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Abstract

A system combining strip-tillage technique and use of cover crops was implemented in a field trial in organic vegetable production. The combination of reduced tillage and in situ mulch is a promising alternative to conventional tillage systems, especially in the face of increased drought due to climate change. A layer of rye mulch was able to retain moisture in the soil without reducing vegetable yield. Leguminous living mulch, on the other hand, reduced cabbage yields and soil moisture.

1. Introduction

Organic farming promotes the diversity of animal and plant life by refraining from using synthetically produced chemical plant protection products. Due to this restriction, pest and disease management becomes challenging. Besides a diversified crop rotation, organic farmers rely on deep inversion tillage for residue incorporation and weed control which can have a detrimental effect on the agroecosystem (Lehnhoff et al. 2017; Panagea et al. 2022). By avoiding inorganic fertilizers organic farmers instead use slow-acting organic fertilizers and are dependent on the pace of for example nitrogen (N) mineralization. However, some vegetables, e.g. cabbage, zucchini, or broccoli, have high nutrient requirements within a short growing period in comparison to arable crops (Feller and Fink 2005; Congreves and Van Eerd 2015). In field vegetable production late closing of bare inter-rows exposes the soil to erosion which can lead to a decline in organic matter and nutrient contents, the breakdown of soil structure and a reduction in water holding capacity (Bosco et al. 2015). Reduced tillage systems, such as strip-till, can help to minimize these detrimental effects.

In strip-till systems, a narrow band is tilled where the crop is to be planted, leaving an undisturbed strip between crop rows to protect and improve soils (Brainard and Noyes 2012). In arable conventional farming the strip-till method is already used (Pearson et al. 2014), whereas challenges remain in organic farming without use of herbicides to suppress weeds (Bietila et al. 2017).

In addition to the beneficial effects on soil physical properties, O'Rourke and Petersen (2016) reported that soil moisture content was higher in strip-till and no-till treatments compared with conventional-till treatment. Other studies observed that strip-till plots had higher soil moisture levels than conventional-till plots and that cover crops contributed to soil moisture retention but could not confirm these findings in the second year (Haramoto and Brainard 2012).

Besides reducing soil tillage, farmers can use cover crops, e.g. grown as living mulch between crop rows, to improve soil quality (Hartwig and Ammon 2002). Together with crop residues, they are a source of soil organic matter, which maintains or even increases soil productivity and soil fertility (Robačer et al. 2015). They can also improve soil structure, soil tilth, and water-holding capacity and reduce the risk of nitrate leaching from agricultural systems (Nouri et al. 2022; Tuomisto et al. 2012). Legume cover crops fix nitrogen from the atmosphere, which can provide a higher N supply for the subsequent vegetable crop (Stein et al. 2023).

In the present experiment vegetable seedlings were transplanted directly into a mulched cover crop, a living mulch and bare soil using the strip-till method.

The objective of this study was to improve crop management by reducing soil tillage to the planting row and keeping the soil between crop rows covered and rooted continuously. We hypothesized that utilizing cover crops to reduce tillage, both with mulched rye and clover living mulch, will maintain vegetable crop yield and increase soil moisture.

2. Data, Methods and Approach

Experimental setup

Field experiments were conducted in the seasons of 2021/2022 and 2022/2023, at Großbeeren, Germany (52°21′N, 13°18′E, 42 m a.s.l.) in a loamy sand soil. Cumulative precipitation and annual mean temperatures during the experimental period were 404 mm and 11.0 °C in 2022 and 796 mm and 11.1 °C in 2023. The experiments in the first and the second cropping year took place in two different fields that were 100 m apart. The experiment was established with four replications as a split plot design in a RCBD with soil cover as the whole plot factor and the vegetable crop as sub plot factor. Soil cover treatments included mulched cereal rye, subterranean clover as a living mulch and a control with no soil cover (bare soil). The vegetable crops grown in both years were celeriac and cabbage. Rye as a cover crop was seeded into each plot in October (2021) and with addition of winter pea at a ratio of 80:40 (in % of seed rate) in September (2022). Subterranean clover was sown in March (2022) and April (2023) after incorporation of the winter crop and was irrigated according to common horticultural practice. For control plots rye was incorporated into the soil at the beginning of May. At BBCH stage 61 rye was mulched and left on the field in the mulch treatments. Following that four 25 cm wide bands were strip-tilled at 20 cm depth and 75 cm row spacing into each plot to establish a planting zone. At the same time sheep wool pellets were applied as underfoot fertilization at a rate of 180 kg N ha^{-1} (2022) and 220 kg N ha^{-1} (2023) at 10 cm depth for both crops and each treatment. The vegetable crops were planted on June 08, 2022 and May 16, 2023 and overhead irrigation was implemented according to the irrigation software BEREST (Gutezeit et al. 1993). Each plot was irrigated equally. Weed control was carried out by hand hoeing in the planting band three times per season in all treatments, as well as the inter-rows in control plots. In rye mulch and living mulch plots only bigger weeds were removed from inter-rows by hand two times per season.

Soil measurements

Soil samples for mineral N measurements were taken at beginning of soil activity (March), before fertilization (April), during crop growth (July), and after harvest. Fifteen sub-samples were randomly taken in each plot at two different soil layers (0-30 and 30-60 cm) and further mixed into a composite sample for each depth and plot.

For soil moisture and temperature, three time domain reflectometry (AcclimaTDR-310H) sensors were inserted into the soil (probe rods parallel to the soil surface) at a soil depth of 25 cm in each plot. For financial reasons this was done for only one crop (celeriac). For further calculation mean values of the three probes per plot were used.

Statistics

The statistical analyses were performed using the R software, version 4.2.2 (R Core Team 2021). Variance homogeneity was checked using Levene's test from the 'car' package. If this prerequisite was not fulfilled, data transformation of the original values was carried out prior to analysis. To assess variations among the treatments, an analysis of variance followed by a Tukey's HSD test was conducted using the "stats" package in R. Differences between treatments ($P < 0.05$) are indicated by different lower- and upper-case letters, respectively in figures and tables. Mean values are reported with standard deviation ($n = 4$).

3. Results and Discussion

The soil mineral N content before fertilization in soil depths of 0-30 cm and 30-60 cm was reduced by half where rye was used as a winter cover crop and terminated in May (mulched and bare soil treatments) compared to earlier incorporation (clover treatment), except for 30-60 cm in 2022 as shown in Table 1. This is in line with findings from Stein et al. (2023) where treatments with rye showed the lowest mineral N contents, while the legume treatments showed no differences when compared to the control. Likewise, Hefner et al. (2020) found that delayed cover crop termination reduced soil mineral N in spring. N was utilized for vegetable growth in mulched and bare soil treatments. At this early stage the experimental design with four replications was not yet established.

Table 1: Soil mineral N at three sampling times. Mean values are followed by standard deviation ($n = 4$). Data without standard deviation are not statistically evaluated due to missing replicates. Significant differences between treatments ($P < 0.05$) are indicated by different lower-case letters.

	2022					2023				
	Before fertilization	Midseason, 35 days after planting		After harvest		Before fertilization	Midseason, 50 days after planting		After harvest	
Soil cover		Cabbage	Celleriac	Cabbage	Celleriac		Cabbage	Celleriac	Cabbage	Celleriac
Soil inorganic N [kg ha^{-1}] in 0-30 cm soil depth										
Mulched rye	5.4	56.8 ± 16.7	57.3 ± 25.3	17.5 ± 10.2	25.8 ± 24.5	4.2	72.8 ± 31.8	141.8 ± 25.1	28.7 ± 20.7	23.4 ± 14.4
Clover	17.7	25.9 ± 10.5	79.2 ± 36.8	12.8 ± 11.4	17.8 ± 3.0	12.1	70.3 ± 41.3	113.6 ± 40.7	29.9 ± 24.9	27.5 ± 11.6
Bare soil	5.4	52.2 ± 26.2	59.6 ± 28.0	15.8 ± 12.4	22.0 ± 18.8	4.2	72.9 ± 35.7	98.0 ± 43.0	61.7 ± 54.44	60.3 ± 48.4
Soil inorganic N [kg ha^{-1}] in 30-60 cm soil depth										
Mulched rye	3.0	27.9 ± 10.3	26.9 ± 6.9	6.0 ± 2.7	12.0 ± 6.7	1.3	38.2 ± 12.3	70.8 ± 18.7	6.9 ± 2.2	26.2 ± 26.3
Clover	3.6	20.8 ± 6.5	25.0 ± 8.9	6.3 ± 2.3	5.3 ± 1.3	6.0	40.8 ± 7.8	54.2 ± 8.8	6.0 ± 1.9	18.0 ± 7.8
Bare soil	3.0	31.8 ± 32.4	17.6 ± 10.7	5.8 ± 3.7	11.0 ± 2.6	1.3	43.4 ± 9.2	68.3 ± 26.0	8.4 ± 5.4	47.2 ± 23.1

Soil mineral N levels were not significantly affected by soil cover treatments in both crops and at both soil depths three to five weeks after planting and after harvest. There were great deviations within the treatments. Mineral N levels remaining in the soil after harvest did not exceed 50 kg ha^{-1} in 2022 and 60 kg ha^{-1} in 2023, in mulched rye and clover, whereas bare soil left 70-100 kg N ha^{-1} in 2023. Thus, N leaching losses can be reduced by rye mulching or clover living mulch.

Data for soil temperature and soil moisture are not presented for 2022 due to problems with the measurement technology and failure of continuous power supply. In the plots with celeriac growing in 2023 the volumetric water content at a soil depth of 25 cm averaged 18% (mulch), 14% (clover), and 17% (bare soil) in June. For the whole growing season (May to October) the soil moisture averaged 15% under a layer of mulch and 13% in living mulch (clover). The uncovered soil provided a soil moisture of 14% on average in that period. However, there were no significant differences. This also holds true for soil temperature in a depth of 25 cm. In June mean temperatures figured 19.3, 19.0, 19.8 °C, in July 20.1, 19.5, and 20.4 °C in mulch, clover and bare soil (control) treatments, respectively. This is consistent with Drakopoulos et al. (2018) where both, soil temperature and soil moisture content, were not found to be greatly affected by tillage practice. In our study there were tendencies for higher soil moisture and lower temperatures under a layer of mulched rye whereas living mulch might be in competition with the vegetable crops concerning water. The relevance of this effect is, however, limited in irrigated vegetable systems, where water can be supplied when necessary.

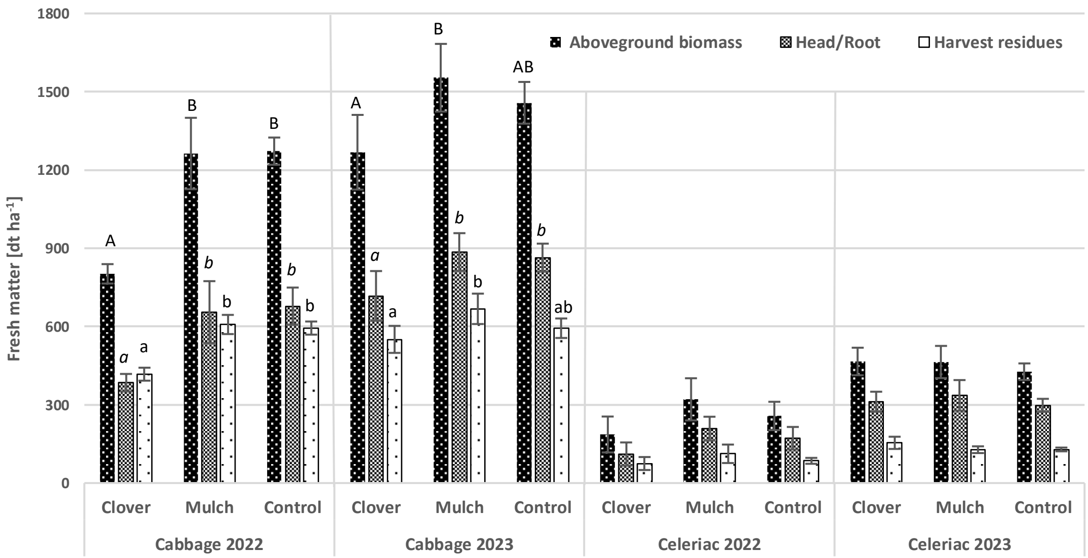

Figure 1: Influence of soil cover on fresh matter of white cabbage and celeriac (means of four replicates, error bars show the standard deviation). Significant differences between treatments (P < 0.05) according to Tukey's HSD test are indicated by different upper-, italics and lower-case letters for aboveground biomass, yield and harvest residues, respectively.

While in 2022 the yield of celeriac showed values below national standard in organic farming, in 2023 adequate yields were gained in all treatments (Figure 1). In years 2022 and 2023, aboveground biomass of celeriac was not affected by the soil cover treatments. White cabbage, on the other hand showed significantly lower yield and aboveground biomass in both years, when cultivated with subterranean clover as a living mulch as opposed to mulched rye. Standard cabbage yields were produced for all treatments in both years except for the living mulch in 2022. It can be assumed that the living mulch competes with the main crop. This stands in contrast to Stein et al. (2022) where living mulches did not result in a reduction of cabbage yield compared to bare soil.

4. Conclusions

Soil cover was successfully established during the growing season. Vegetable yields showed values matching national standard in organic farming when grown with a layer of mulched rye whereas leguminous living mulch reduced cabbage yield, probably due to competition for water, nutrients, and light. Even though the effect of leguminous cover crops after soil incorporation was not investigated, it is presumed to be positive for succeeding crops, indicating the need for further investigations.

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