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Increasing the sustainability of vegetable crops production by using intercropping

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Abstract. Some scientific reports support the idea of using plant interactions to promote the growth and yielding of vegetable crops. The plant interactions in vegetable production under intercropping conditions were investigated in ERDF funded project 'Elaboration of environment-friendly crop growing technologies identified by the Green Deal and their implementation in horticultural production in Latvia (GreenHort)' implemented in Latvia Institute of Horticulture with the aim to introduce strip cropping in the vegetable production. The investigations were carried out at the Institute of Horticulture, Latvia (57°03'44.6''N, 22°54'53.2''E), during the growing seasons of 2021 and 2022. The vegetable crops (carrots, cabbage, onions, and pumpkins) were grown in intercropping with agroecological service plants or aromatic plants as companion plants (white clover, marigolds, tagetes, lavender, sage, coriander). The investigated variants were compared with the control, where vegetable crops were grown in monoculture as usual. Each intercrop variant consists of 7 alternating rows (each 0.6 m wide) - 4 rows of service crop and 3 rows of vegetable. There was observed significant influence of the growing system on the plants productivity. The sharpest differences between variants were observed for cabbage - marigold, sage and lavender had a positive influence on the cabbage yield formation, but white clover had an extremely negative influence on the cabbage plant growth. White clover had a negative influence also on carrot and pumpkin productivity. Sage had a yield-promoting influence on the carrot crop. There was not found any significant influence of the agroecologial crops on onion productivity.

Key words: cabbage, carrot, onion, strip cropping.

INTRODUCTION

Greening measures are increasingly being introduced in agriculture to foster the implementation of environment and climate-friendly farming practices in line with EU decisions (European Green deal). These measures include a sharp reduction of pesticide use, recommendations to cultivate the legumes for the biological fixing of atmospheric nitrogen (BNF), as well as increasing the microbiological activity of the soil, in order to contribute to the proportion of biologically sequestered carbon (C) which can be achieved by introducing the green manure in the crop rotation. The abovementioned solutions can be assumed also as potentially effective in the changed geopolitical situation in the world

- a critical obstacle encumbering agricultural production is the war in Ukraine causing an increase in energy costs and reduced supply of mineral fertilisers in Europe.

The proposed greening measures are not novel per se: intercropping, catch crops, and green manure are long-known technological elements used by farmers, which, based on past knowledge and experience, can become important retroinnovations (Stuiver, 2006; Zagata et al., 2020; Kaci et al., 2022) by combining past knowledge with the needs and aims of modern society, including the promotion of sustainable farming practices. However, until now these environment-friendly green technologies have not been sufficiently widely and effectively implemented, although several studies have been carried out in this area that demonstrates the effectiveness of these technological solutions (Canali & Coopman, n.a; Talgre et al., 2012; Piotrowska-Dlugosz & Wilczewski, 2015).

It is widely known that some plants containing many flavouring substances have repellent properties that deter pests (Parker et al., 2013; Song & Han, 2020), or allelopathic influence on the soil microorganisms (e.g. nematodes) (Sharadchandra et al., 2012). In addition, aromatic plants attract beneficial insects, that help plants to pollinate, and predatory insects limiting plant pests (Parker et al., 2013; Lauren et al., 2020). By cultivating aromatic plants in intercropping with other horticultural crops, it is possible to reduce the spread of pests to horticultural cash crops. Research on this topic is more prominent in the central and southern part of Europe and other continents. Consequently, the horticultural crops whose mutual interactions are being studied are often different from the commercially important crops which are cultivated in the agro-climatic conditions of Latvia (Parker et al., 2013; Scariot et al., 2016).

However, some scientific reports are found supporting our idea of using plant interactions to promote the growth and yielding of vegetable crops commercially grown in the North Europe region. The findings report not only on the positive plant interactions but also on the depressing (allelopathic) influence. So, John (2010) reports on the inhibitory properties of Trifolium sp. plants on the growth of onions, carrots and tomatoes. Some researchers point out also the influence of soil biological and agrochemical properties on plant interactions, where allelochemicals are involved (Cheng & Cheng, 2015; Schorohodova, 2019). To get an insight into the plant interactions in vegetable production under intercropping conditions, European Regional Development Fund (ERDF) funded project 'Elaboration of environment-friendly crop growing technologies identified by the Green Deal and their implementation in horticultural production in Latvia (GreenHort)' is implemented in Latvia Institute of horticulture with the aim to introduce strip cropping in the vegetable production. The purpose of the research was to clarify the plants interactions in strip cropping design and evaluate the influence of intercropped plants on the soil properties.

MATERIALS AND METHODS

The investigation was carried out at the Institute of Horticulture (LatHort) located 90 km to the west of Rīga (in Pūre) (57°03'44.6''N, 22°54'53.2''E) during the growing seasons of 2021 and 2022. The trial was set up in a multifactorial design, where factor A – horticultural crops (carrots, cabbage, onions, and pumpkins), factor B – agroecological service plants or aromatic plants as companion plants (white clover (*Trifolium repens* L.), marigolds (*Calendula officinalis* L.), tagetes (Tagetes tenuifolia in 2021 and Tagetes patula in 2022), lavender (*Lavandula angustifolia* L.), sage (*Salvia* *officinalis* L.), coriander (*Coriandrum sativum* L.)); factor C – year (2021 and 2022). The plant combination schemes (variants) are shown in Figs 1 and 2. The investigated variants were compared with the control, where crops were grown in monoculture as usual in the institute. Each variant consists of 7 alternating rows (each 0.6 m wide) - 4 rows of service crop and 3 rows of vegetable. Variant size 4.2 m × 24 m = 100.8 m^2, where 3 replication plots are randomly dispersed for yield and quality measurements.

Year	1st variant		2nd variant		3rd variant	
2021	Carrot	White clover	Cabbage	White clover	Cabbage	White clover
2022	Cabbage		Carrot		Cucurbits	

Figure 1. Scheme of variants of vegetable strip cropping with the white clover as biological nitrogen fixation plant and living mulch plant.

Year	1st variant		2nd variant		3rd variant		4th variant		5th variant	
2021	Carrot	Sage	Cabbage	Lavender	Onion	Coriander	Carrot	Calendula	Cabbage	Tagetes
2022	Cabbage		Onion		Carrot		Cabbage		Onion	

Figure 2. Scheme of variants of vegetable strip cropping with aromatic plants.

The detailed crops growing technological elements are included in Table 1 to characterise vegetable varieties, growing density, sowing and harvesting times. In monocropping onion and carrot were grown in three-row beds, with the distance between bed centres 1.5 m. Cabbage was grown in rows 0.5 m apart and 0.5 m between plants in the row. Pumpkin was grown in 1.2 × 1.4 m density.

Table 1. Summary of growing technology elements for vegetables and service crops in the intercropping trials of the 2021 and 2022 seasons

Crop	The growing scheme in the intercropping strips of 0.6 m width	Sowing/planting time		Harvest time	
		2021	2022	2021	2022
Carrot `Solvita`	2 rows in 0.3 m distance	June 1	May 19	October 5	September 22
Cabbage `Holsteiner Platter`	1 row, 0.5 m between plants	May 28	May 25	October 5	October 5
Onion `Stutgarten riesen`	2 rows in 0.2 m distance	May 14	May 19	August 16	August 29
Pumpkin `Red Kuri`	1 row, 1.4 m between plants	N.A.	June 10	N.A.	September 20
White clover	sown sparsely in all strip width	May 29	N.A.	N.A.	N.A.
Sage	1 row, 0.5 m between plants	June 1	N.A.	N.A.	N.A.
Lavender	1 row, 0.5 m between plants	June 1	N.A.	N.A.	N.A.
Coriander	sow 1 row	May 14	May 24	N.A.	N.A.
Calendula	sow 1 row	June 1	May 24	N.A.	N.A.
Tagetes	1 row, 0.2 m between plants	May 29	June 10	N.A.	N.A.

*N.A. – not applicable.

Meteorological conditions during the investigation periods (precipitation and average air temperature) were collected by an automatic meteorological station 'Davis' located at Pūre (Fig. 3). The precipitation sums of the vegetation period (May–October) for each year were 333.0 and 296.2 mm, respectively. In 2022 precipitation was spread more evenly through the vegetation period in comparison to 2021, when sharper drought periods were observed. In 2021 in May precipitation was almost regular, but in the I decade of June, there was registered a drought period. A dry beginning of the vegetation period was observed in 2022 when in the I and II decade of May the precipitation was only 0.6 and 10.0 mm. In 2022 short drought period was observed at the end of June. Both years' precipitation in July reached more than 60 mm per month. In 2021, August was very wet with 121.4 mm of precipitation, but in 2022 the first two decades were dry - only 3 mm and in the III decade a very high precipitation amount was registered - 83.4 mm (concentrated in two last days of the decade). In September for both years, the precipitation was similar. October 2022 was drier than 2021.

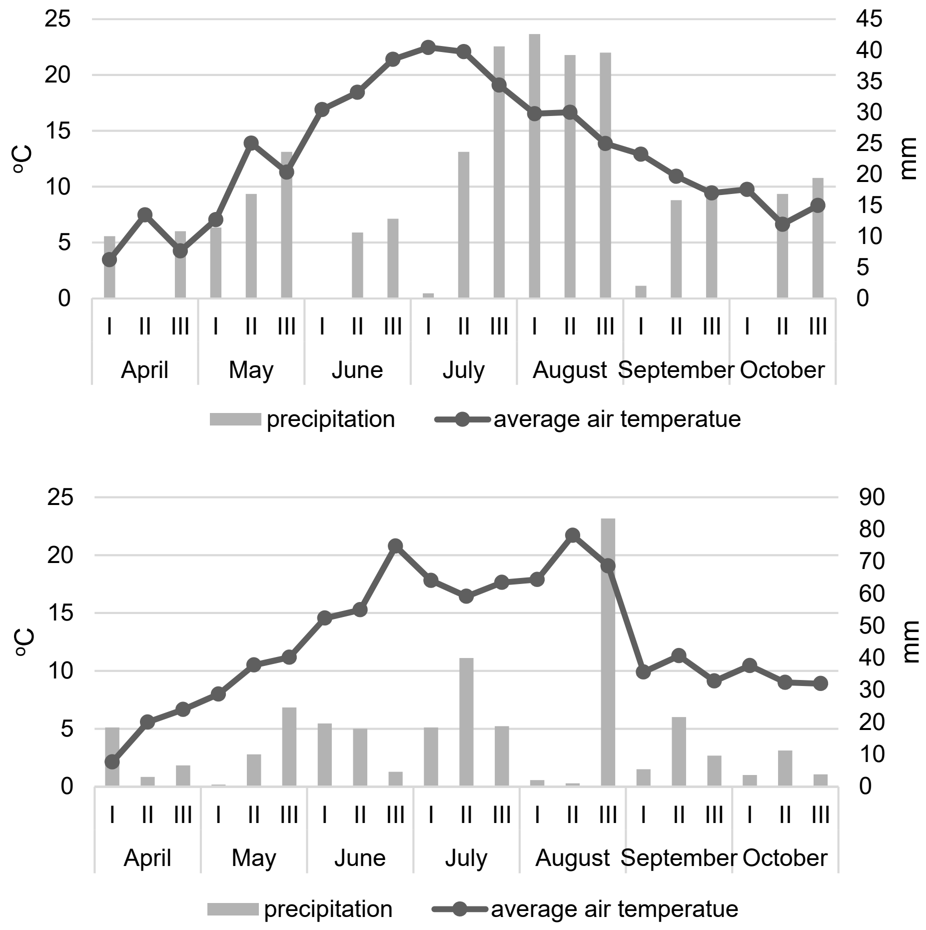

Figure 3. Meteorological conditions of growing seasons of 2021 and 2022 (per 10 days periods (decades) – I, II and III).

The air temperature overall was suitable for vegetable growth and development in both years. The average monthly air temperature during the seasons of 2021 and 2022 was 8.2–21.2 °C and 9.5–19.6 °C, respectively. 2022 was cooler from May–July (except in the I decade of May) compared to 2021. The rest of the vegetation period in 2022 was warmer than in 2021 (except I and III decades of September, when the difference was only 0.3 °C). The warmest period of the season 2021 was in the I and II decade of July but in the 2022 – II and III decades of August.

For the description of the growing conditions, particularly the balance between moisture and temperature during the vegetation period, the hydrothermal coefficient (HTC) was assessed as the ratio between precipitation to 1/10 of the sum of active temperatures (mean daily temperature of the days when it was above 10 °C). Thus, this parameter provides rational information on the correlation between the amount of precipitation in the period, when the average day temperature exceeds +10 °C, and the sum of temperature in degrees in the same period (Table 2). The HTC was calculated by applying the equation described by Selyaninov:

$$HTC = \frac{\sum x}{\sum t} \times 10$$

where $\sum x$ and $\sum t$ – the sums of precipitation and temperatures in the period, when the temperature has been above 10 °C (Selyaninov, 1928; Evarte-Bundere & Evarts-Bunders, 2012; Tchebakova, 2015).

The driest period according to the hydrothermal coefficient (HTC) in 2021 was June when HTC was 0.0–0.6. In the first decade of July, in September and October also HTC was below 1 – which indicates insufficient precipitation and too high temperature during the period. In 2022 were fewer drought periods. The driest period was the first part of August.

Table 2. Hydrothermal coefficient during the trial period in 2021 and 2022

Month	10-days period	2021	2022
May	I	6.6	0.2
	II	1.2	1.4
	III	1.9	2.4
June	I	0.0	1.3
	II	0.6	1.2
	III	0.6	0.2
July	I	0.0	1.0
	II	1.1	2.4
	III	2.1	1.0
August	I	2.6	0.1
	II	2.1	0.0
	III	2.6	4.0
September	I	0.2	1.0
	II	2.8	1.9
	III	3.2	2.3
October	I	0.0	0.5
	II	19.4	2.4
	III	5.5	0.6
Average		2.9	1.3

HTC from 1.0 to 2.0 – humidity is sufficient; HTC > 2.0 – immoderately humid; HTC < 1.0 – insufficient humidity; HTC from 1.0 to 0.7 is assumed as dry period; HTC from 0.7 to 0.4 – very dry period.

The soil type of the trial site was a sandy loam, before the experimental set-up characterized by pH_{KCl} 6.4, P – 31.68 mg kg^{-1}, K – 81.34 mg kg^{-1}, Mg 209 mg kg^{-1} and Ca mg kg^{-1} 1,125, and organic matter of 3.7%.

The yield was harvested in three replications per variant both in monocrop and intercrop variants. To compare the influence of intercropping on the yield formation, the yield outcome in the intercropped variants is calculated for a particular plot area (2 m^2) and expressed in t ha^{-1}. There is no recalculated yield outcome from ha in the intercropping, as it would be harvested from ha (not divided by two). In monocropping variants, the yield was harvested from 3 m^2 plots and expressed in t ha^{-1}.

Mathematical data processing was performed using ANOVA. The data were processed using single-factor dispersion analysis for each year separately. The least significant difference (*LSD*) between individual factor values is indicated in the graphs. A 95% confidence level was used to determine the significance of the difference between the variables.

RESULTS AND DISCUSSION

The influence of intercropping on vegetable plant development was observed for two year period in plant rotation, where the agroecological service crops were not always the same for a particular vegetable crop for both years (see Figs 1 and 2). Therefore ANOVA was performed accordingly for both years separately, and thus *LSD* is calculated for each year separately. There was observed significant influence of the growing system on the plants ability to produce yield. The sharpest differences between variants were observed for cabbage (Fig. 4).

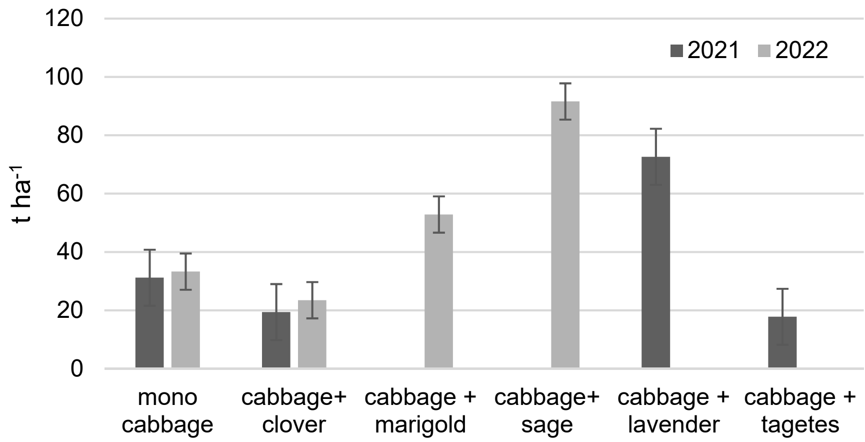

Figure 4. Cabbage yield in the trials of 2021 and 2022.

In 2021, the significantly highest cabbage yield (72.6 t ha^{-1}) was observed in the intercropping with lavender. Where the disorientation of cabbage butterfly (*Pieris brassicae*) was observed - they were strongly attracted by lavender and thus did not lay eggs so much on the cabbage as in monocrop and thus plants were less damaged. The damages in lavender intercrop were scored by 4 (out of 10), but in monocrop by 7. Probably the positive influence of lavender volatiles on cabbage growth also took place. The stimulating effect of lavender oil on the tomato was found in Turkey (Şener et al., 2018). Also sage showed a significant stimulating influence on cabbage yield formation in 2022 (91.6 t ha^{-1}). The scientific evidence on the influence of sage on the neighbouring plants is not found. Probably similar to lavender, it produces volatiles promoting vegetable growth. In 2022, also marigolds as a neighbouring plant had a positive influence on the cabbage yield formation, reaching 52.8 t ha^{-1}. The real influence of tagetes on the cabbage plant growth and development is hard to estimate, because, in 2021, when high-growing *Tagetes tenuifolia* were planted in intercropping with cabbage, they completely depressed the cabbage plants, thus creating impossible conditions for cabbage plant development. The findings of others support the positive influence of tagetes (*T. patula*) on cruciferous vegetable development (cauliflower) and other vegetables (Li et al., 2020; Mrnka et al., 2020).

The most surprising was the cabbage yield reduction in the intercropping variant with white clover as living mulch and BNF plant for both years. The harvested yield was only 19.4 and 23.5 t ha^{-1} correspondingly. It was observed that white clover is a rather aggressive plant, which spreads towards the cabbage strip every year more and more, although it was limited by a hack. We can assume that white clover has dispensed allelochemicals suppressing cabbage development. A slight phytotoxic influence of pea residues on the vegetable crops, such as carrot, eggplant, bean and Chinese cabbage is reported by John (2010). He mentions also that volatile emissions from residues of the winter cover legumes, Berseem clover (*Trifolium alexandrinum* L.), hairy vetch (*Vicia hirsute* L.), and crimson clover (*Trifolium incarnatum* L.), inhibited germination and seedling development of onion, carrot and tomato. Hydrocarbons, alcohols, aldehydes, ketones, esters, furans, and monoterpenes were identified in these residue emission mixtures (John, 2010). We can speculate that probably white clover (also belonging to *the Fabaceae* family) has an allelopathic influence on the development of cabbage. Further research is needed to confirm our assumption.

Regarding carrot yield in the trials, similarly, we can state that there are significant differences between the cropping systems (Fig. 5).

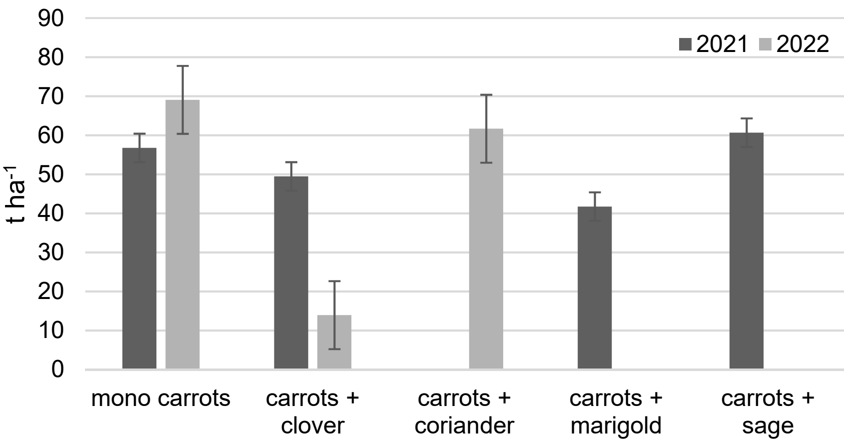

Figure 5. Carrot yield in the trials of 2021 and 2022.

In 2021, the highest yield was harvested in the intercropping variant with sage (60.7 t ha^{-1}), but the difference with the monocrop was not statistically significant. Notably lower yield in comparison to monocrop was harvested in the intercropping with marigold - 41.7 t ha^{-1}. In 2021, the variant with white clover yielded slightly lower carrot yield as it was harvested in monocrop variant (49.5 and 56.8 t ha^{-1}, correspondingly).

In 2022, there was not found a statistically significant difference between monocrop variant and intercropping with coriander - 69.1 and 61.7 t ha^{-1}, correspondingly. Contrary, in other trials where the carrot was intercropped with coriander, the positive influence of coriander on the carrot growth and yield formation was found

(Mehta et al., 2010). In our trial, similarly like in other crops, also for carrot significantly lower yield was obtained in intercropping with white clover (13.9 t ha^{-1}).

Summarizing carrot trial results, white clover had a negative influence on the yield formation as in cabbage. Contrary, the sage had a stimulating influence on the carrot yield formation, but coriander had no significant influence on the carrot yield formation.

In evaluating the onion yielding in intercropping with different agroecological service plants, some similarities were found regarding service crop influence on the cash crop (Fig. 6).

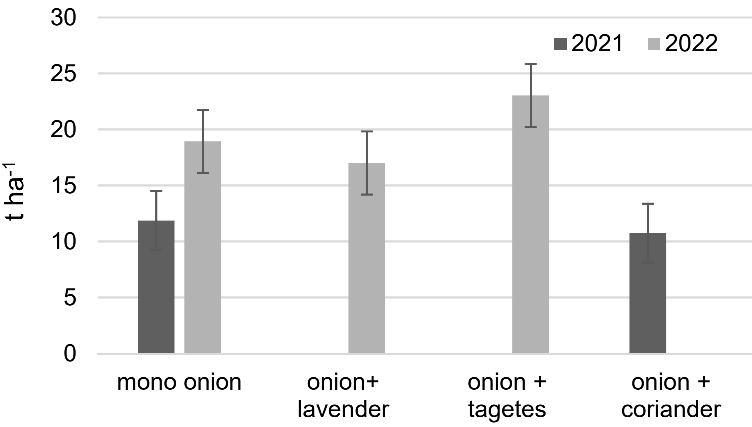

Figure 6. Onion yield in the trials of 2021 and 2022.

In 2021, there was not found a significant influence of coriander on onion crop formation. There was statistically indifferent yield harvested in both variants - 11.9 and 10.8 t ha^{-1} in monocrop and intercropping with coriander, correspondingly. Our results are supported by the findings of the trial in India, where coriander had no positive impact on the onion yield when both crops were intercropped (Talukder et al., 2015).

In 2022, the statistically significant influence of lavender and tagetes was not found in the intercropping with onions. Although higher onion yield was obtained in the intercropping with tagetes (23.0 t ha^{-1}). Also, tagetes are reported as an efficient attractant of natural enemies of onion pests, particularly trips in the trials in Brasil (Silveira et al., 2009). Also, other positive interactions of vegetable crops with tagetes are mentioned by others, mostly on the limitation of pest damages (Shiu & Wu, 2010.). In our trials thrips damages for onion crops for the years of the investigation were not found, therefore the influence of tagetes on the trips spreading was not evaluated. Obviously, also other mechanisms of plant interaction have taken place in our trial.

Summarizing the onion intercropping results, we conclude that during the two years of investigation, there was not found a statistically significant influence of tested service crops on the onion yield.

The trials on the pumpkin intercropping were performed only in the year 2022. Only one intercropping variant was tested – pumpkin with white clover. Similarly like in the trials with cabbage and carrot, also for pumpkins there was obtained sharply lower yield (4.2 t ha^{-1}) in comparison to monocropped pumpkins (24.7 t ha^{-1}).

Summarizing the results of our two-year trials, the most surprising was the negative influence of white clover on the cash crop plant development and yielding. The tendencies of the slight leek yield reduction when grown with white clover are mentioned also by den Hollander et al. (2007). They mention clover's competitive habitus character and hindered nitrogen uptake as two main reasons for the obstructive influence on the neighbouring crops. Although white clover is mentioned as a less influencing specie. In our assumptions, the hindered nitrogen uptake in cash crops and possible diffusion of allelochemicals in the soil should be investigated further as causes of the negative influence of white clover as neighbouring plant to vegetable crops.

CONCLUSIONS

Concluding the results of the two-year trials, we find out that sage and lavender have a positive influence on vegetable yield formation, similar, to calendula and low-habitus tagetes. Notable reaction on the intercropping was stated for cabbage, both positive and negative. An especially clear negative influence of white clover as a neighbouring plant was observed for cabbage and pumpkins, but also carrot yield suffered from the white clover intercropping. Further investigations on the white clover interaction mechanisms with neighbouring plants should be investigated.

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