Hungarian University of Agriculture and Life Sciences

Complex Study of the Effects of Irrigation, Organic Mulching and Artifical Soil Compaction on the Earthworm Community

Thesis of doctoral (PhD) dissertation

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Doctoral school

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1. THE BACKGROUND TO THE WORK, OBJECTIVES SET

Climate change has brought new challenges to agricultural professionals. The former approach of intensive crop production has been replaced by sustainable farming systems. While crop production used to be exclusively focused on high yields, the focus has shifted to land management that takes into account soil structure, fertility, and biodiversity. As a result, the use of environmentally harmful chemical inputs has been reduced and systems causing soil degradation have been abandoned. In the 2010s, the focus on advances in irrigation increased, with farmers being able to apply for non-reimbursable funds for their investments under several support schemes and to access irrigation water with public subsidies. Despite all these efforts, the size of the areas actually irrigated in Hungary is currently below potential compared to our natural conditions and utility supply.

Drought has become the most pressing challenge facing global agriculture. Average temperatures on our planet have risen by approximately 1°C over the past 50 years. At the same time, water resources have decreased, seasons have changed or been missed, and the distribution of rainfall has changed significantly. These effects are posing new challenges to plant breeders, soil cultivators, and irrigation professionals. While drought is increasing, food demand is also rising as a result of the world's growing population. Preserving soil conditions and soil life in drought-affected areas is key for future agriculture, as the challenges of climate change cannot be adequately addressed without protecting the soils.

In my research, I spent several years on agricultural fields examining the impact of two types of sprinkler irrigation technologies, namely the replenishment of water with linear (LI) and drum irrigation (DI), on the biological activity of soils. One of the questions I was looking to answer was whether linear irrigation, which is considered to be more soil-friendly, has a more favourable effect on physical and chemical soil properties. I compared the physical and chemical parameters of irrigated soils with data collected from non-irrigated (NI) areas, and therefore the data arrive from three experimental treatments. Within each of the three treatments, I investigated the effects of mulching and soil compaction from cultivation separately and in comparison with each other. The effects of the above factors on soil life are investigated in my thesis through the number and biomass of earthworms. I collected my data from an area that I have become thoroughly acquainted with over the years as a farmer. Based on my experience, I will try to scientifically answer the questions I have raised in my thesis.

During the design of the experiment, I selected the following tasks:

- Detectable difference in physical and chemical soil properties between linear (LI) and drum (DI) irrigation compared to each other and to the non-irrigated control (NI).
- Within each of the three plots with unique irrigation systems (LI, DI, NI), I have established both straw-covered and uncovered areas to investigate the effects of soil cover on soil moisture and penetration resistance.
- Detection differences in earthworm numbers between irrigation methods.
- Possible explanation for differences in earthworm abundance as a function of changes in soil properties.
- Investigation of the effect of soil cover on the occurrence of earthworms.
- Demonstration of the effect of artifical soil compaction on earthworms numbers and biomass.

2. Materials and Method

2.1. Research context

The area of investigation is 55,6926 hectares, next to the Kunszentmárton-Tiszaföldvár road, west of it, approximately 0.6-2.0 km west-northwest of the internal boundary of the municipality of Kungyalu, and approximately 1.7-3.1 km south of the municipality of Tiszaföldvár. with GPS coordinates 46 54'47.2 "N 20 15'46.7 "E. The soil of the experimental area is flat, even, genetically of the calcareous chernozem type. It is in good cultural condition and is classified as a medium-bedded loam on the basis of its physical composition.

The dates of the agrotechnical operations applied in the experimental plot, the amount of input materials used and the yield results are given in *Table 1.*

Table 1. Schedule for the applied agricultural management methods.

Year/Crop	Management	Depth	Seeding rate	Doses	Date
	Fertilization (PK 10-28)			250 kg ha^{-1}	28th October 2014
	Disking	12 cm			29th October 2014
	Seedbed preparation	5 cm			5th and 15th April 2015
2014/2015	Sowing	4 cm	420 000 ha^{-1}		18th April 2015
	Fertilization (NP starter)			370 kg ha^{-1}	18th April 2015
Soybean	Plant protection (Agrichem			2 l ha^{-1}	10th May 2015
(SG Eider)	Bentazon)*				
	Desiccation (Reglone)**			2.5 l ha^{-1}	25th August 2015
	Harvest		2416 kg ha^{-1}		17th September 2015
	Disking	8cm			20th September, 2015
	Fertilization (NPK 5-10-				
	30+3S+5CaO+3MgO)			230 kg ha^{-1}	12th October 2015
	Subsoiling	35 cm			20th October 2015
2015/2016	Seedbed preparation	6 cm			14th April 2016
	Sowing	6 cm	66 000 ha^{-1}		20th April 2016
Seed maize	Fertilization (N 34)			100 kg ha^{-1}	20th April 2016
(PR38A24)	Plant protection (Lumax)***			4.5 l ha^{-1}	30th April 2016
	Inter row cultivation	8 cm			16th May 2016
	Harvest		770 kg ha^{-1}		1st September 2016
	Stubble residue mulching	10 cm			6th September 2016
	Fertilization (NPK 5-10-30				
	+3S+5CaO+3MgO)			250 kg ha^{-1}	27th October 2016
	Ploughing	30 cm			3rd November 2016
2016/2017	Seedbed preparation	6 cm			10th April 2017
	Sowing	5 cm	72 000 ha^{-1}		18th April 2017
Maize	Fertilization (N 34)			100 kg ha^{-1}	18th April 2017
(P9486)	Plant protection (Lumax)***			4.5 l ha^{-1}	4th May 2017
	Inter row cultivation				24th May 2017
	Harvest	8 cm	8500 kg ha^{-1}		9th October 2017
	Stubble residue mulching	10 cm			12th October 2017
	Fertilization (NPK 5-10-30)			150 kg ha^{-1}	3rd November 2017
2017/2018	Disking	12 cm			5th November 2017
	Subsoiling	25 cm			17th November 2017
Sunflower	Seedbed preparation	5 cm			7th April 2018
(P64LE25)	Sowing	5 cm	50 000 ha^{-1}		15th April 2018
	Fertilizing (NP 15-25)			100 kg ha^{-1}	20th April 2018

	Plant protection (Express 50 SX)****			45 g ha^{-1}	29th April 2018
	Harvest		2960 kg ha^{-1}		17th September 2018
	Disking	10 cm			20th September, 2018

*Active ingredients in Bentazone (480 g/l bentazone); **Active ingredients in Reglone (37,3% diquat-dibromide + pyrazinediium dibromide); ***Active ingredients in Lumax (37,5 g/l mesotrione + 375,0 g/l S-metolachlor + 125,0 g/l terbuthylazine); **** Active ingredients in Express 50 SX (500g/kg tribenuron-methyl)

2.2. Presentation of the experiments

In my experiment, I examined the effects of three types of irrigation treatments. In a regular rectangular area, irrigation water is delivered by a linear irrigation system (LI), while in an extended section exceeding 500m, irrigation water is delivered by a drum irrigation system (DI). A part of the study area is not irrigated (NI), from which the control measurements were taken. The timing and quantity of water application was determined by taking into account the water requirements of the plants, the current soil moisture content and rainfall conditions. Water was applied three times in 2015, six times in 2016 and 2017, and once in 2018, at a typical rate of 20mm.

The mulch-covered treatments were always established in the same three locations in the study years, corresponding to the three irrigation treatments. The covered plots occupied an area of 10x10 m, on each of which a round bale of wheat straw was spread. The mulch cover was applied twice a year: at the end of the growing season, immediately after the last autumn work was completed, and during the growing season between the already growing crops. This ensured a continuous mulch cover throughout the experiment. The dates of mulching were 21 May and 25 October 2015; 12 May and 15 October 2016; 22 May and 24 October 2017; 04 May 2018 At a given time, I used half of a round bale for covering, so the amount of straw used was around 150kg per irrigation treatment and per season. I carried out the mulching in the same locations each year throughout the study period. I identified the locations of the mulch cover both visually and by using a GPS device.

Artificially compacted (C) and non-compacted (NC) sampling points were defined within each irrigation and mulching treatment, both for earthworm sampling and soil penetration measurements. An equal number of compact (C) and non-compact (NC) samples are obtained from each irrigation and mulching treatment.

The soil tests were carried out for two purposes. Firstly, to investigate the short-term effects of experimental treatments on soil properties. Secondly, to investigate the changes in soil profile caused by irrigation activities in long-term comparative studies.

The impact of irrigation treatments. The aim of the study was to investigate the changes caused by irrigation activities in the 0-150 cm layer, in particular the changes in the salinity profile due to salinisation propensity. To this end, a feasibility study was carried out in 2007 prior to the irrigation investment during the water permit procedure. The data from this measurement reflect the baseline condition, which can be considered as an absolute control for irrigation. The irrigation investment was completed in 2008 and the impact assessments were repeated in the permit renewal procedures in 2013 and 2017.

The impact of mulching. The aim of the studies was to understand the changes in soil chemical properties that may be detected as a result of experimental treatments. In order to explore how irrigation treatments and mulching may affect soil chemical properties, I sampled all irrigation treatments in five replicates on 09 April 2016.

I determined the penetration resistance of the soil by field measurements. Tests were performed at the same time as the worm sampling. Measurements were taken randomly in the covered area and in the surrounding 5-10m of the uncovered areas. For both types of treatments, half of the measurements were taken on the areas compacted by the cultivation tools and the other half on the uncompacted areas. For the penetration measurements I used a hand-held instrument (MOBITECH Bt.) and the measured data were given in Mega Pascal (MPa). Measurements were taken at five depths: 0-7.5; 7.5-15; 15-22.5; 22.5-30 and 30-37.5 cm.

At the same time as the soil resistivity test, I measured the soil moisture content using a PT-1 type measuring device manufactured by Kapacitív Kkt. The results of the measurements were obtained as a percentage by weight (m/m%). The measurements were made for the upper 0-15cm depth.

Following the planting, Irriga – System sensors providing continuous measurement were installed in the area in 2016. The system displayed the amount of natural rainfall and the amount of irrigation in graphical form throughout the growing season on a web interface. In 2016, the soil water tension (SWT- cbar) was continuously measured in 0-10 and 10-30 cm layers using a measuring station. These measurements were converted to SI and expressed in kPa.

Earthworm sampling was planned in accordance with the relevant ISO (2006) standards. At the start of the study, sampling pits of 25x25x30 cm were dug, the exact locations of which were recorded and the area of the covered plots was determined. The number of earthworms (pcs/m^2) and their biomass in g/m^2have been determined under laboratory conditions. The earthworm species were identified according to their external and internal characteristics according to the method described by CSUZDI and ZICSI 2003.

I measured the number and biomass of earthworms twice a year, in summer and autumn. In total, six measurements were taken during the study period 2015-2018: 12 September 2015; 10 June and 20 September 2016; 19 July and 10 October 2017; 24 June 2018. Three measurements reflect the irrigation season data and three measurements reflect the post-irrigation season data. A total of forty-eight samples were taken on a sampling day. Sixteen samples (n=16) were obtained from each of the three irrigation treatments, half of which came from mulched (M, n=8) soils and the other half from non-mulched (NM, n=8) soils. Within both M and NM treatments, 4 samples were taken from the compacted area (T, n=4) and 4 samples from the uncompacted area (NT, n=4).

2.3. Statistical analysis

For statistical analyses, I used the IBM SPSS Statistics 25 software package. Differences between different irrigation regimes (NI, LI, DI) in soil resistance and soil moisture values, as well as in earthworm numbers and masses, were investigated using one-factor analysis of variance. Where the empirical significance level (p-value) did not exceed 0.05, the null hypothesis of group mean identity was rejected and the difference was considered significant. Significant relationships between groups were determined using Tukey's HSD (Honestly Significant Difference) post hoc test. The Tukey test can be applied to multiple paired comparisons for samples of different sizes and is a commonly used method in international soil research (BALDIVIESO-FREITAS et al. 2018; CASTRO et al. 2019; HENEGHAN et al. 2007; SALEHI et al. 2013). Prior to analysis of variance, I checked the normality of the data using the Kolmogorov-Smirnov test and the homogeneity of variances using the Levene test. Since the two-sample t-test may be sensitive to the violation of normality and in most cases the Kolmogorov-Smirnov test was significant, I used the F-test to compare the mean values of two groups (mulched - M and non-mulched - NM, trodden - T and non-trodden - NT soils) as suggested by KAO and GREEN (2008).

3. RESULTS

3.1. Examination of the moisture content of 0-10 and 10-30 cm soil layers in 2016

This year, with the help of the measuring equipment available to me, I obtained continuous measurement data on the amount of rainfall and irrigated water falling on the examined area. This can also be considered as a control measurement in terms of operational and meteorological data at my disposal, giving me the opportunity to examine the differences.

Generally speaking, a lower soil moisture potential value is associated with a more favourable soil moisture condition for plants, as long as the soil does not become over-saturated with moisture, i.e. airless. When the moisture potential data for the 0-10 cm and 10-30 cm layers are evaluated together, it can be said that no over-irrigation occurred, as the application was only intended to maintain a favourable moisture status and to make up for water deficits.

3.2 Moisture content of the topsoil

The highest soil moisture was measured in the summer samples in the non-mulched trodden (LI-NM -C) treatment with a value of 50.0 m/m %. The lowest value was also obtained from a summer sample (9.2 m/m %). In both cases, samples were taken from non-mulched (NM) soil. The extreme values for mulched (M) soils were similar (10.50 - 47.60 %), so the differences can be attributed to the season. On average over the five samples, only the samples compacted (T) by cultivation (32.04%) in the irrigation seasons differed significantly ($p<0.05$) from the non-compacted (NC) samples (25.37%). The values of the autumn trampled (C) sample (23,09 %) were not significantly different from the autumn non-trampled (NC) samples (22,28%).

3.3. Results of irrigation water and groundwater quality tests

The laboratory test results of the irrigation water tested complied with most of the standards and parameters set out in the 90/2008. (VII. 18.) FVM decree. Irrigation water is of the mixed anion type, EC = 0,5 mS/cm, i.e. 0,78 – 1,56 mS/cm. The SAR value was 3.7, i.e. <6.5; the pH value was 7.36, i.e. within 6.5-8.4, the magnesium content was 52.8%, i.e. >50%, and the sodium content remained below 40% (38.2%). The amount of chloride ion is moderate (40.7 mg/l), i.e. non-toxic.

The groundwater has a salinity of 6380.0 mg/l and a nitrate content of 49.9 mg/l. The salinity is very high, with a SAR of 32.4%, an Na of 83.3% and an Mg of 88.9%. The composition of the groundwater is very unfavourable (highly saliniferous), it has a high total salt and sodium content, which increases the secondary salinisation of the deeper layers by rising.

3.4. Impact of irrigation methods on soil chemical properties

No harmful salt accumulation occurred during the period considered and no signs of leaching or substantial changes in the distribution of cations were observed. There was no significant change in physical and chemical properties compared to the soil layers of the previous sections. There was no significant difference in the salt profile of the (DI) and (LI) treatments. This is partly explained by the fact that the irrigation season was aimed at applying the same amount of water with both methods, and partly by the compensatory effect of the periodically high groundwater.

3.5. Effect of surface cover on soil chemical properties

Soil pH (KCl) was homogeneous in all samples, ranging from 7.38 (DI-NC) to 7.48 (LI-NC). The humus content was also relatively homogeneous, occurring between 2.38% and 2.69%. The lowest value was measured in the uncovered (DI-NM) areas with drum irrigation and the highest value of the humus content was measured in the uncovered (LI-NM) area with linear irrigation. The $CaCO_3$ content was also homogeneous between 2.08 (DÖ-NM) and 4.4% (LI-NM), which means that the examined soil can be classified as low calcareous.

3.6. Impact of irrigation and surface cover on soil resistance

In artificial water replenishment methods, irrigation water application with both the drum and the linear equipment can be classified as a surface rain-like irrigation method. However, the two application methods caused different changes in soil penetration resistance, which was significantly modified by mulching (M) and no mulching (NM). When comparing the linear (LI) and drum (DI) irrigated treatments, it is important to mention the differences in irrigation efficiency, i.e. the ratio between the planned and the actual applied water, which is significantly affected by the different evaporation and carry-over losses; and the changes in soil structure caused by the different kinetic energy of the droplets due to the different droplet size.

Based on my field observations, I concluded that a single jet of water delivered by a sprinkler drum caused more damage to the soil structure than a similar amount of water distributed over several nozzles by a linear device. The soil penetration values of irrigated treatments were more favourable in summer than those of non-irrigated plots. However, by autumn, due to slow infiltration, the irrigated treatments became more compact than the non-irrigated treatment, especially in the deeper layers.

3.7. Effect of mechanical trampling on soil resistance

Comparing the results of the summer and autumn sampling periods, it can be concluded that, although to different extents, clear soil compaction was detected in all treatments. While during the irrigation period, the soil with the most favourable soil resistivity values at most depths was clearly the linear irrigated (LI), by autumn this advantage disappeared and at most depths became similar to, and in some cases exceeded, the values of drum irrigation. In the autumn, the most favourable value was measured in the top (0-7.5 cm) layer of the NI-M-NC treatment with a value of 0.98 MPa, which was significantly different ($p<0.05$) from the results obtained in this layer for both other treatments. Treatment with LI-M-NT significantly exceeded 1.21 MPa ($p<0.05$) DI-M-NC with a result of 1.33 MPa.

The soil compacting effect of irrigation was mainly demonstrated in the LÖ-NM-T and DI-NM-C treatments in the autumn period. In these non-mulched, trodden treatments, the extent of adverse soil compaction was already observed in the 15-22.5 cm layer, with both treatments reaching 3.40 MPa, significantly ($p<0.05$) higher than the 2.85 MPa of NI-NM-C in the same layer. The most unfavourable average soil resistivity for the whole study period developed in the 30-37.5 cm layer of the DI-NM-C treatment with a value of 4.09 MPa. The relationship between soil moisture content and soil compaction was pointed out by SOANE and VAN OUWERKERK (1994), who considered soil moisture content to be the the main factor influencing soil compaction.

However, organic mulching in all treatments compensated to some extent for the adverse effects on the soil during the growing season, regardless of the season. The most compacted value measured in the mulched (M) soils was below the minimum compaction value of the non-mulched (NM) soil except for one layer. The average result of 3.68 MPa measured in the 30-37.5 cm layer of the DÖ-M-T treatment in the autumn was 0.2 MPa higher than the result of the NÖ-NM-T treatment. BUESA et al. (2021) found that mulching improved soil water management independently of the irrigation system and reduced the soil's volumetric density. LIAO et al. (2021) found that organic cover effectively reduced evapotranspiration, thereby significantly increasing irrigation water use efficiency.

3.8. Species and age composition of the earthworm community

Five earthworm species were identified during my investigations. These were in descending order: Aporrectodea *caliginosa* (Savigny, 1826)*, Aporrectodea rosea* (Savigny, 1826)*, Aporrectodea georgii* (Michaelsen, 1890)*, Proctodrilusopisthoductus* (Zicsi, 1985)*, Octolasion lacteum* (Örley,1881). The species identified in the sampling are endogenous earthworm species that are well adapted to agricultural land and tillage (CSUZDI and ZICSI 2003).

In all years studied, the proportion of non-mature individuals was several times higher than the proportion of mature individuals, regardless of the season. A higher proportion of adults would be essential for the regeneration of the population. Earthworms must reach a certain weight in order to mature and be able to reproduce (LOFS-HOLMIN 1983).

3.9. Impact of irrigation on the number and biomass of earthworms

The highest number of earthworms (92.5 pcs/m^{2}23.98g/m^2) was detected in the non-irrigated (NÖ) treatment in the autumn. This was followed by linear irrigation (55.5 pcs/m^2; 14.71 g/m^2), followed by drum irrigation (45.33 pcs/m^2; 12.61 g/m^2), both with autumn data. During the summer irrigation season, the control data again provided the most favorable conditions (28.16 pcs/m^2; 5.55 g/m^2), followed by the DI (23.16 pcs/m^2, 4.9 g/m^2), and finally the LÖ treatment (18.33 pcs/m^2; 4.16 pcs/m^2). Based on the results of ANOVA, there was a significant difference ($p<0.05$) between the earthworm number (*Fig. 1.*) and biomass values *(Fig. 2.)* of the non-irrigated (NI) treatment compared to the other two irrigation treatments (LI; DI) and only in the autumn period.

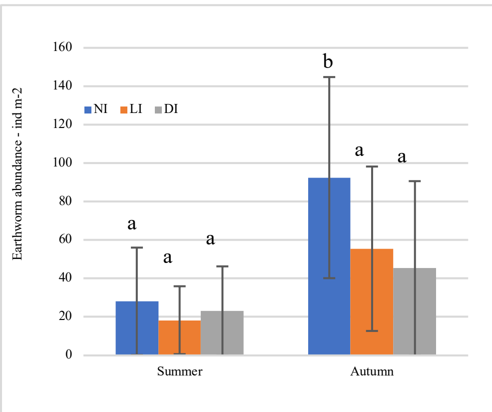

Fig. 1. Abundance of earthworms (ind m^{-2})

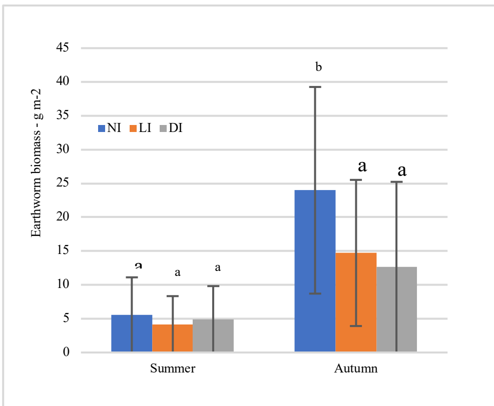

Fig. 2. Biomass of earthworms (g m^{-2})

Notice: The lowercase letters (a, b) indicate significant difference between the irrigation treatments.

The life cycle of earthworms includes winter and summer dormancy. These dormant periods are related to temperature and soil moisture content. The amount of soil brought to the surface suggests that they are most active in the autumn months. This can be explained by the preparation for the winter rest period (SMEATON et al. 2003).

3.10. Impact of mulching on the number and biomass of earthworms

The highest number of individuals was obtained from samples taken after the irrigation period. In the autumn mulched (M) soil, the number of individuals and biomass (68.11 pcs/m^2; 17.37 g/m^2) was not significant, but slightly higher than in the autumn non-mulched (NM) soil (60.77 pcs/m^2; 16.84 g/m^2). The mulched soil (M) data (29.88 pcs/m^2; 6.61 g/m^2) exceeded the values of non-mulched (NM) treatments (16.55 pcs/m^2; 3.13 g/m^2).

In mulched (M) and non-mulched (NM) treatments, the earthworm number *(Fig. 3)* and biomass values *(Fig. 4)* were significantly different only in summer samples ($p<0.05$). Also in autumn, earthworm abundance was higher in the mulched plots, but the difference between the two treatments was not significant during this period.

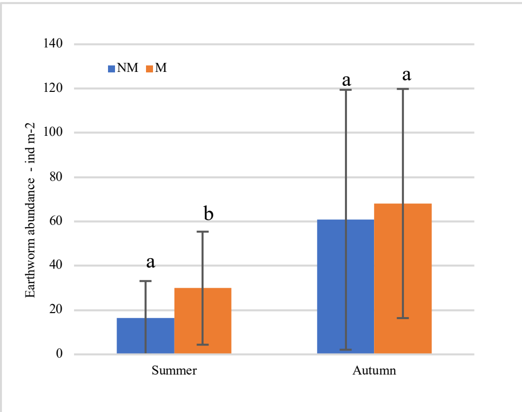

Fig. 3. Abundance of earthworms (ind m^{-2})

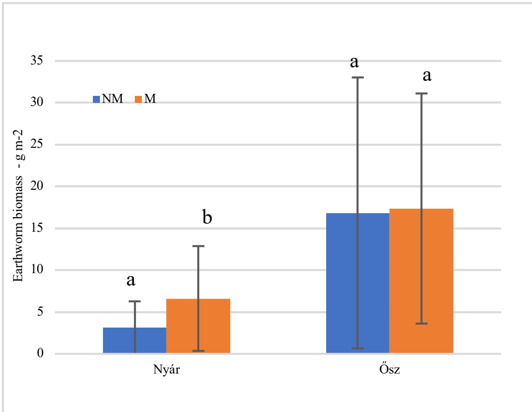

Fig. 4. Biomass of earthworms (g m^{-2})

The lowercase letters (a, b) indicate significant difference between the irrigation treatments.

As soil moisture increased, the number of burrows decreased proportionally, but the biomass of earthworms increased. In wetter soil, earthworms probably fed more intensively and dug less. Earthworms living in drier conditions consumed less of the available food, while creating more and deeper burrows (PERREAULT and WHALEN 2006).

3.11. Impact of soil compaction on the number and biomass of earthworms

I was able to detect the highest incidence from the non-compact (NC) autumn sample (67.77 pcs/m^2; 18.15 g/m^2), followed by the autumn compact (C) sample (61.11 pcs/m^2; 16.05 g/m^2). During the irrigation season, the values of the solid (C) samples (27.66 pcs/m^2; 5.88 g/m^2), although not significantly higher than the values of the non-compact (NC) samples (18.77 pcs/m^2; 3.87 g/m^2).

I used one-way ANOVA to analyze the data. The data from the tracks compacted (C) by tillage tools and irrigation systems did not differ significantly from the values from the untrodden (NC) areas in any season. When comparing the data between seasons, a significant difference was observed. In autumn, the number of earthworms and their biomass were more than twice as high as in summer.

According to VRSIC et al. (2021), the highest earthworm abundance is found under straw mulch. They concluded that different soil management practices have a strong influence on soil environmental conditions (temperature, humidity), especially in the upper 15cm of the soil, and it is this layer whose characteristics have the greatest influence on earthworm abundance.

3.12. New scientific findings

My research has led me to the following new scientific findings:

1. I have detected little change in the chemistry of deep saline solanaceous soil after three years under two different irrigation regimes, using water rates tailored to the location and to weather conditions. I measured a lower water-soluble salinity in the cultivated layer of the irrigated plots as an effect of irrigation (average 0.055% water-soluble salts) than in the year of the baseline study (average 0.16% water-soluble salts).
2. I have shown that both sprinkler irrigation methods (LI-NM and DI-NM) during the irrigation season resulted in better soil penetration values compared to the non-irrigated and non-mulched treatment (NI-NM 15 – 22.5 cm, average: 1.70 MPa). In the absence of mulching, linear irrigation resulted in an average soil compaction of 52% less in this layer than in the case of drum irrigation.
3. I confirmed the delayed, prolonged settling effect of slower infiltration in the two different sprinkler irrigation systems, which resulted in 13.8% higher penetration values in the 30-37.5 cm soil layer for linear irrigation and 12.5% higher penetration values for drum irrigation compared to the non-irrigated treatment. By autumn, the beneficial effect of linear irrigation had disappeared and the deeper layers showed the highest compaction compared to the other treatments.
4. I have demonstrated the beneficial effect of organic mulching on irrigation water infiltration into the soil, whereby soil settling and tillage-induced compaction remained below the critical resistance value (≤3MPa) in all tested layers during the irrigation season. Among the mulched treatments, only the 30-37.5 cm layer of soil that was drum irrigated showed adverse soil compaction after the irrigation season.
5. I have measured the negative effect on earthworm abundance of denser soil associated with irrigation. On average, the highest earthworm number and weight (92.5 pcs/m^2; 23.98 g/m^2) was detected in the autumn in the non-irrigated treatment. This was followed by linear irrigation in the autumn (55.5 pcs/m^2; 14.71 g/m^2), followed by drum irrigation in the autumn (45.33 pcs/m^2; 12.61 g/m^2). The adverse effects of soil compaction were mitigated by permanent surface cover to provide food and shelter for earthworms. The average of mulched soil data over the entire research period (29.88 pcs/m^2; 6.61 g/m^2) significantly exceeded the values of non-mulched (NM) treatments (16.55 pcs/m^2; 3.13 g/m^2).

4. Conclusions and suggestions

Before irrigation investments are established, a soil conservation plan must be prepared by soil section mapping differing soil patches, but at least every 10 hectares, to be reviewed every five years. In areas prone to salinisation, changes in the salinity profile should be monitored in particular and irrigation practices should be changed as necessary. In my thesis, I have highlighted the need to monitor changes in living systems in addition to changes in soil and irrigation water properties.

Every artificial intervention in the complex system of living and non-living soil causes changes. Quantitative measurements were needed to establish the exact extent. In 2016, remote sensing equipment was used to help prepare the decision. The research period was characterised by one dry and one wet year and two average years. In order to maintain crop reliability, I applied the water supplementation required for the smooth development of the crop in addition to the precipitation of the period. Irrigation adapted to the site and the weather conditions avoided overwatering, which could damage the soil, thus avoiding the risk of salinisation and nutrients being washed into deeper layers. The soil test values during the study period did not differ significantly from the results of the soil tests carried out before the irrigation investment. Soil chemistry results were not affected in the short term by organic surface coverage. In the case of regular irrigation, chemical tests are recommended irrespective of the soil texture.

Among the physical properties of the soil, moisture content and soil resistivity were investigated in particular. Monitoring of soil moisture showed that precipitation falling before the growing season is present in deeper layers, providing a certain amount of water replacement for the plants. Water deficits in the deeper layers should be avoided, as their subsequent recharge is already beyond the capacity of the irrigation system in most cases. The evaluation suggests that continuous moisture testing during the irrigation season is recommended. It is also recommended to monitor the changes in soil conditions caused by the infiltration of irrigation water into the soil in order to help plan the cultivation before the next season.

The biggest change in physical soil properties within a year was observed in soil penetration values, especially in the case of uncovered treatments. The favourable soil resistance values in summer became unfavourable in autumn due to the slow settling of irrigated soils. In terms of soil penetration resistance, the advantage of linear irrigation cannot be clearly established, as the slow infiltration of water caused a more significant sedimentation of deeper layers. Mulching had a positive effect on the values of all three treatments, their penetration values did not differ as much as those of the unmulched treatments. My measurements confirmed that the soil resistance values of the mulched soils were more favourable than those of the non-mulched treatments in all three irrigation treatments, despite the mechanical compacting. Since soil settling often occurs as a result of irrigation, monitoring is needed to slow down the phenomenon influenced by soil slump and to carry out remedial action at the end of the season.

I paid special attention to the investigation of the impact of the two sprinklers (drum, linear) on the soil structure. The crusting is indicative of surface structural degradation due to higher droplet energy during drum irrigation. Surface coverage, at a favorable rate (at least 30%), can contribute to the prevention of silting and crust formation.

I chose earthworms, which are considered to be indicators of soil quality, to study the living system of the soil. I measured the number and biomass of earthworms on three summer and three autumn dates. The proportion of adult earthworms capable of reproduction was below 30% in all but one case, and the species composition was limited to only five species. These were in descending order: *Aporrectodea caliginosa* (Savigny, 1826)*, Aporrectodea rosea* (Savigny, 1826)*, Aporrectodea georgii* (Michaelsen,1890)*, Proctodrilus opisthoductus* (Zicsi,1985)*, Octolasion lacteum* (Örley,1881). The regeneration of the population can be ensured by the adults and physical protection can be provided them by mulching.

In the summer, the number of earthworms was higher in settled wetter soils, while in the autumn, the number of earthworms was higher in loose soils. When comparing the data of the two sprinkler irrigation systems, we find no significant difference in the occurrence of earthworms in either season. However, considering the autumn data of irrigated and non-irrigated treatments, the abundance of earthworms in non-irrigated areas was significantly higher than in irrigated areas. This phenomenon also draws attention to habitat protection.

My results show that mulching is an effective tool for protecting against weather extremes, reducing the adverse effects of artificial interventions and preserving soil life. Extensive application of this solution is recommended not only in deep saline solanaceous soils, but also in many soils and growing areas where weather events or cultivation interventions jeopardise the maintenance of crop security.

5. REFERENCES

BALDIVIESO-FREITAS, P. - BLANCO-MORENO, J. - GUTIÉRREZ-LÓPEZ, M. - PEIGNÉ, J. - PÉREZ-FERRER, A. - TRIGO-AZA, D. – SANS, F. 2018. Earthworm abundance response to conservation agriculture practices in organic arable farming under Mediterranean climate. *Pedobiologia* 66. pp. 58-64.

BUESA, I. - MIRÁS-AVALOS, J. - DE PAZ, J. - VISCONTI, F. - SANZ, F. - YEVES, A. - GUERRA, D. – INTRIGLIOLO, D. 2021. Soil management in semi-arid vineyards: Combined effects of organic mulching and no-tillage under different water regimes. *European Journal of Agronomy* 123. pp. 126198.

CASTRO, J. - BARREAL, M. - BRIONES, M. – GALLEGO, P. 2019. Earthworm communities in conventional and organic fruit orchards under two different climates. *Applied Soil Ecology* 144. pp. 83-91.

CSUZDI, CS. - ZICSI. A. 2003. Earthworms of Hungary (Annelida: Oligochaeta, Lumbricidae). *Pedozoologica Hungarica (1) Budapest*.

HENEGHAN, L. - STEFFEN, J. - FAGEN, K. 2007 Interactions of an introduced shrub and introduced earthworms in an Illinois urban woodland: Impact on leaf litter decomposition. *Pedobiologia* 6(50). pp. 543-451.

KAO, L. - GREEN, C. 2008. Is there a difference in means and what does it mean? *Journal of Surgical Research* 144(1). pp. 158-170.

LIAO, Y. - CAO, H. - LIU, X. - LI, H. - HU, Q. - XUE, W. 2021. By increasing infiltration and reducing evaporation, mulching can improve the soil water environment and apple yield of orchards in semiarid areas. *Agricultural Water Management* 253. pp. 106936.

LOFS-HOLMIN, A. 1983. Reproduction and growth of common arable land and pasture species of earthworms (Lumbricidae) in laboratory cultures. *Swedish Journal of Agricultural Research* 13(1). pp. 31-37.

PERREAULT, J. – WHALEN, J. 2006. Earthworm burrowing in laboratory microcosms as influenced by soil temperature and moisture. *Pedobiologia* 50(5). pp. 397-403.

SALEHI, A. - GHORBANZADEH, N. - KAHNEH, E. 2013. Earthworm biomass and abundance, soil chemical and physical properties under different poplar plantations in the North of Iran. *Journal of Forest Science* 59(6). pp. 223-229.

SMEATON, T. - DALY, A. - CRANWELL, J. 2003. Earthworm population responses to cultivation and irrigation in a South Australian soil. *Pedobiologia* 47(4). pp. 379-385.

SOANE, B. - VAN OUWERKERK, C. 1994. Soil compaction problems in world agriculture.

In: Developments in Agricultural Engineering. Elsevier 11. pp. 1-21.

VRSIC, S. - BREZNIK, M. - PULKO, B. - RODRIGO-COMINO, J. 2021. Earthworm abundance changes depending on soil management practices in Slovenian vineyards. *Agronomy* 11. p. 6.

6. SCIENTIFIC PUBLICATIONS

6.1.Publications in international scientific journals

Radics Z., Dekemati I., Gyuricza Cs., Simon B., Ibrahim H., Vinogradov Sz., Birkás, M. 2022. Effects of irrigation and organic mulching on the abundance and biomass of earthworms. Polish Journal of Environmental Studies 31: 3 Paper: 143258, 11 p. **IF: 1,699**

Dekemati I., Bogunović, I., Kisić, I. **Radics Z.**, Szemők A., Birkás M. 2019. The effects of tillage-induced soil disturbance on soil quality. Polish Journal of Environmental Studies 28 (5). pp. 3665-3673. **IF: 1,699**

6.2. Publications in Hungarian scientific journals on Hungarian language

Birkás M., Dekemati I., Kende Z., **Radics Z.**, Szemők A. 2018. A sokszántásos műveléstől a direktvetésig – Előrehaladás a talaj művelésében és védelmében. Agrokémia és Talajtan, 67. 2. pp. 253-268

6.3. Further scientific publications

6.3.1. Conference proceedings in English

Birkás M., Bogunović I., Đekemati I., Kisić I., **Radics Z.** 2018. Adaptable tillage – is that a solution for the present climate situation? Proceedings and Abstracts, 11th International Scientific/Professional Conference Agriculture in the Nature and Environment Protection, 28th-30th May, 2018, Vukovar, Croatia. Glas Slavonije d.d., Osijek.

Dekemati I**., Radics Z.**, Kende Z., Bogunovic I., Birkás M. 2017. Responses of maize (Zea mays L.) roots to soil condition in an extreme growing season. Columella 4. 1. Suppl. pp. 27-30.

Dekemati I, **Radics Z.**, Kende Z., Birkás M. 2016. Soil state assessment in Croatia and in Hungary – Similiarities and differences. Növénytermelés, 65 (Suppl.), pp. 139-142.

6.3.2. Conference proceedings in Hungarian

Birkás M., Đekemati I., Kende Z., **Radics Z.**, Szemők A. 2017. A sokszántásos műveléstől a direktvetésig – Előrehaladás a talaj művelésében és védelmében. "70 éves a Karcagi Kutatóintézet" Tud. Konferencia, Karcag, 2017.09.06