weeks.

The following regression functions were used (see also Section 3.1):

$$WHC_{mix:compost-sand} = -0.586 \times a_{target,\ sand,\ 0} + 80.81\ (\%) \quad (4)$$

$$WHC_{mix:compost-turf} = 2.499 \times a_{target,\ turf,\ 0} + 87.15\ (\%) \quad (5)$$

where $WHC_{mix:compost\text{-}sand}$ is the water holding capacity of compost mixed with silica sand, in %; $WHC_{mix:compost\text{-}peat}$ is the water holding capacity of compost mixed with peat, in %; $a_{target,\ sand,\ 0}$ is the target percentage of sand based on the oven-dry mass, in %; $a_{target,\ peat,\ 0}$ is the target percentage of peat based on the oven-dry mass, in %.

Table 2. Soil moisture content MC_{soil} (%) for combinations of target WHC [1] and target MC_{soil} expressed as (%WHC).

MC_{soil} (%WHC) [1]	**WHC (%) [1]**							
	21.8 [2]	**30.0**	**40.0**	**50.0**	**60.0**	**70.0**	**80.0**	**90.0**
30.0	6.5	9.0	12.0	15.0	18.0	21.0	24.0	27.0
50.0	10.9	15.0	20.0	25.0	30.0	35.0	40.0	45.0
70.0	15.3	21.0	28.0	35.0	42.0	49.0	56.0	63.0
80.0	17.4	24.0	32.0	40.0	48.0	56.0	64.0	72.0
95.0	20.7	28.5	38.0	47.5	57.0	66.5	76.0	85.5
120.0	26.2	36.0	48.0	60.0	72.0	84.0	96.0	108.0

[1] WHC determined according to the “cylinder sand bath method” according to ISO 11268-2 [19]. [2] WHC of pure silica sand was 21.8% and consequently the lowest WHC achieved.

The WHC of the substrates used for TMCs were determined exclusively according to ISO 11268-2 [19]. The basic substrate was compost. Silica sand and peat were added according to the regression obtained by comparative WHC measurements as described in Section 2.4 (Figure 1).

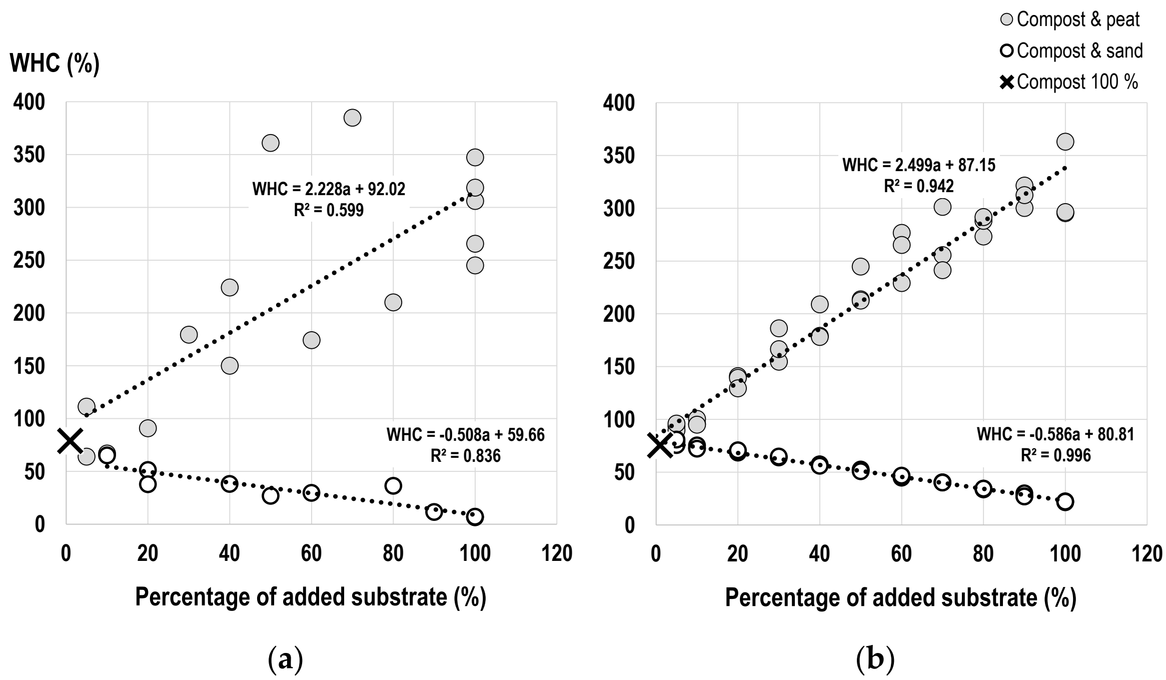

Figure 1. Interrelationship between the percentage of added sand and peat and the WHC of the substrate mixtures: (**a**) WHC determined according to the "droplet counting method" [10]. (**b**) WHC determined according to the "cylinder sand bath method" [19].

The soil mixtures used for the TMCs are summarized in Table 3.

Table 3. WHC of different mixtures of compost with sand and peat.

	WHC (%) [1]							
	21.8 [2]	**30.0**	**40.0**	**50.0**	**60.0**	**70.0**	**80.0**	**90.0**
Percentage compost (%)	0.0	13.2	30.3	47.4	64.5	81.6	98.6	98.6
Percentage sand (%)	100.0	86.8	69.7	52.6	35.5	18.5	1.4	0.0
Percentage peat (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4

[1] WHC determined according to the "cylinder sand bath method" according to ISO 11268-2 [19]. [2] WHC of pure silica sand was 21.8% and consequently the lowest WHC achieved.

2.6. Preparation and Exposure of Wood Specimens

Specimens of 5 × 10 × 100 (ax.) mm^3 were prepared from Scots pine sapwood (*Pinus sylvestris* L.), Douglas fir heartwood (*Pseudotsuga menziesii* Franco), English oak heartwood (*Quercus robur* L.), and European beech (*Fagus sylvatica* L.). All specimens were free from defects such as cracks, decay, and discoloration. For each of the 48 combinations of WHC and MC_{soil}, n = 5 replicate specimens of each species were prepared, which corresponded to a total of 960 specimens.

In total, 48 soil substrates, i.e., combinations of WHC and MC_{soil}, were prepared and each was used to fill two containers (miniature TMCs). Wood specimens were conditioned at 20 °C/65% RH until constant mass before soil exposure. Afterwards, ten wood specimens were buried to 4/5 of their length in each container and exposed for three weeks. The MC_{soil} was maintained by adding water about every third day if needed.

2.7. Determination of the Wood Moisture Content (MC_{wood})

Specimens from selected TMCs were used to determine the MC_{wood} distribution within the specimens. Therefore, after harvest, the specimens were cleaned from adhering soil particles, cut into five segments of 20 mm length using ratchet scissors, weighed, dried, and weighed again in each step separately. Segment-wise MC_{wood} was determined on specimens after exposure in TMC with substrates of 30, 60, and 90% WHC, and a MC_{soil} of 30, 75, and 95% of its WHC.

$$MC_{wood} = \frac{m_{wood,\ wet} - m_{wood,\ 0}}{m_{wood,0}} \times 100\ (\%) \quad (6)$$

where MC_{wood} is the wood moisture content, in %; $m_{wood,wet}$ is the wet mass of the wood specimen, in g; $m_{wood,0}$ is the oven-dry wood mass, in g.

2.8. Statistical Analysis

Regression functions between different variables were established using the method of least squares to achieve the best fit. Statistical differences between collectives were considered significant at a probability of error less than 5% according to a modified Student *t*-test (Welch test).

3. Results and Discussion

3.1. Water Holding Capacity (WHC) of Soil Mixtures

The WHC of the three initial substrates was highest for peat, followed by compost and sand according to both methods applied (Table 4).

Table 4. WHC (%) of the initial soil substrates determined according to the "droplet counting method" and the "cylinder sand bath method". Standard deviation in parentheses.

	WHC (%) [1]		
	Silica Sand	**Compost**	**Peat**
Droplet counting method	6.7 (0.3)	78.9 (1.3)	296.6 (40.9)
Cylinder sand bath method	21.8 (0.4)	75.5 (1.1)	318.3 (38.8)

[1] Number of replicate samples was $n = 3$ and $n = 5$ for peat tested according to the droplet counting method.

According to both methods, the WHC of the different soil mixtures was linearly correlated with the percentage of added sand or peat, respectively. With increasing percentage of sand and decreasing percentage of peat, the WHC decreased (Figure 1).

It became evident that: (1) single WHC values scattered more and (2) the regression between substrate ratios and WHC was less pronounced when using the "droplet counting method". Furthermore, the following advantages of the "cylinder sand bath method" over the "droplet counting method" became apparent:

- Less time consumption: 7 min/sample compared to more than 60 min/sample using the "droplet counting method".
- Consistency of the test setup: Time for counting droplets varied between 6 and 60 min/sample. Intervals between single droplets varied partly drastically, especially when testing substrates of high WHC. In contrast, up to several hundred cylinders can be used in parallel and the duration of test was always constant.
- Clear description of setup: Simple, less expensive, and well described setup. In contrast, the description of the "droplet counting method" suffers from some vagueness: size of Buchner funnel, applied vacuum, and type of filter paper are not specified, but likely affect the test results.
- Independency from sample size and volume: In contrast, the given sample thickness according to the "droplet counting method" led to strongly varying mass of the soil sample in the Buchner

funnel and affected the WHC, as shown for peat in Figure 2. With increasing sample size (= sample mass) the WHC increased.

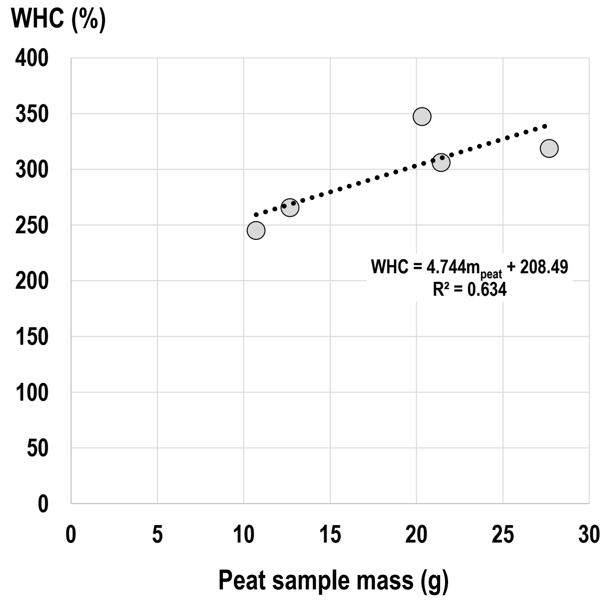

Figure 2. Interrelationship between the WHC of peat according to the 'droplet counting method' (CEN/TS 15083-2, 2005) and the mass of the peat sample.

Generally, it was observed that substrates with very high WHC, such as peat, require longer wetting periods than specified by the standards, i.e., 1–2 h according to CEN/TS 15083-2 [10] and 3 h according to ISO 11268-2 [19]. After 3 h of submersion, the peat was still not fully water saturated when oven-dried before, which consequently led to an underestimation of its WHC.

The WHC determined according to both methods were highly correlated, especially for WHC below 200%, as shown in Figure 3. Therefore, and regarding its numerous advantages, in the following, all WHC measurements were conducted using the "cylinder sand bath method".

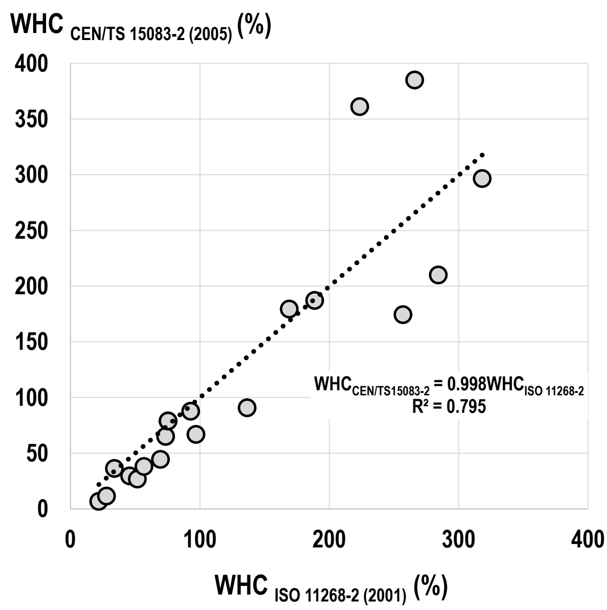

Figure 3. Interrelationship between the WHC of different substrate mixtures according to the "droplet counting method" [10] and the "cylinder sand bath method" [19].

3.2. *Impact of WHC and MC_{soil} on the Moisture Content of Wood (MC_{wood}) Exposed in TMCs*

After three weeks of exposure in different TMCs, the average MC_{wood} was highest in Scots pine sapwood (88%), followed by English oak (75%), Beech (67%), and Douglas fir (48%). In general, MC_{wood} increased with increasing MC_{soil}, but was strongly dependent on the WHC of the soil. The lower the WHC, the higher was the MC_{wood} at a given MC_{soil}, which coincided with previous findings [12]. Lower WHC in this study corresponded with a higher percentages of silica sand, which can only physically absorb water in contrast to organic soil substrates such as compost soil and peat, which also form chemical bonds with water [20]. The capacity to bind water is therefore higher in organic substrates which restricts the amount of available water which potentially wets the wood specimens.

This effect became especially prominent when considering MC_{soil} as a percentage of the WHC of the soil as illustrated in Figure 4. The lower MC_{soil} (%WHC), the lower the MC_{wood} was at a given WHC of the substrate in the TMCs. However, it also became apparent that the effect of MC_{soil} became more pronounced at higher WHCs, i.e., the range of MC_{wood} between 30% and 120% MC_{soil} expressed as percentage of its WHC was higher by up 2 factors in substrates of high WHC (120%) compared to those with very low WHC (30%).

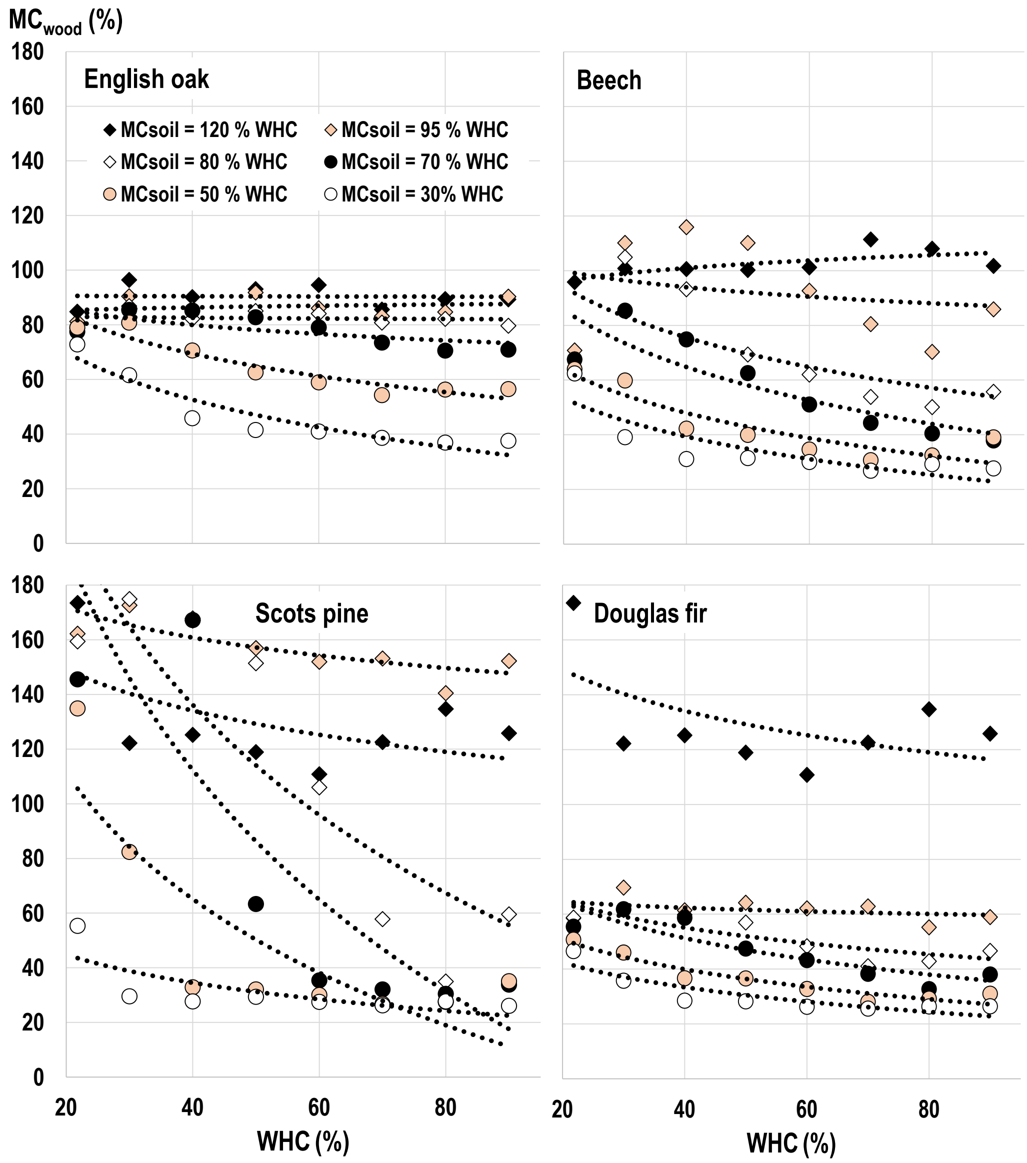

Figure 4. The interrelationship between wood moisture content (MC_{wood}) and WHC for different MC_{soil} expressed as a percentage of the WHC of the TMC (regression functions are shown in Table 5).

Table 5. Regression functions for fitting curves shown in Figure 5 (y = wood moisture content MC_{wood}; x = water holding capacity WHC).

MC_{soil} (%WHC)	English Oak	Beech	Scots Pine Sapwood	Douglas Fir
120	$-0.20\ln(x) + 91.20$	$6.81\ln(x) + 75.78$	$-16.06\ln(x) + 220.01$	$-21.77\ln(x) + 214.39$
95	$1.56\ln(x) + 80.56$	$-8.52\ln(x) + 125.38$	$-21.77\ln(x) + 214.39$	$-3.25\ln(x) + 74.33$
80	$-0.65\ln(x) + 84.98$	$-26.67\ln(x) + 173.92$	$-99.34\ln(x) + 502.65$	$-14.01\ln(x) + 106.82$
70	$-8.17\ln(x) + 110.07$	$-30.11\ln(x) + 175.84$	$-116.8\ln(x) + 543.26$	$-19.14\ln(x) + 121.88$
50	$-20.27\ln(x) + 144.18$	$-22.67\ln(x) + 131.58$	$-66.53\ln(x) + 310.55$	$-15.69\ln(x) + 97.79$
30	$-25.01\ln(x) + 144.87$	$-20.20\ln(x) + 113.81$	$-14.83\ln(x) + 89.25$	$-13.02\ln(x) + 81.44$

The difference between MC_{wood} results achieved after three weeks of in-soil exposure was surprisingly small between Beech and English oak heartwood, because the latter is known to take up water more slowly due to the formation of tyloses in the vessels. In contrast, Beech wood—apart from false heartwood which was excluded in this study— usually takes up liquid water very easy, although its vessel diameters are much smaller compared to the early wood vessels of English oak. Similarly, the maximum MC_{wood} of Douglas fir heartwood was in the same range of that of Scots pine sapwood when exposed in soil at an MC_{soil} of 120% WHC. Solely, at a lower MC_{soil}, the more permeable Scots pine sapwood showed higher MC_{wood} compared to the refractory heartwood of Douglas fir. In summary, it became evident that already after a short exposure period of three weeks in wet soil, wood anatomy-induced differences in moisture uptake diminished confirming previous findings [12].

To further illustrate the interdependency between WHC and MC_{soil} and their effect on MC_{wood}, the distance to water saturation of the soil substrate (S_{soil}) was determined according to Equation (7) and correlated with MC_{wood} (Figure 5).

$$S_{soil} = MC_{soil} - WHC\ (\% - \text{points}) \tag{7}$$

where S_{soil} is the distance to water saturation of the soil substrate, in %-points; MC_{soil} is the soil moisture content, in %; *WHC* is the water holding capacity, in %.

Generally, with increasing S_{soil}, the MC_{wood} increased as well, but followed wood species-specific curves with differently steep increases and a plateau at S_{soil} = 0%, i.e., soil water saturation. For English oak, Beech, and Douglas fir, the MC_{wood} stayed approximately constant at $S_{soil} > 0\%$. Solely, for Scots pine sapwood, MC_{wood} dropped significantly after exceeding the saturation point, although unlimited uptake of liquid water was expected to be provided above this threshold.

The distance to water saturation from which MC_{wood} remarkably rose differed also between wood species and was approximately at −55%-points for English oak, −25%-points for Beech and Douglas fir, and −20%-points for Scots pine sapwood. Scots pine sapwood showed also by far the highest increase in MC_{wood} with increasing S_{soil}, i.e., between 32% and up to 180% MC_{wood} between −20 and 0% S_{soil}.

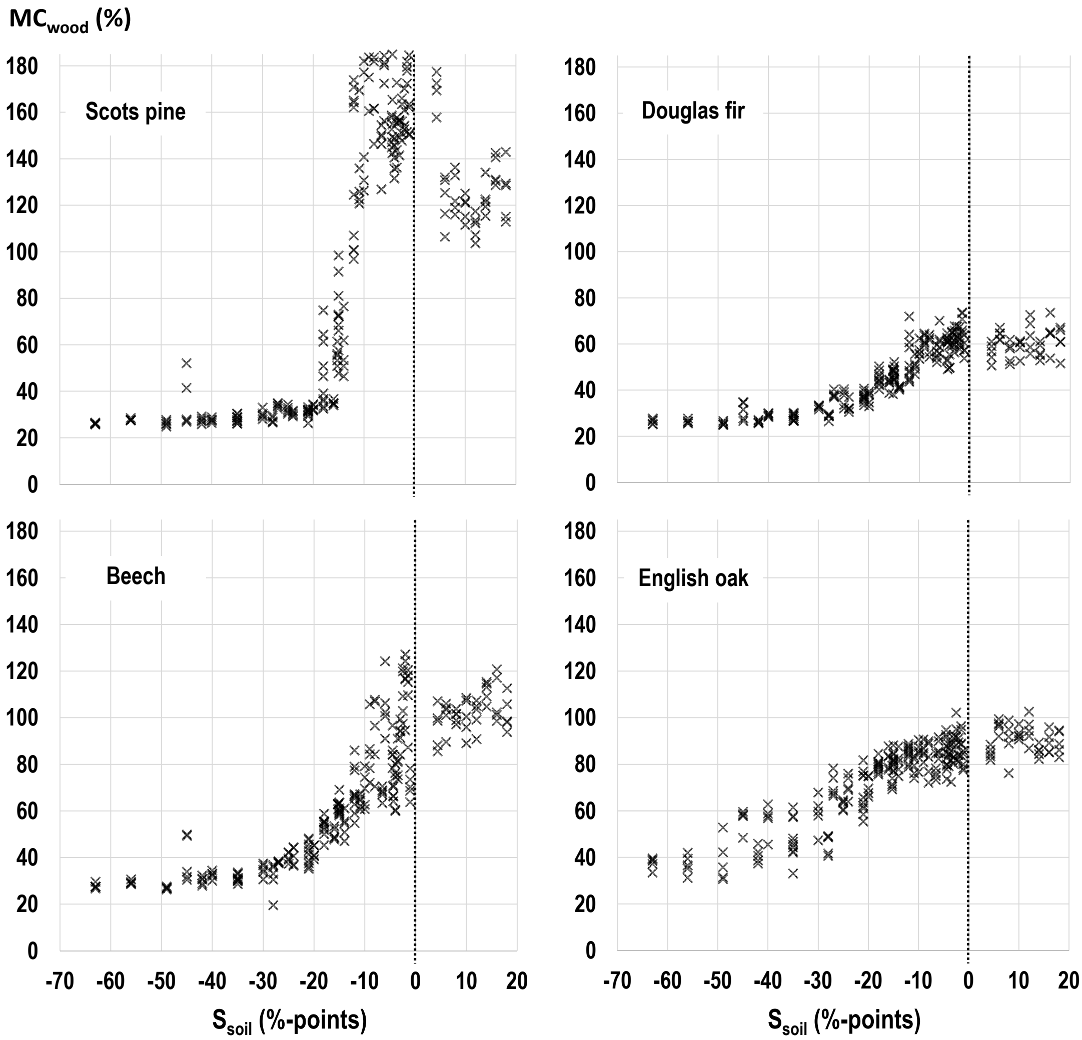

Figure 5. The interrelationship between the distance to water saturation of the soil substrates (S_{soil}) and the wood moisture content (MC_{wood}).

3.3. Moisture Content Gradients in Buried Wood Specimens

The MC_{wood} in specimens buried to 4/5 of their length in TMCs showed partly drastic gradients from high moisture content in the bottom to less in the upper part, which was not buried (Figures 6–9). Solely, Scots pine sapwood specimens exposed at high MC_{soil} (95%WHC) showed barely significant gradients, but very high MC_{wood} in all parts of the specimen. Similarly, deviating MC_{wood} gradients were reported by Mieß [12] for Scots pine sapwood specimens. As expected, generally, the highest difference in MC_{wood} was found between the upper segments and upper next segments.

The MC_{wood} in the upper segments of English oak and Douglas fir specimens was in the range of their equilibrium moisture content (EMC) at fiber saturation. In contrast, the upper segments of Scots pine sapwood and Beech specimens showed MC_{wood} up to 180 and 80% respectively, indicating strong capillary water transport along the specimen axis.

The MC_{wood} gradient in the specimens was positively correlated with MC_{soil} (%WHC). However, two types of MC gradients became apparent: (1) increasing MC_{wood} from the upper to the next segment, but rather constant MC_{wood} below (e.g., English oak at WHC = 30%), and (2) a steady increase of MC_{wood} from the upper to the bottom segment (e.g., Beech and Scots pine sapwood).

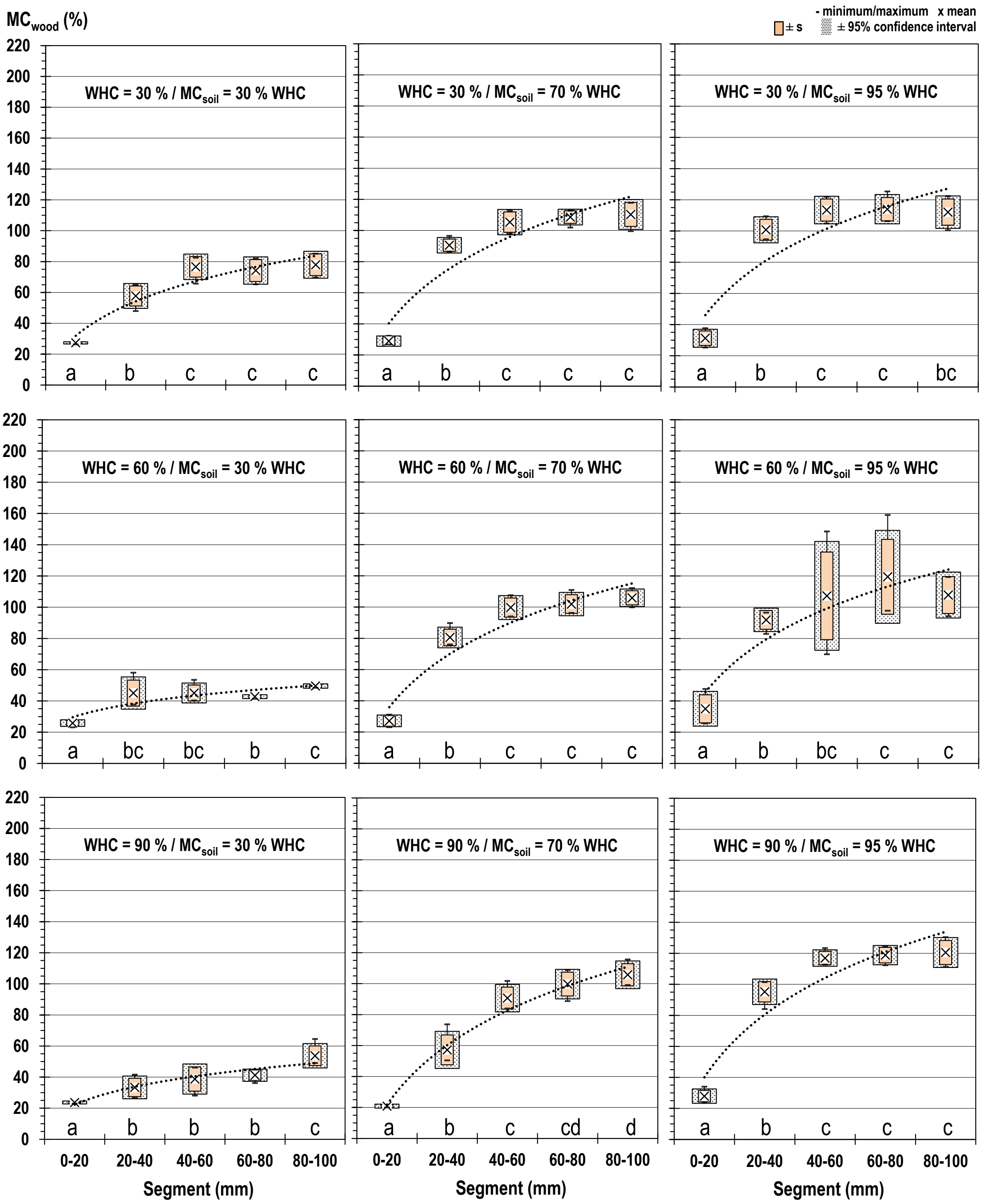

Figure 6. Distribution of MC_{wood} in English oak specimens buried to 4/5 of their length (20–100 mm) in different TMCs. Different letters indicating significant differences between groups at $p < 5\%$ according to a Student *t*-test for non-paired samples.

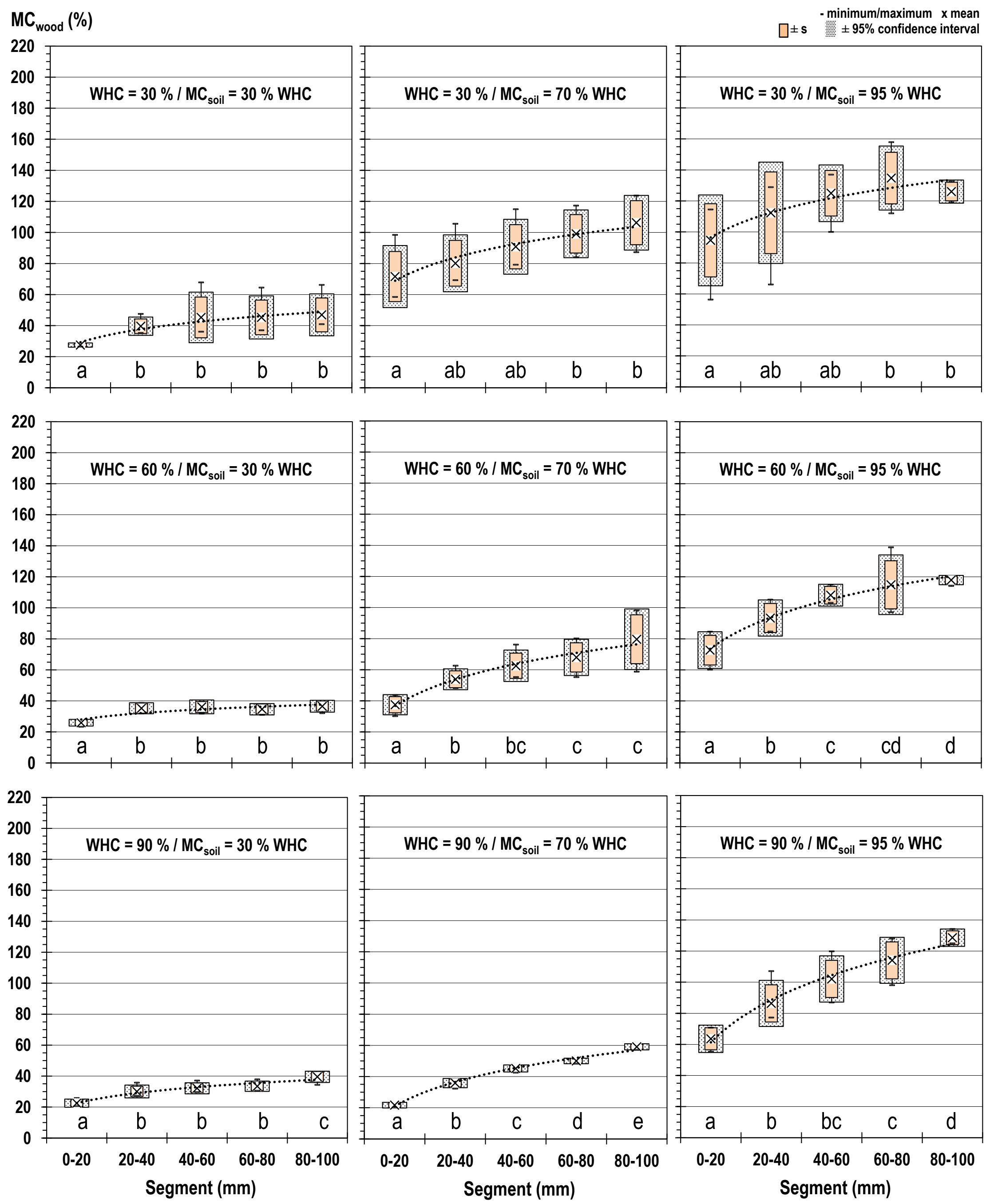

Figure 7. Distribution of MC_{wood} in Beech specimens buried to 4/5 of their length (20–100 mm) in different TMCs. Different letters indicating significant differences between groups at $p < 5\%$ according to a Student t-test for non-paired samples.

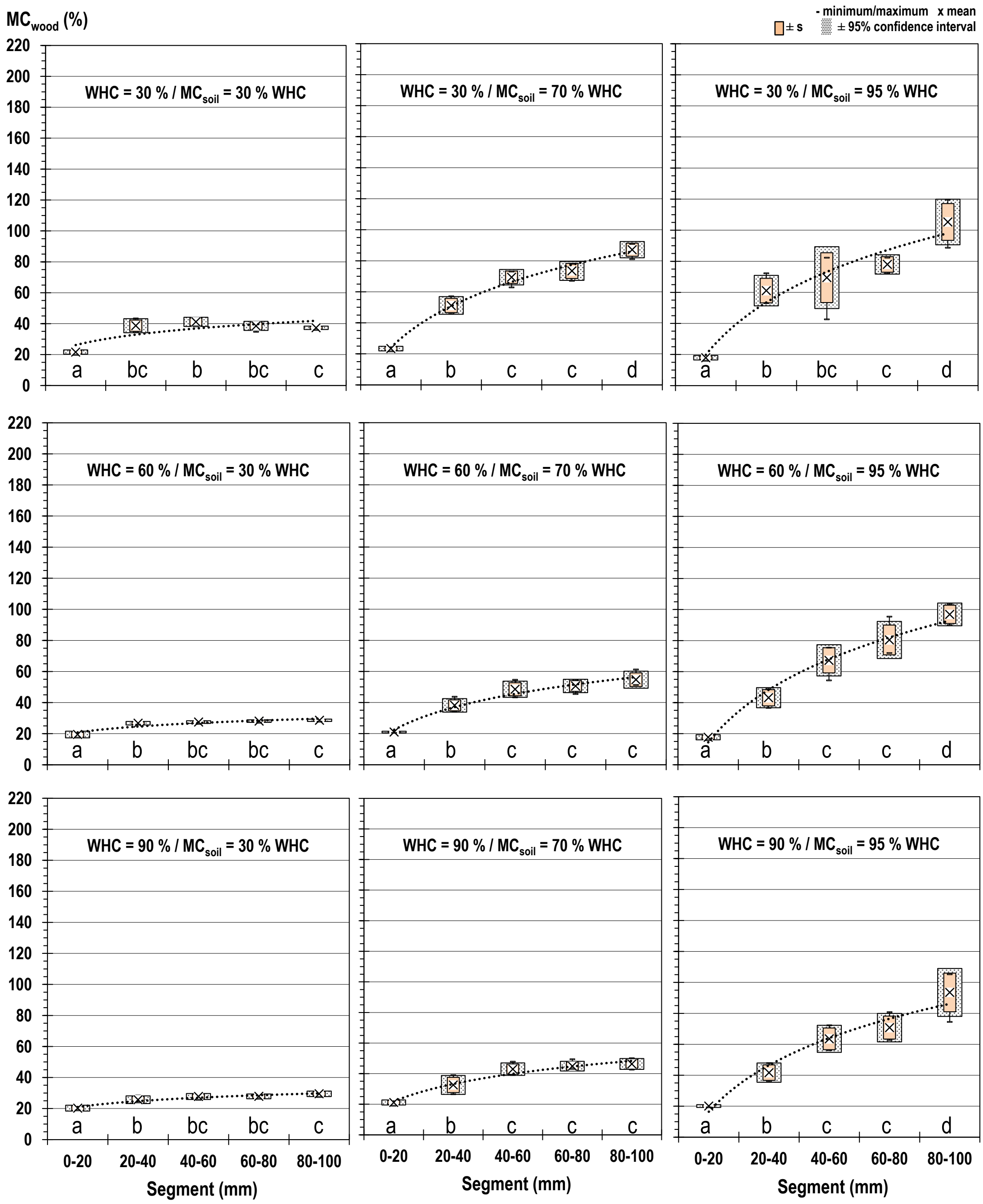

Figure 8. Distribution of MC_{wood} in Douglas fir specimens buried to 4/5 of their length (20–100 mm) in different TMCs. Different letters indicating significant differences between groups at $p < 5\%$ according to a Student *t*-test for non-paired samples.

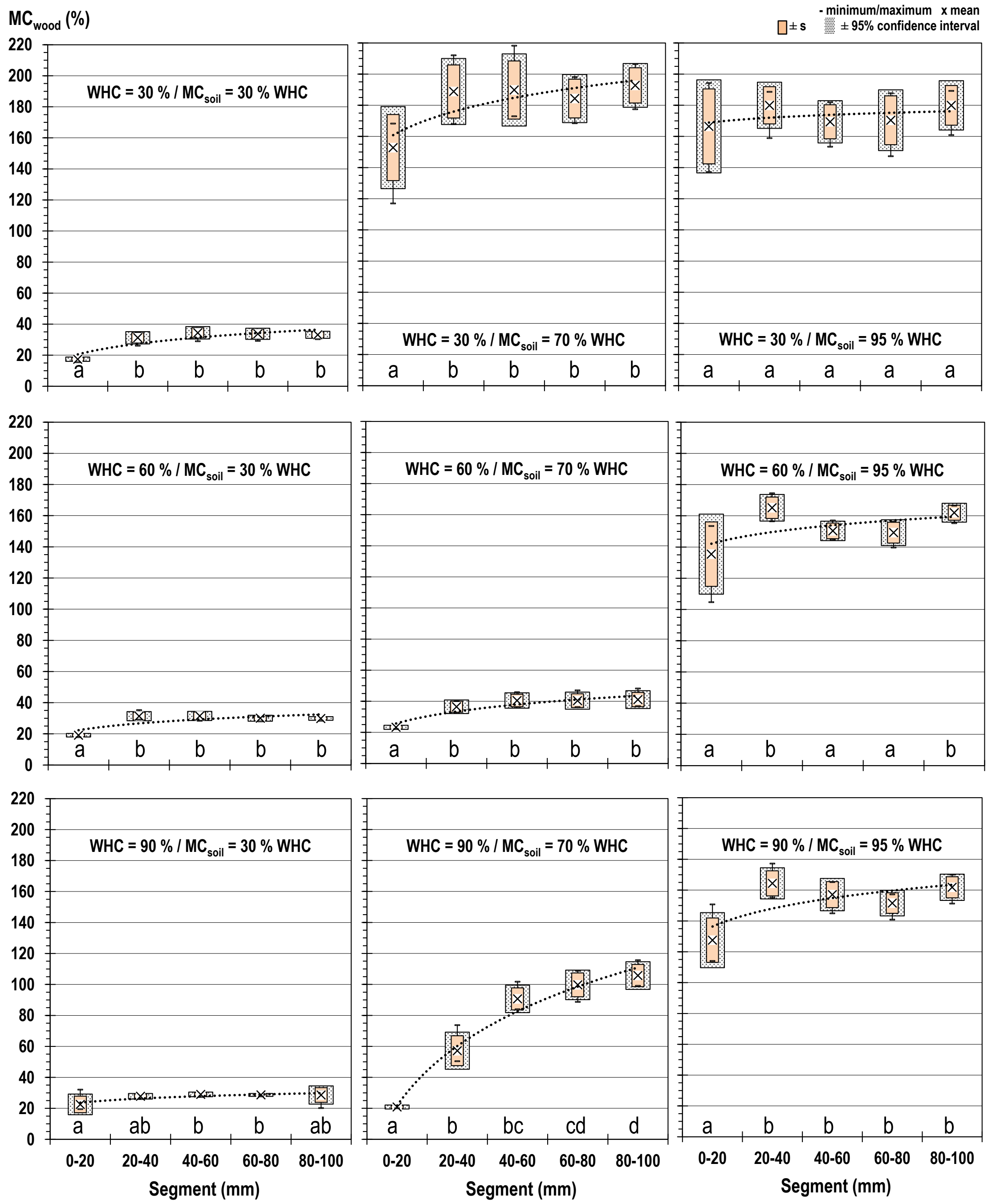

Figure 9. Distribution of MC_{wood} in Scots pine sapwood specimens buried to 4/5 of their length (20–100 mm) in different TMCs. Different letters indicating significant differences between groups at $p < 5\%$ according to a Student *t*-test for non-paired samples.

4. Conclusions

The findings from this laboratory study on the soil–wood–moisture interactions in terrestrial microcosms led us to the following conclusions:

- The more advantageous "Cylinder sand bath method" should consequently be seen as an adequate alternative for the "Droplet counting method", which turned out disadvantageous regarding practical applicability, reproducibility, and reliability.

- Water holding capacityvalues obtained from both test methods applied seemed to be easily transferable to each other. It is, therefore, recommended to replace the "droplet counting method" with the "cylinder sand bath method".
- The average MC_{wood} of specimens buried in TMCs increased with rising MC_{soil}, but WHC was often negatively correlated with MC_{wood}.
- The distance to water saturation S_{soil} appeared as a more predictive measure for MC_{wood}.
- With increasing S_{soil} the MC_{wood} increased but followed wood species-specific curves with differently steep increase and a plateau at S_{soil} = 0%.
- The distance to water saturation S_{soil} from which MC_{wood} increased most intensively was found to be wood-species specific and might, therefore, require further consideration in soil-bed durability testing. Thus, S_{soil} can likely be used to establish moisture conditions which are favorable for a specific decay type, i.e., brown, white or soft rot.
- The segment-wise determination of MC_{wood} revealed that a combination of low MC_{soil} and high WHC of the soil can easily lead to moisture conditions which are not favorable, neither for fungal decay in general, nor for soft rot decay in particular. They should, therefore, be avoided in durability testing, but might be of interest for the service life prediction of wood exposed to soil.

Based on the findings from this study, further experiments have been initiated to examine the effect of soil–wood–moisture interactions on fungal decay, in particular soft rot decay. In addition, the outstanding role of soil and wood temperature on decay in constantly wet wood will be further investigated.

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