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Mirjam Westram*, Michael Kumschier, Jana Zinkernagel

Upgrading vegetable cropping systems' soils to fight climate change effects – lessons learned from collaborating practice and science

Hochschule Geisenheim University, Department of Vegetable Crops,
Von-Lade-Straße 1, 63566 Geisenheim, Germany;
Mirjam.Westram@hs-gm.de, Michael.Kumschier@hs-gm.de,
Jana.Zinkernagel@hs-gm.de

* Correspondence: Mirjam.Westram@hs-gm.de

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Mirjam Westram, Michael Kumschier, Jana Zinkernagel

Hochschule Geisenheim University, Department of Vegetable Crops, Germany

Abstract

Increasing variability of precipitation and drought poses a high risk to vegetable cultivation. A new evolving approach for application-oriented developments to tackle these challenges and find solutions to increase plant available water are living labs, transdiciplinary research and innovation platforms. A living lab for organic vegetable cultivation in open field has been formed to minimize this risk. Since 2022, a two-year field trial on fields of three organic vegetable farms and at a research station has been conducted to examine the effect of different organic materials (OM) applied to the field prior to cultivation, on the water infiltration rate. Green waste compost or composted manure are compared to a control treatment without added OM. Soil organic carbon (SOC) and C:N-ratio (CN_soil), soil texture, cover crop dry matter yield (DM) and the stationary infiltration rate (SIR) were measured. On a cross-farm level, the OM-treatments did not affect the SIR, though various other soil organic parameters (SOC, CN_soil) contributed to its variability. The soil C:N-ratio and SOC correlated with the total irrigation amount (0.86 and 0.74), concluding the mineralization processes need sufficient water to build SOC and consequently the soil structure, which improves the SIR. As cultivation factors varied significantly between the farms, greater efforts need to be made to incorporate most of the drivers (e.g. machinery, cultivation practices) and the constraints to practical soil management in transdisciplinary research.

1. Introduction

As farmers increasingly face prolonged periods of drought and intensified rain fall in the model region (Schmidt and Zinkernagel 2017), defined by its geomorphological driven unique climate, approaches for building more resilient field cropping systems towards these stressors are mandatory. To surpass the time periods of water deficiency or excess water supply, various technical methods, such as irrigation and rain water harvesting are used to manage both extremes. A method to avoid the risk of soil degradation is the application of soil amendments that increase soil porosity, store more water in the mid-sized pores (Evanylo et al. 2008) and consequently reduce the effect of runoff and erosion (Rieke et al. 2022; Bartoli and Dousset 2011). Essential for the built-up of these beneficial effects as part of the soil's structure are water stable aggregates (Puget et al. 2000; Rieke et al. 2022) and bio pores, formed by large earth worms (Bouma et al. 1982). Vertical dug earth worm channels quickly drain water in deeper soil layers, irrespective of the soil type.

The living lab approach comprises collaborators from practice, extension-service and science (Lehmann et al. 2015; Meurer et al. 2015). Developing a co-creative, user-driven solution is usually an iterative process (McPhee et al. 2021) with equal responsibility and more required interaction from all partners. Experiments are run jointly together at agricultural and scientific sites, latter for exact trials. The approach offers the opportunity to eludicate the actual representative variability due to different treatments (as system approaches) and soil management affecting water infiltration. Thus, the cross-farm variability and the factors driving the variability are extracted in this study. The focus of this study was to a) quantify the effect of organic amendments on the SIR, b) to analyse the variability in results of a cross-farm study based on various soil and water parameters, and c) to generate broadly applicable findings for living lab trials in organic vegetable production.

2. Data, Methods and Approach

Data were collected in 2023, one year out of a three-year trial with organic vegetable crops. The farms were located near Bad Nauheim (lat 50.39, long 8.76), Steinfurt (lat 50.36, long 8.80, Darmstadt (lat 49.84, long 8.57) and in Geisenheim at the research station of the Hochschule Geisenheim University (HGU-site) (lat 49.98 long 7.96) in Hessia, Germany. Details to the farm sites are given in Table 1. The effect of two different organic materials, applied to the soil prior to cultivation, on the hydraulic properties of the soil have been examined. Green waste compost (compost) or composted manure (manure) (10 and 15 t ha^{-1} in 2022, followed by 15 and 20 t ha^{-1} in 2023, respectively) were incorporated into the soil and compared to a control treatment without added OM (control). The experimental design was a full randomized block design in 2022 until in 2023 the control was added at the edge of the field as an additional block. All fields were overhead-irrigated with fixed installed sprinkler plants at the farms' sites and a linear-move irrigation machine at the research site and irrigation scheduling was handled individually according to farm's practice. At the HGU experimental site the cultivation was deficit irrigated (75%) according to the Geisenheim Irrigation Scheduling (Zinkernagel et al. 2022).

Table 1: Soil type, crop, cover crop, cultivar, breeder, country from two seasons (2022-2023) and infiltration measuring dates of the farms (anonymized).

	Experimental site	Farm 1		Farm 2		Farm 3		HGU
	Soil type	Clayey loam to sandy clay loam		Loamy sand to loam		Silty loam to loam		Sandy loam to loam
2022	Crop	**Leek**		**Pointed cabbage**		**Onion**		**Leek**
2022	Cultivar	Hilari G 322		Castello F1		Bajosta G 462		Hilari G 322
2022	Breeder	b-d EHZ		Hazera		b-d EHZ		b-d EHZ
2022	Country	Germany		Germany		Germany		Germany
2022	Treatment	Compost	Manure	Compost	Manure	Compost/ Control	Manure	All
2022	Cover crop	**Winter vetch**	**Winter wheat**	**Weed**	**Winter rye**	**Winter vetch**	**Winter rye**	**Winter wheat**
2022	Cultivar	D 200	unknown (for consume)	Welta (sowed but frozen)	Dankowskie Rubin	Inspector	Ostsaat-Dr. Baumann	Alessio
2022	Breeder	Bingenheimer Saatgut AG	unknown	Euro Grass Breeding GmbH	Danko Saatgut GmbH	Saatenunion GmbH	Deutsche Saatveredelung AG	Saatzucht Donau GesmbH & Co KG
2022	Country	Germany	Germany	Germany	Germany	Germany	Germany	Austria
2023	Crop	**Red cabbage**		**Red beet**		**Celery**		**Red cabbage**
2023	Cultivar	Travero F1		Boro F1		Markiz		Travero F1
2023	Breeder	Bejo		Bejo		Hild		Bejo
2023	Country	Netherlands		Netherlands		Germany		Netherlands
	Dates of IR measurement	26-27/09/2023		04-05/09/2023		19-21/09/2023		04-07/10/2023

The stationary infiltration rate was measured with hood infiltration devices (IL 2700, UGT, Müncheberg, Germany) at the HGU-site continuously and at all farm sites at the end of cultivation. For measurements the hood was located in the planting row, between two plants. Infiltration rate readings were taken at three pressures (-0.1, -2.1 and -4.1 hPa) on the soil surface. Only results for the -0.1 hPa-measurement are shown here.
One square meter of cover crop (Table 1) was harvested from all sites, except those with a newly introduced control treatment. Samples were weighed fresh, dried at 60 °C in the oven and weighed again to determine the dry matter (DM, t ha^{-1}).
A mixed sample from each plot, consisting of 16 subsamples to measure the sand, silt and clay fraction by wet-sieve analysis were taken before the start of the 2022 season from 0-30 cm soil depth. Hydrometer analysis (Kaur and George 2016) was performed for all farm sites, except the newly introduced control treatment for the farms. Soil organic carbon (SOC) and total nitrogen (N) concentration (%) were determined according to Dumas with a CNS-analysator (vario MAX cube, Elementar Analysensystheme GmbH, Langenselbold, Germany), correcting the carbonate fraction by deducting the carbonate-content with the Scheibler-analysis. Compost and manure samples were analysed by their N contents (% of DM) in external labs based on the Kjeldahl-method (compost) and DIN EN 13342; 2001-01 (manure).
The SIR data was analysed with a linear model in a two-way ANOVA (aov-function), considering design imbalance without interference (type II) including the fixed factors treatment (compost, control, manure) and farm (farm 1-3, HGU) and the random factor replicate (a-d). Including the remaining dataset (soil texture, cover crop dry matter, SOC, soil C:N-ratio, OM nitrogen content and OM total mass) a principle component analysis (PCA) with the stats (version 4.2.3) and the factoextra-package (version 1.0.7) was run in R (version 4.2.3). As post-hoc test emmeans with the emmean-package (version 1.8.9) was applied.

3. Results and Discussion

The established treatments do not show differences in SIR at a cross-farm level at the end of the season (Figure 1). At the HGU-site, significant larger values of SIR were measured, compared to the SIR measured at the practical farms ($p < 0.01$). Among the treatments at the HGU-site, the soil amended with compost scored the highest SIR. The high SIR at the HGU-site is mainly due to a strongly conductive soil structure. Comparing the HGU results to those from Bouma et al. (1982), the authors found the SIR by 0.6 (compost), 0.7 (control) and 1.4 (manure) fold increased, taking into account that hood infiltrometers tend to overestimate the infiltration rate, compared to infiltration columns due to the horizontal movement of the wetting zone in the field. At farm 1, the increased SIR in the control treatment likely benefited from observed dense weed growth. When digging with a spade in the soil of the experimental site from farm 3, no soil life (worms and centipedes) was observed. Apart from lacking soil life, soil crusts impede infiltration. They form on soils with an elevated ratio of silt and clay (farm 1 and 3) (Todisco et al. 2023; Di Prima et al. 2018). As a drawback the hood infiltrometer measurement takes the dry crust into account, so that the measurement does not represent the subsurface soil structure. Other the disk infiltrometer measurement, where the water repellant forces of the dry crust are reduced by the capillary forces of the sealing layer above as the crust becomes part of the pore system. The main publication about the two methods did not elaborate on crusts, especially dry crusts (Schwärzel and Punzel 2007). The SIR at farm 2 and 3 reflect the soil types' commonly known hydraulic conductivities.

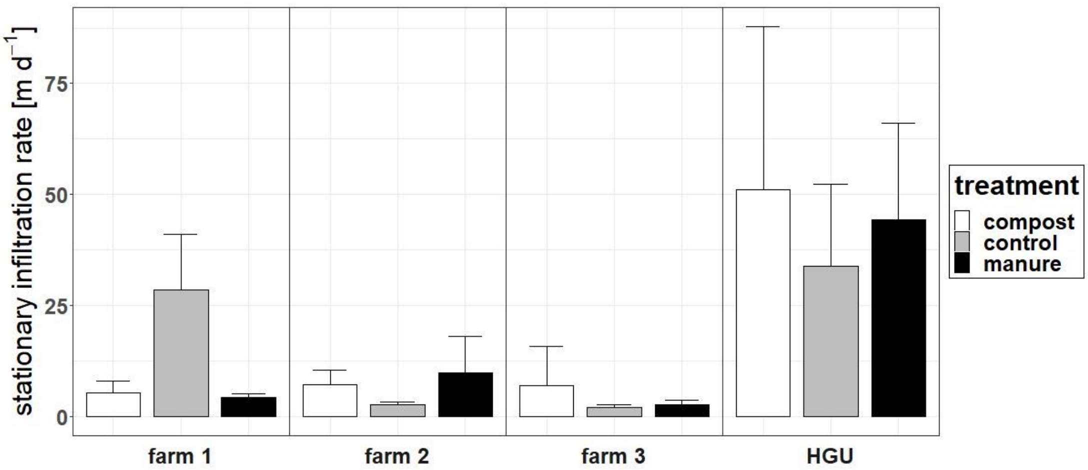

Figure 1: SIR measured at the four sites in the compost (white), control (grey) and manure (black) treatment. Averages are represented as bars and the standard deviation with whiskers. Sample size was four per treatment, at the HGU-site eight per treatment. The data presents the results from the -0.1 hPa pressure.

A PCA was applied to examine the variability between the experimental sites (Figure 2). An issue are the missing control data from the farms' sites in 2022, not included in the PCA, leading to a more HGU-biased outcome. The first two dimensions explain 76.8% of the variability of the data set. The first dimension (54.7%) contains foremost the soil (SOC and C:N-ratio) and water (SIR and irrigation) data. These organic and hydrological parameters sufficed to separate the data from farm 1+2 and the HGU. The soil C:N-ratio and SOC correlate well with the irrigation (0.86 and 0.74) whereas the C:N-ratio and SOC correlate as well (0.76).

This ties in the fact that the water-dependent mineralization processes are only to the amount induced, as there is sufficient (not excess) water available. Cover crop DM counter-acted to the soil organic and water parameters in the first PC (- 0.25). This effect contradicts the expectation of degraded biomass leading to the formation of SOC. The improved organic content, however, leads to more water binding capacities and attenuated SIR in terms of sandy soil, in case it has no stimulation effect on the soil fauna (Kranz et al. 2023). Since the origin of OM has an effect on the water sorption to its surface and thus to the degradation process (Bughici and Wallach 2016), this might be an explanation to this ambivalent result.
The second dimension (22.1%) is dominantly influenced by the N supplemented by the OM (as the representative parameter of the treatments), and to a lesser extend by the cover crops' DM yield as well. Soil texture parameters were not found within the first two PCs. Since the soil C:N-ratio and especially SOC are parameters known for the formation of soil structure, the finding is in agreement with the thesis, that soil structure dominantly affects the SIR more than the soil texture (Bonetti et al. 2021).

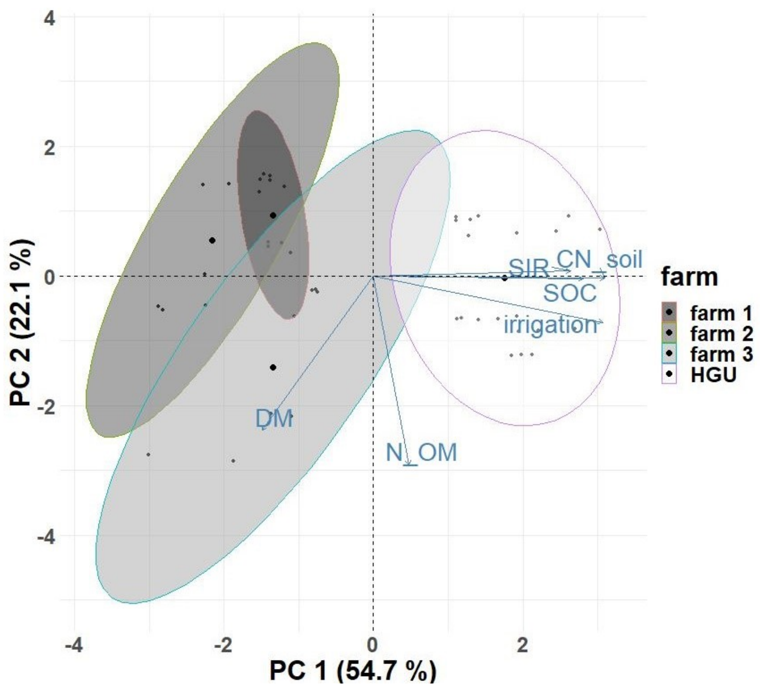

Figure 2: Principle Component Analysis of various water (total irrigation amount and SIR) and soil parameters (soil texture, cover crop DM, N_OM, OM total mass, SOC and CN_soil) from the farms.

4. Conclusions

The cross-farm level study (as living-lab) demonstrated how different conditions due to differing soil type and soil management at different experimental sites increase the variability in the SIR. Therefore, an overall-effect of the treatments on the water infiltration could not be confirmed. The water and soil structure related parameters predominated in variability, followed by the nitrogen input of the treatments. The authors suggest that researchers need to include the remaining random factors (machinery, further aspects of soil management practices, such as timing and repetition of a soil working step, and irrigation scheduling) as fixed factors in the planning stage and to ensure to monitor the parameters during the ongoing experiment.

The authors [M. Westram, M. Kumschier, J. Zinkernagel] declare to not have had any economic or personal connection within the last three years that would lead into a conflict of interest.

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