Farming Systems Ecology - MSc Thesis

# Spatial effects of strip cropping on pest suppression and yield in a commercial complex organic cropping system in the Netherlands


February 2018

Harpreet Singh Sondh
MSc programme: Organic Agriculture
Registration number: 760918785120
Thesis code: FSE - 80436
Supervisor: dr.ir. DF (Dirk) van Apeldoorn
Examiner: dr.ir. WAH (Walter) Rossing

WAGENINGEN
UNIVERSITY & RESEARCH

# Contents

# Spatial effects of strip cropping on pest suppression and yield in a commercial complex organic cropping system in the Netherlands

Harpreet Singh Sondh[a]

[a]Department of Farming Systems Ecology, Wageningen UR, P.O. Box 430, 6700AK, Wageningen, The Netherlands.

MSc. Thesis submitted by Harpreet Singh Sondh (760918785120) MSc Organic Agriculture (FSE 80436) at Wageningen UR harpreet.sondh@wur.nl
Supervisor: dr.ir. DF (Dirk) van Apeldoorn, Department of Farming Systems Ecology, Wageningen UR, P.O. Box 430, 6700AK, Wageningen, The Netherlands
Examiner: dr.ir. WAH (Walter) Rossing, Department of Farming Systems Ecology, Wageningen UR, P.O. Box 430, 6700AK, Wageningen, The Netherlands

## ABSTRACT

A study was conducted, involving a farming organisation in an organic strip cropping system at a commercial and practical level in the Netherlands. The objective of this study was to evaluate the spatial effect of crop diversification, by strip cropping Potato, Carrot, Cabbage, Spinach and Grass Clover with strips of width 6, 12, 24, 48m (monocrop), on pest suppression ability, and yield. In Potato, reducing the strip width contributed to significant reduction of late blight, with 6m giving the best results. In Cabbage, only 6m treatment was significantly better regarding aphid pressure, while no significant differences were found for cabbage flea for any of the treatments. For yields and quality, Potato yields were significantly higher for 12m and 24m treatments than in monocrop, with no significant differences in DM ratio. Carrot showed no significant differences for yields between treatments and monocrop, DM ratio for 6m was significantly higher. Cabbage (Sprouts) yields were significantly lower for 6m and 24m than in monocrop, there were no significant differences regarding DM ratio. The study demonstrated that customising organic farming system designs by selection of component crops and specific strip width can enhance pest suppression by utilising the ecological principles of spatial diversity and can improve the production efficiencies by bringing down the reliance on chemical usage, thereby reducing the costs, and benefitting the environment altogether.

## SAMENVATTING

In samenwerking met een landbouwbedrijf in Nederland is onderzoek gedaan naar een biologisch strokenteelt landbouwsysteem op commercieel toepasbaar niveau, met als doel het evalueren van het ruimtelijke effect van biodiversiteit op plaagonderdrukking en opbrengst bij strokenteelt met aardappel, wortel, spruiten, spinazie en gras-klaver met stroken van 6, 12, 24, 48m (monocultuur) breed. Voor aardappel resulteerde een afname in strookbreedte in een significante afname van de aardappelziekte, waarbij de 6m brede stroken het beste resultaat gaven. Bij spruiten gaf 6m strookbreedte een significant beter resultaat voor vermindering van bladluizen. Voor wat betreft opbrengst en kwaliteit, de aardappel opbrengst was bij strokenteelt significant hoger voor strookbreedtes 12m en 24m in vergelijking met monocultuur, er was geen significant verschil qua DS (droogstof) ratio. Bij wortel, is geen significant verschil geconstateerd in de opbrengst tussen de verschillende strookbreedtes en monocultuur, de DS ratio voor 6m was significant hoger. Voor spruiten was de opbrengst bij strokenbreedtes 6m en 24m significant lager dan voor monocultuur, er was geen significant verschil tussen strokbreedtes en monocultuur qua DS ratio. Het onderzoek toont aan dat het loont om ecologische principes van ruimtelijke diversiteit te hanteren bij het ontwerpen van landbouwsystemen, in specifiek bij de selectie van gewas componenten en specifieke strook breedtes, gezien dit leidt tot plaagonderdrukking en verbeterde productie, door afname van de afhankelijkheid van chemische bestrijdingsmiddelen, en het daarmee kostenreductie en overal bevorderlijk voor het milieu is.

## KEYWORDS

Strip cropping; Spatial diversity; Commercial organic farming system; Arable crop yield; Pest suppression

## Introduction

### *Biodiversity and Resilience*

Modern agriculture faces an increase in insect-pest problems, due to the loss of local habitat diversity caused by the increase of large scale monocropping (Altieri and Nicholls 2004). Loss of biodiversity can alter the balance of ecosystems, in addition to loss of genetic resources, loss of ecosystem buffering against ecological disturbances, loss of aesthetic and commercially valuable resources, and loss of productivity (Naeem et al.1994; Wagg et al. 2014; Liang et al. 2015). Declining biodiversity and its consequences have been the subject matter of intensive discussions among scientific community (Cardinale et al. 2012; Hooper et al. 2012). Recent study conducted in European landscape, which put the insect biomass decline at alarming rate (75% in the last 27 years), has led to widespread interest in the mainstream media and in public, to stem the decline and protect the natural habitat (NOS 2017; Briggs 2017; Hallmann et al. 2017).

Preservation of biodiversity is an important basis for restoring the ecological balance to achieve stable production over a longer period in organic farming and, to design climate change resilient systems (Altieri and Nicholls, 2004; Altieri et al. 2015; Oliver et al. 2015). The ecological role of biodiversity has been well recognised and implemented in designing suitable pest stable agricultural systems derived from traditional farming systems with management practices like cover cropping, intercropping and mixed cropping etc. However, it is still a challenge to maintain productivity and conserving biodiversity at the same time (Fischer et al. 2013; Altieri et al. 2017).

### *Biodiversity and Pest Suppressive dynamics*

Increased spatial diversity (growing more than one crop species) at the farm level improves resilience and productivity; one of the underlying principles explained is beneficial pest suppressive dynamics (Lin 2011; Martin et al. 2016). Riechert (1999), highlights the importance of agricultural systems with minimal chemical application and the maintenance of ground cover in achieving desirable pest control dynamics, resulting in augmented influence of spiders on targeted insect population due to indirect effects (e.g., the cessation of feeding in the presence of a predator) and superfluous killing of prey. Thus, an increase in natural enemy populations and lower pest pressure in complex landscapes is the key to conserving biodiversity and sustaining the pest control function (Bianchi et al. 2006).

Natural enemies and spatial context both have major effects on the natural biocontrol, the effects could be direct (spatial context and natural enemies) and/or indirect (spatial effects on natural enemies) (Maisonhaute et al. 2017). Natural Enemy diversity is positively related to crop damage, indicating positive density-dependence of enemies on pests (Martin et al. 2016). Other factors like adjacent crop fields, and distance of field from the margin strips also have a significant effect on predators and predator-prey ratio (Denys and Tscharntke 2002). Thus, the relative importance of natural habitat (spatial diversity) for biocontrol can depend on various factors like type of crop or crop combinations, land management, pest, predator and landscape structure (Tscharntke et al. 2007).

### *Diverse cropping systems – Strip cropping*

At field scale, one way to increase temporal and spatial crop arrangements, is by employing cropping practices like polycultures to increase within-field habitat diversity and help break the monocultures; consequently, providing pest control benefits (Altieri and Letourneau,1982; McLaughlin and Mineau, 1995; Kremen and Miles 2012). Temporal diversification or crop arrangements in time can be employed by practices like crop rotation, while spatial diversification or crop arrangements in space could be achieved at varying scales through practices like mixed cropping, alternate row or plot cropping and strip cropping (Ofori and Stern 1987; Anders, Potdar and Francis 1995).

Strip cropping is the cultivation of more than one crop in strips that are narrow enough for the crops to interact, yet wide enough to permit independent cultivation (Altieri et al. 2015). Such methods reduce the pest level below economic threshold and thus could prove to be a viable alternative to chemicals for organic farmers to maximise profits (Fischer et al. 2006, Tschumi et al. 2015, September). Reduced pest pressure and yield advantage because of crop diversification could be explained by the spatial diversity leading to increasing yields per land unit when compared with the sole crop based on planned and associated diversity, and different weed and insect assemblages (Elba et al. 2014; Gómez-Macpherson et al. 2016). Also, compared to conventional farming, diversified farming systems have lesser environmental degradation, at a marginal cost of mean crop productivity (Kremen and Miles 2012).

### *Social and Scientific relevance and Objective*

Farmers have a need to know about 'management and cultural practices' in their specific habitat with respect to managing natural enemy diversity, crop damage and yields, landscape configuration and diversity, across scales (Martin et al. 2016; Dainese et al. 2015)**,** and how the variation of such factors can be utilised while designing the farms for better biocontrol mechanisms or maintaining the natural habitats (Tscharntke et al. 2016; Fischer et al. 2006).

Evaluation of current landscape structure and the restoration of desired ecosystem services, with the help of farmers and other stakeholders is the way forward to redesigning and building resilient farming ecosystems with crop- and region-specific approaches to control weeds, diseases, and pests (Kremen and Miles, 2012; Landis, 2017). Specific studies (localised/European) for the effect of strip sizes (width) involving arable crops at the commercial scale is lacking and needs to be researched. This study was conducted as a part of a long-term project, directly involving a farming organisation, to research the long-term gains and effect of different strip widths in organic farming at a commercial and practical level in the Netherlands (van Apeldoorn, Rossing and Oomen 2017).

The objective of this study was to evaluate the spatial effect of crop diversification (strip cropping with flower strips) with varying scales (strips of width 6, 12, 24, 48m) on pest suppression ability and on yield, in a complex organic cropping system in the Netherlands. To address the main objective of this research, the following research questions were addressed in this study,

- What is effect of different widths of strip cropping on the yield?
- What is the effect of strip width on pest/pathogen population?

Based on the research questions, we tested the hypothesis that reduction in strip width in a multi- cropping system leads to lower pest pressure, and higher yields of higher quality. Results for the pest/pathogen population per strip width are presented. For yields, the results are presented in terms of land equivalent ratio (LER) explaining the land resource utilisation and, Partial land equivalent (PLER) as a measure of productivity by crops per strip width.

## Materials and Methods

### *Experiment Site*

The experiment was conducted on the 50ha (circa 1000m x 500m) certified organic farmland (Co-ordinates: 52.39, 5.34) managed by ERF BV, in the polder region of Flevoland in Zeewolde (Figure 1) in the Netherlands. In consultation with the stakeholders, under the rotation plan following crops were selected: Spinach (*Spinacia oleracea*), Cabbage-Sprouts (*Brassica oleracea*), Grass clover (*Lolium-Trifolium sp.*), Potato (*Solanum tuberosum*) and Carrot (*Daucus carota*).

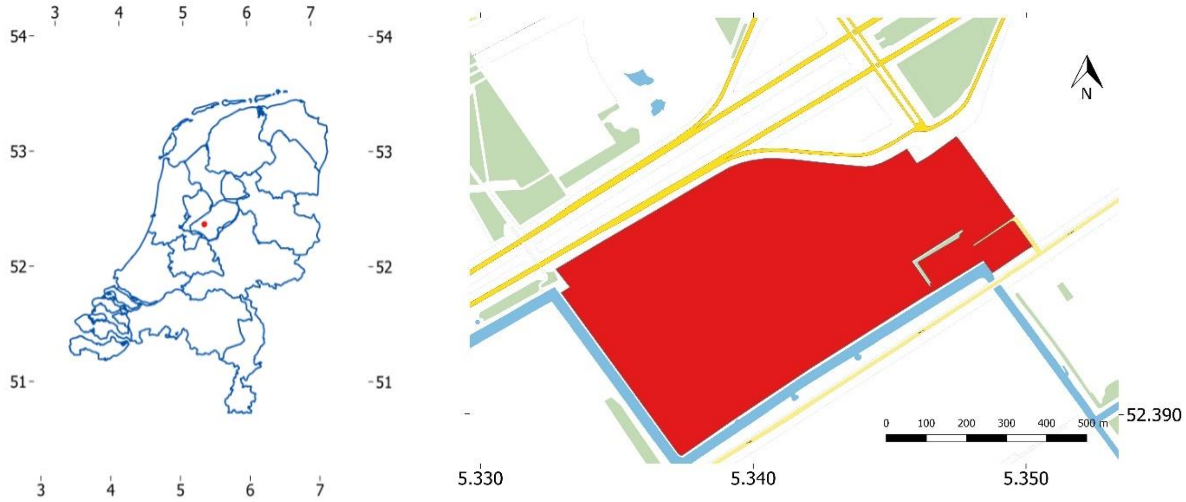



Figure 1. The experiment location in the Netherlands

### *Approach*

The study was conducted with a participatory approach involving the farmers (employees of ERF BV) for selection of the study site, planning and implementing the experimental design for strip cropping following socio-economic and agroecological principles.

### *Experimental Design*

This study focussed mainly on spatial diversity (strip cropping) and did not research temporal diversity in practice. However, temporal diversity was built in as part of the experimental design to some extent. The study involved growing different crops in strips, adjacent to each other, with different agronomic practices such as different sowing and harvesting

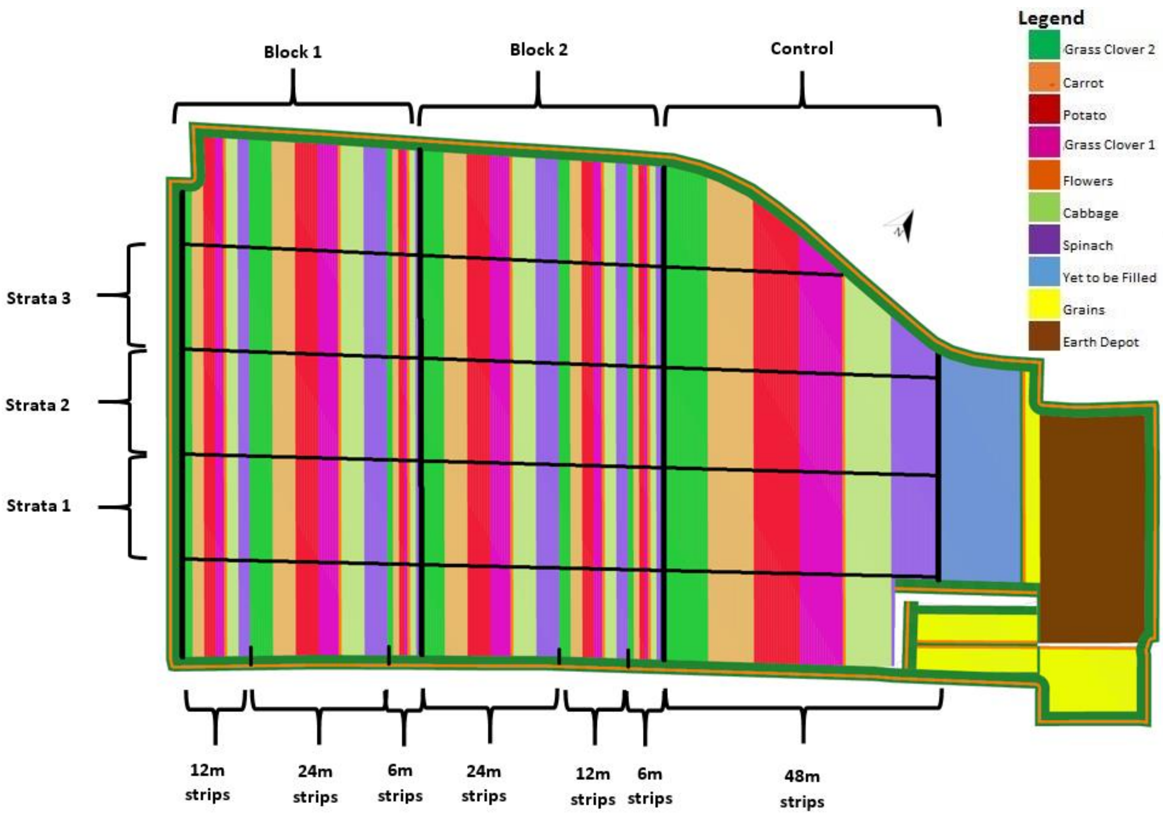



Figure 2. The experimental design - representation of blocks, strata, and strips of crops with their respective widths

dates, irrigation, etc; which could also be viewed as relay cropping.

*Temporal and Spatial variability*

The experimental design of the strip-cropping system (Figure 2) followed a randomised complete block design for the study and included 6 crop strips of different widths 6, 12, 24m (treatment) and of length 500m and a flower strip (3m wide) of 500m length. The control group had crops at 48m width. The design considers a crop rotation sequence of 6 years, and the requirement for the flower strip to be near the cabbage and spinach strips for pest control and for a grass strip to be next to cabbage for harvesting convenience. Furthermore, there were two kinds of grass clover strips, 1st year and 2nd year, where the location of the 2nd year was fixed by the location of the 1st year grass strip in the previous year. The design included a flower strip of 3-meter width in each of the treatments and the control group. The flower strip partly replaced the grass clover 1st year strip (on the cabbage/spinach edge side).

The experimental design was a randomised complete block design, for which the field was divided into 3 parts, consisting of 2 blocks and a control group. And the field was further divided into 3 strata (Figure 2). Each stratum was approx. 100m wide, leaving aside non-sampling zones on the periphery. Each block consisted of a fixed arrangement of 6 crop strips for the year 2017, namely Grass clover year 2, Carrot, Potato, Grass clover year 1, Cabbage (Sprouts) and Spinach (From left to right in Figure 2).

*Cropping History*

The experimental field had the following cropping history. Prior to this study which started in 2017, the following crops were grown 2013 onwards. In 2013, beans were grown, followed by Winter Wheat (Triticum aestivum)14 ha, Maize (*Zea* *mays*) 21 ha and Potato (*Solanum tuberosum*) 7 ha, starting block 1 side (see Figure 2) in 2014. In 2015, Peas (*Pisum sativum*) were grown, followed by beans (*Phaseolus vulgaris*) in the same year. In 2016, Beetroot *(Beta vulgaris*) was grown.

### *Data Collection*

The experiment consisted of (Table 1):

- Sampling for pest(s)/pathogen for the 2 main crops, namely Potato and Cabbage (Sprouts)
- Harvesting samples for measurement of yield (quantity and/or quality) for the 3 main crops, namely Potato, Carrot and Cabbage (Sprouts)

Table 1. List of pests and natural enemies (Flint and Dreistadt,1998) and Harvesting schedule

| **Crop** (*In Dutch*) | **Potato** (*Consumptieaardappelen*) | **Carrot** (*Grove peen*) | **Cabbage** (*Spruitkool*) |
|---|---|---|---|
| **Pests and natural enemies** | | | |
| Pest/Pathogen of Interest | Late blight *(Phytophthora infestans)* | - | Cabbage flea (*Phyllotreta sp.*) Aphids (O: Hemiptera) |
| Natural Enemy | Two-spotted stink bug (*Perillus bioculatus*), Wasp (*Edovum puttleri)* | - | Lady bugs (F: Coleoptera), Lace wings (O: Neuroptera), Spiders (O: Araneae) |
| **Harvesting schedule** | | | |
| Variety | Ditta | Kormano | Martinus |
| Sowing Date | 04-05-2017 | 30-05-2017 | 17-05-2017 |
| Sampling Date | 28-08-2017<br>29-08-2017 | 15-10-2017<br>16-10-2017<br>14-11-2017 | 31-10-2017<br>02-11-2017 |
| Method of Sampling | Machine | Hand/Machine | Hand |

#### *Sampling for Pests/Pathogen*

Visual inspection of the potato crop was done for *Phytophthora infestans*. The field was scouted for first detection of *Phytophthora infestans* visually as well as remotely using nationally available online tools (Dacom 2017). Field assessment days were 24th, 26th, 28th of July 2017, starting from the first detection of *Phytophthora infestans*. After a week of observation, the potato plants were required to be defoliated (1st application on 28th July; 2nd on 1st August 2017) as per Dutch sanitary regulations on *Phytophthora infestans* (Government of Netherlands 2017). Each treatment consisted of random selection of 32 plants (approx. 7.5 sqm) per day. Visual inspection of the potato crop was also initiated for Colorado beetle, after it was spotted in the test field outside of the experimental design on the location.

Cabbage (Sprouts) was scouted for cabbage flea. 35 plants (5 per strip) were measured, all within the same stratum to analyse the intensity of the Cabbage flea plague in the monoculture and the different strip widths (treatments). The sampling was taken along the rows in the middle. Carrot was scouted for the pest-carrot fly throughout the growing season. However, at no stage the Carrot fly was found or any crop damage was observed.

### *Harvesting*

Potato - The mechanised harvest was stored in wooden crates per strip, and each crate was weighed to arrive at the fresh yield per strip. For analysis of quality, three random samples of approximately 10kg each from each strip were taken. Each sample was oven dried at 100°C for 48h to assess the dry matter (DM) ratio.

Cabbage - For the quantity and quality comparative analysis of the harvest between the treatments and control, samples were taken from the middle rows. Per treatment 48 samples were taken (24 samples per strip), and 48 samples were taken from the control. The samples (sprouts without the plant mass) were weighed for fresh yield. For analysis of quality, a sample (approx. 300 to 400g) from the total harvest was oven-dried for, 55°C for first 24h, and,105°C for next 24h. Each sample was assessed for dry matter (DM) ratio for sprouts. Additionally, a batch of 100 sprouts was sampled for physically assessment of external damage caused by pests.

Carrot - For the quantity and quality comparative analysis of the harvest between the treatments and control, samples were taken from the middle rows. Per treatment 6 samples were taken (3 samples per strip), and 6 samples were taken from the control. From block 1 the 24m strip could not be sampled, as it had been harvested earlier as per buyer's requirement. For fresh yield, the samples were weighed on the field. For analysis of quality, approximately 5 kg per sample was taken, of which, a sample (approx.300 to 400g) was oven-dried for, 55°C for first 24h, and,105°C next 24h. Each sample was assessed for dry matter (DM) ratio for roots(carrot).

### ***Statistical Analysis***

The statistical analysis for the data obtained was done using statistical software R (R version 3.4.2 2017). The results were further analysed to arrive at answers to the research questions.

To analyse the effect of strip width on late blight of potato, the Zero inflated negative binomial model [count model coefficients (negbin with log link); zero-inflation model coefficients (binomial with logit link)] was used, as it was found to be the best fit following protocol of Zuur, Elena, and Meesters (2009). For Cabbage flea data, the Negative binomial model (link: log) was used, as it was found to be the best fit.

For the analysis of yields, Mix Models were used (Pinheiro et al. 2009). Tukey's post-hoc test (Hothorn et al. 2008) was used to analyse and compare the differences between the treatments (significant level $p < 0.05$).

### ***Land Equivalent Ratio (LER)***

Partial Land equivalent (PLER) ratios and Land equivalent ratio (LER) were used to compare the effectiveness of a cropping system in terms of productivity and land use efficiency (Mead and Willey 1980; Vandermeer 1992). For example, a Land Equivalent Ratio (LER) 1.2, would suggest a 20% yield increase for strip crops compared with sole crop.

From this study's perspective, PLER was used as an indicator to compute the productivity difference between strip cropping (treatments- 6m, 12m and 24m) and monocrop (control- 48m). LER and PLER were calculated using the formula,

$$PLERct = (\frac{Yct}{Yc\ control})$$

$PLER_{ct}$ is the partial land equivalent ratio for a specific crop for a specific treatment, where c is crop (Potato, Carrot or Sprout); t is treatment (6m, 12m or 24m), $Y_{ct}$ = Yield (t/ha) for the crop for a specific treatment; $Y_{c\ control}$ = Yield for the crop for the control

$$LERt = (PLERpt + PLERct + PLERst)/3$$

$LER_t$ is the land equivalent ratio for a specific treatment, where p is potato, c is carrot, s is sprout, t is treatment (6m, 12m or 24m).

Example: LER for treatment 6m is,

$$LER6 = (\frac{Yp6}{Yp48} + \frac{Yc6}{Yc48} + \frac{Ys6}{Ys48})/3$$

## Results

An overview of the results for 'pest/ pathogen' is presented in Table 2. Additionally, Figure 3 illustrates the spatial effects on 'late blight', Figure 4 illustrates the pest populations of Aphids and Flea per treatment on cabbage. Results for yield and quality are presented in Table 2. Partial Land Equivalent Ratio (PLER) are further illustrated in Figure 5.

Table 2. Overview of the results for Pest/Pathogen, Visual Quality assessment, Yield and Quality

| | Treatments (Strip width) (m) | | | |
|---|---|---|---|---|
| | **6** | **12** | **24** | **48 (Control)** |
| **Pest/Pathogen – Late Blight** | | | | |
| *Pi* infected leaflets (median)* | 135 | 83 | 220 | 263 |
| P-value | 0.001 [c] | 0.072 [a] | 0.017 [b] | - |
| **Pest/Pathogen – Cabbage Flea per plant** | | | | |
| No. of pests/plant (median) | 4.5 | 7.5 | 6.0 | 6.0 |
| P-value | 0.396 [a] | 0.741 [a] | 0.491 [a] | - |
| **Pest/Pathogen – Aphids per plant** | | | | |
| No. of pests/plant (median) | 7 | 12 | 12.5 | 16 |
| P-value | 0.036 [b] | 0.430 [a] | 0.629 [a] | - |
| **Visual Quality Assessment – Cabbage (Sprout)** | | | | |
| Affected Sprouts (%) | 61 | 53 | 57 | 62 |
| P-value | 0.926 [a] | 0.118 [a] | 0.327 [a] | - |
| Damage mass ratio (w/w) | 0.090 | 0.082 | 0.088 | 0.084 |
| P-value | 0.656 [a] | 0.888 [a] | 0.776 [a] | - |
| **Land Equivalent Ratio (LER)** | | | | |
| LER | 0.95 | 1.01 | 1.00 | 1.00 |
| **Partial LER, Yield and Quality** | | | | |
| **Potato** | | | | |
| PLER | 1.05 | 1.12 | 1.07 | 1.00 |
| Yield (t/ha) | 34.5 | 36.9 | 35.3 | 32.9 |
| P-value | 0.137 [a] | 0.004 [b] | 0.046 [c] | - |
| DM ratio | 0.168 | 0.167 | 0.162 | 0.166 |
| P-value | 0.597 [a] | 0.678 [a] | 0.302 [a] | - |
| DM Yield (t/ha) | 5.8 | 6.2 | 5.7 | 5.5 |
| **Carrot** | | | | |
| PLER | 0.95 | 0.95 | 1.02 | 1.00 |
| Yield (t/ha) | 63.3 | 63.3 | 67.6 | 66.6 |
| P-value | 0.497 [a] | 0.502 [a] | 0.854 [a] | - |
| DM ratio | 0.116 | 0.116 | 0.111 | 0.107 |
| P-value | 0.053 [b] | 0.067 [a] | 0.496 [a] | - |
| DM Yield (t/ha) | 7.4 | 7.3 | 7.5 | 7.1 |
| **Cabbage (Sprout)** | | | | |
| PLER | 0.84 | 0.95 | 0.91 | 1.00 |
| Yield (t/ha) | 16.6 | 18.8 | 17.9 | 19.7 |
| P-value | 0.001 [c] | 0.289 [a] | 0.036 [b] | - |
| DM ratio | 0.147 | 0.150 | 0.151 | 0.153 |
| P-value | 0.249 [a] | 0.544 [a] | 0.729 [a] | - |
| DM Yield (t/ha) | 2.4 | 2.8 | 2.7 | 3.0 |

P values- different superscripts are significantly different ($P \leq 0.05$); Control-48m (Monocrop) LER/PLER taken as 1.0. * Values from the last day (28th July 2017) of observation.

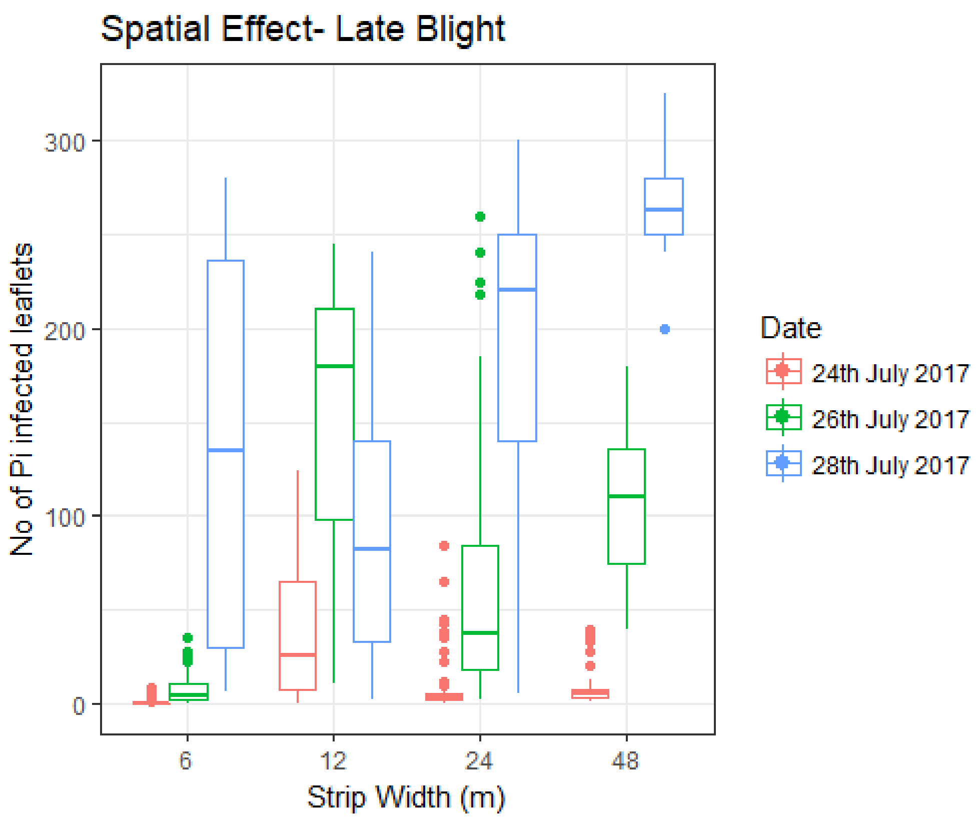



Figure 3. Boxplot showing spatial distribution of the *Phytophthora infestans (Pi)* across strip widths (Treatments- 6, 12, 24m; Control-48m) with observed number of *Pi* infected leaflets for 3 sampling dates.

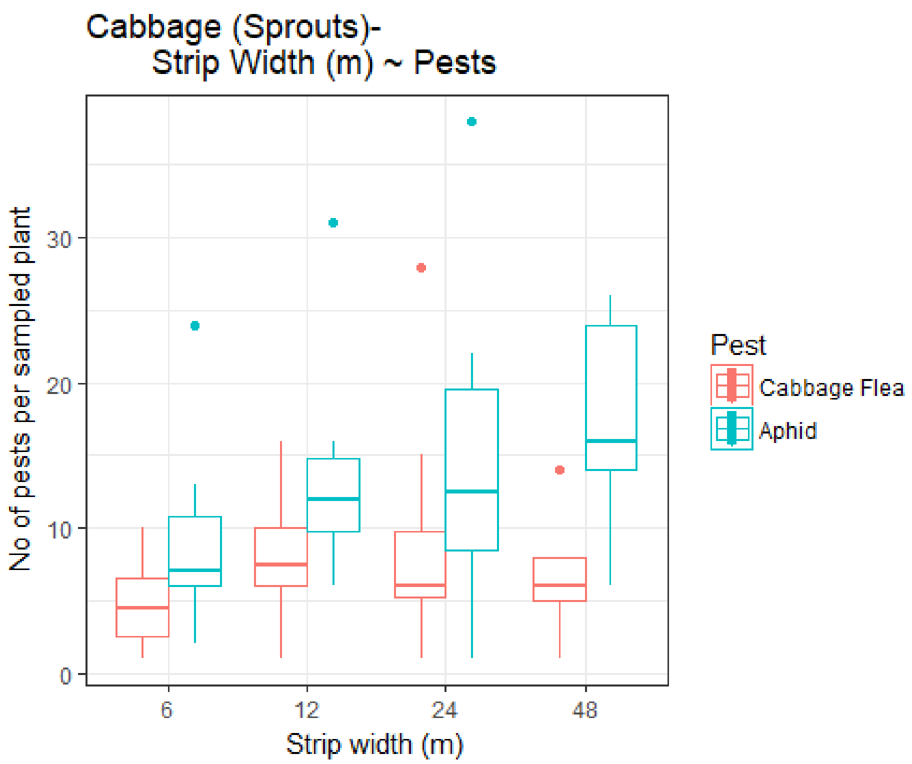



Figure 4. Boxplot showing spatial distribution of the number of pests (Cabbage Flea and Aphids) sampled for Strip-width (Treatments- 6, 12, 24m; Control-48m)

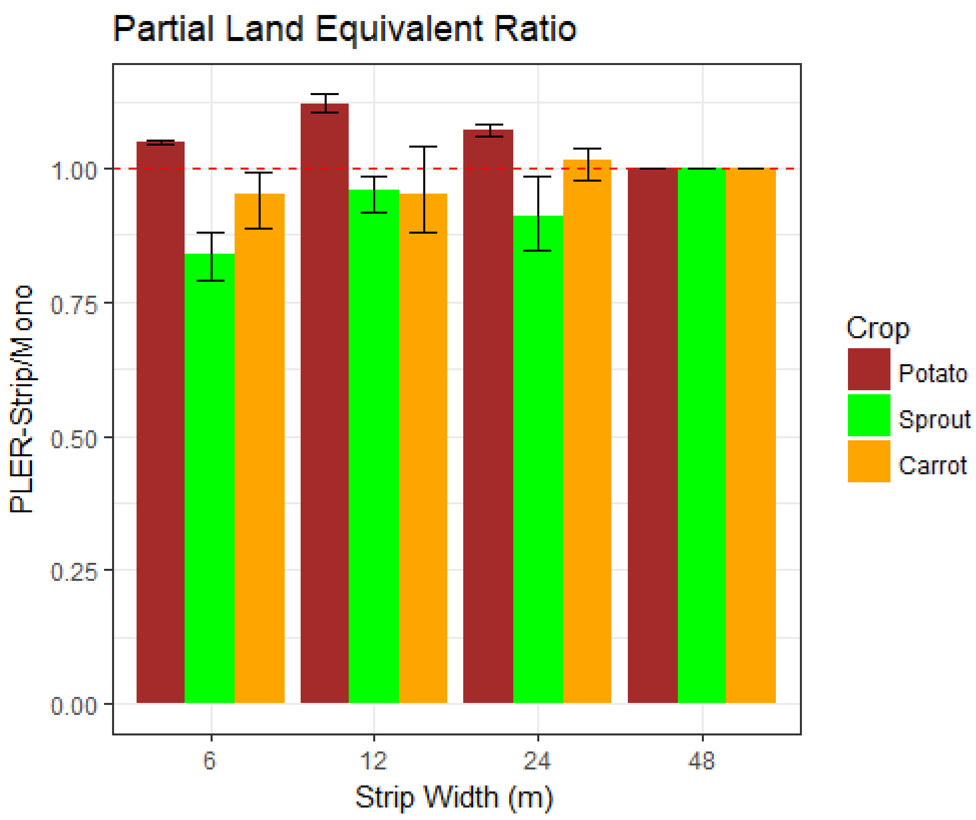



Figure 5. Plot showing PLER (Partial Land Equivalent Ratio): Treatments- 6, 12, 24m (Strip cropping) and Control- 48m (Monocrop); Control (Monocrop) PLER taken as 1.0

## Discussion

### *Pest /Pathogen*

*Phytophthora infestans (Pi)* infected leaflets in treatment 6m and 24m were significantly lower (Table 2; Figure 3) than the control (48m), successfully demonstrating the pest suppressive potential of the strip cropping system. It may be noted that the infection was first observed in the 12m strip, the observation on day 1 reported higher median values than other strips. Results also pointed out that the 6m had lowest *Pi* median values across the days. These findings support the conclusions from Skelsey et al. (2009), which assumes that spores are spread in equal amounts in all directions and that highly fractioned landscape designs are favourable in limiting spore distribution. Thus, making a strong case for farming system with greater heterogeneity, such as strip cropping or as in intercropping systems. *Pi* values for control on day 2 and 3, were lower than the *Pi* values at the edge of the treatments indicating a lower *Pi* pressure at the edges, hence showing a spatial strip effect. Further, during the visual assessment, it was found that the plants in 6m strip and the edge rows of 12m and 24m were less succulent and the inter-nodal length of the shoots was also shorter than the plants in the middle of 24m and 48m strips. The plants in 6m were found to be more robust and with relatively less number of shoots. Also, it may be noted that the preferred planning direction is parallel to wind direction to facilitate drying. In this study, however, the wind direction was perpendicular to the strip widths, hence, it may have kept only the narrower strips relatively well aerated and less humid thus explaining a lower effect of *Pi*, even after *Pi* infection. Thus, such phenotypic features may be the result of less humidity due to cross winds, more radiation and the adaptability of the potato plants to the conditions, which may prove to be useful against the spread of late blight of potato (Waggoner, 1952; Hirst and Stedman 1960). Further, this study corroborates the findings of Bouws and Finckh, (2008) that the most important factors in disease reduction are, the loss of inoculum outside the plot, perpendicular direction of the wind and the barrier effect of the non-host crops, which are amply highlighted by the results of this study, with the control (48m) showing increased disease severity in comparison with the treatment.

For Cabbage (Sprouts), Booij, Noorlander, and Theunissen (1997) studying the effects of intercropping cabbage with clover on the epigeal predator activity and pest suppression, concluded that intercropping results in higher predator activity and may lead to reduced pest pressure. During this study, the underlying hypothesis for cabbage could not be tested as the cabbage crop was twice treated with an insecticide, Tracer (Spinosad), which may have affected the biodiversity of insects. Thus, potential loss of natural enemies which may also explain the extensive and intensive crop damage (Table 2) observed during the visual analysis of quality. The aphid pressure was found to be significant and lowest in 6m strips, however, it was difficult to quantify the pest suppression effect across treatments. The results (Table 2; Figure 4) were mostly non-significant and inconclusive for other quality aspects, and for the cabbage flea.

## *Yields and Quality*

The results (Table 2) for the strip cropping system using LER per treatment as an indicator showed, treatment 12m, with LER is 1.01, as the most productive treatment under a strip cropping system when compared with a monocropping system. However, crop-wise contribution to LER, specific crop-treatment combinations were looked at detail to better understand the performance of component crops. The partial yields were computed to arrive at the production efficiencies. PLER (Partial land equivalent ratio) was used as an indicator to compute the productivity difference per crop (for fresh yields), between strip cropping (treatments- 6m, 12m and 24m) and monocrop (control- 48m). PLER (Table 2; Figure 5) helped to highlight the performance of each crop as a component of the overall system level or treatment LERs. Further, Dry matter (DM) ratios highlight the differences in quality per crop per treatment. To highlight both the quality and quantitative factors, DM yield- a combination of Yield and DM ratio, was used.

For Potato (Table 2; Figure 5), fresh yields were significantly higher for the treatments- 24m($p<0.05$) and 12m ($p<0.01$) strips than for the monocrop. The 6m strip had best DM ratio, and the 12m strip had the best PLER of 1.12. All the treatments did better than control (48m) with regards to DM ratio as well as fresh yields. Using DM yield as an indicator, 12m strip was found to be the best performer and control (48m) to be the least. Thus, showing a spatial strip effect. Literature on potato studies, attributes yield variation to premature senescence and defoliation resulting in small leaf area index and reduced radiation interception leading to lower fresh and DM yields as illustrated by Bangemann, Sieling, and Kage (2014) in an experiment in Germany. Thus, affirming the results and observations from *Pi* and yields of this study, as loss of leaf area was maximum in control (48m). As per Möller et al (2006), N availability was most important in limiting yields in organic potato crops contributing to 48% of the yield variation, while 25% of this variation in yield could be attributed to the influence of late blight. In this study, no relation could be established between the influence of *Pi* and Yield. However, from this study's perspective, it is important to make a distinction between the treatments, for example, 6m strip and control 48m monoculture strip, as the data shows both had varying degree of *Pi*, but due to the commercial and practical reasons all the strips were defoliated at the same time. In a separate setting, the 6m strip or 12m, depending upon the disease severity regulations, may have been allowed to grow further and may have yielded more, thus contributing to higher yields. Therefore, given the management practice, the *Pi* also indirectly contributed to the potential yield loss. Thus, this experiment highlights the positive effects of spatial diversity in the form of strip cropping on potato yields, however, with better management practice it has the potential to perform even better.

For Carrot the results for yields (Table 2; Figure 5), were found not to be significant for any of the treatments, DM ratio showed a trend with treatment-6m being the highest and significant at $p=0.05$. As per DM yield all the treatments did better than control (48m), 24m strip was found to be the best performer and control (48m) to be the least. Research for similar crop combinations on commercial scale is limited, however, for mixed cropping Błażewicz-Woźniak and Wach (2011) noted that the carrot yields are positively affected when grown with onions and affected negatively when grown with parsley and marigold. Suresha et al (2007) noted higher carrot yield when grown with chili pepper. A recent research (Inagro vzw 2017, Unpublished) reports LER of 1.12 for an intercropping system with Carrot and Onion in comparison with monocrop. This study suggests to further research the spatial strip effect for Carrot in combination with Potato and Onion. For both quality and quantitative aspects 24m strip treatment gave better yields (not significant) than control (from hand-harvested data), and 12m strip treatment gave better yields than control (from machine harvested data), with 6m, faring significantly better on DM ratio. Since the hand-harvest data and machine harvest data represent different stages of the growing cycle of carrots, and from the marketable perspective they may represent different segments (*wortelen, winterpenen*), the optimum strip width may differ depending on the intended commercial purpose.

For Cabbage, Guvenc and Yildirim (2006), in their experiment concluded that cabbage is more productive intercrop than as a sole crop, when grown as an intercrop with bean, onion and lettuce and less productive when grown with radish. However, the results (Table 2; Figure 5) from this study show that Cabbage (Sprouts) is not a successful strip crop in this experimental system, where samples were taken only from the middle rows. Visual inspection, however, showed that the plants on the edges were doing relatively better, suggesting compensation differences at play. In this experiment, strip cropping with Grass Clover/flower strip and spinach, the best results were for monocrop. It may be noted that the Cabbage was plagued by cabbage flea and aphids which may have influenced the results for this experiment. Also, it contributed to quality deterioration of the produce to great extent, highlighting the risks associated with farming. Strip cropping also works as a crop insurance to overcome the challenges of climate change and economic needs. With the farmer able to cultivate diverse crops, and spreading crops over different fields, the risks of complete crop failure is reduced in comparison to monoculture (Altieri 2009).

### *Limitations and Recommendations*

The study notes that for *Phytophthora* sampling it would be useful to use technology like drones for aerial photography to detect the pathogen spreading. Such a technology can help to map the propagation of the pathogen to arrive at a better estimate and model for large cropping fields. With the existing method of sampling, the sampling becomes labour intensive for the given short window of phytophthora sampling. With the relatively small number of sample locations, even though the sampling was randomised, there is a chance, that the results are skewed, showing greater variation from day to day, depending on, whether the randomised sample location featured a pathogen colony. A better method for sampling in large scale fields could be counting of colonies and estimating their spreading, thereby estimating the area under pathogen infection. This would also help in preventing spreading of pathogen infection due to sampling activity.

The study also notes that, in the existing experimental design, the block effect could not be estimated across the blocks as control was not part of the same blocks as treatments were. Thus, block effect could only be estimated for 'within treatments' and not for variation between control and blocks. Another reason to add the control in both the treatment blocks would be to eliminate location bias, in studies involving large cropping fields. Thus, this study recommends adding control to each treatment block, which may not be feasible in combination with complete block design, alternatively an incomplete block design with smaller plots may be considered.

Knowing the performance and understanding the interaction of component crops further enhances our understanding in designing better strip cropping farming systems for future researches as well as practical applications (Fukai and Trenbath 1993). Bedoussac et al. (2015) emphasise the collaboration of value chain actors to select crops and cultivars better suited to such multi-cropping systems. As this study is a part of long term project, this study recommends that, for Potato and Carrot, the study may be repeated to strengthen the findings of this study. Thus, experiments may also be conducted by using only Potato and Carrot as component crops along with grass clover or as research has shown, other crops such as legumes, which has yielded successful results as a component crop in combination with cereals, could be combined with winter cereals, upon discussion with the farmers.

## Conclusion

The present study demonstrated the positive effect of spatial crop diversification on pest/pathogen suppression for arable crops. For Potato, reducing the strip width contributed to significant reduction of the effect of late blight, with 6m giving the best results, thus, demonstrating the role of strip cropping as an effective management tool to reduce the late blight severity in Potato. For Cabbage crop, the results were non-significant and inconclusive for Cabbage flea, while Aphid pressure reduced with reduction in strip width, with 6m showing a significant difference. The underlying hypothesis relating biodiversity and pest suppression could not be tested because of insecticide application. There was also extensive and intensive crop damage.

For yields, in the given strip cropping system, using Land equivalent ratio as an indicator, 12m performed better than control (48m), 24m as good as control and 6m performed worse (under yielded) than control. Using Partial land equivalent ratio, specific crops and crop-treatment combinations were looked at in detail to better understand the performance of component crops to design better systems. Potato yields were significantly higher for 6m and 12m treatments than in monocrop, with no significant differences in DM ratio. Carrot showed no significant differences for yields between treatments and monocrop, DM ratio for 6m was significantly higher. Cabbage (Sprouts) did not prove to be a successful strip crop in this experimental system. It showed adverse results for both fresh yields as well as DM yields in comparison with the monocrop, yields were significantly lower for 6m and 24m than in monocrop, there were no significant differences regarding DM ratio. Strip cropping also works as a crop insurance to overcome the challenges of climate change and economic needs. In case of crop failure of one of the component crops, the farmer still has other crops to keep him/her financially secure as compared with a monocrop system.

The study demonstrated that, in an organic commercial strip cropping farming system, selection of component crops and specific strip width can improve the production efficiencies and enhance the pest suppression by utilising the ecological principles of spatial diversity. Thus, customising farming system designs including strip cropping has the potential to improve performance. At the same time, it can bring down the reliance on chemical usage thereby reducing the costs and benefitting the environment altogether.

## Acknowledgements

I would like to thank my supervisor for his continued guidance, staff members of ERF BV for participating in the research, my friends and peers from the study group, and most importantly my wife-best friend Amy Ahluwalia in contributing to this study.

## References


Altieri, M. A. 2009. Agroecology, small farms and food sovereignty. Monthly Review 61 (3):102–14. doi:10.14452/MR-061-03-2009-07.

Altieri, M. A., & Letourneau, D. K. (1982). Vegetation management and biological control in agroecosystems. *Crop protection*, *1*(4), 405-430.

Altieri, M. A., Nicholls, C. I., & Montalba, R. (2017). Technological Approaches to Sustainable Agriculture at a Crossroads: An Agroecological Perspective. *Sustainability*, *9*(3), 349.

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development*, *35*(3), 869-890.

Altieri, M., & Nicholls, C. (2004). *Biodiversity and pest management in agroecosystems*. CRC Press

Anders, M. M., M. V. Potdar, and C. S. Francis. "Significance of intercropping in cropping systems." *Series on International Agricultural Research* 3 (1995): 1-18.

Bangemann, Lars-Wilhelm, Klaus Sieling, and Henning Kage. "The effect of nitrogen and late blight on crop growth, solar radiation interception and yield of two potato cultivars." *Field Crops Research* 155 (2014): 56-66.

Bedoussac, Laurent, Etienne-Pascal Journet, Henrik Hauggaard-Nielsen, Christophe Naudin, Guenaelle Corre-Hellou, Erik Steen Jensen, Loïc Prieur, and Eric Justes. "Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review." *Agronomy for sustainable development* 35, no. 3 (2015): 911-935.

Bianchi, F. J. J. A., Booij, C. J. H., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society of London B: Biological Sciences*, *273*(1595), 1715-1727.

Błażewicz-Woźniak, Marzena, and Dariusz Wach. "The effect of intercropping on yielding of root vegetables of Apiaceae family." *Acta Sci. Pol., Hortorum Cultus* 10, no. 4 (2011): 233-243.

Booij, C. J. H., J. Noorlander, and J. Theunissen. "Intercropping cabbage with clover: effects on ground beetles." *Biological agriculture & horticulture* 15, no. 1-4 (1997): 261-268.

Bouws, H., and M. R. Finckh. "Effects of strip intercropping of potatoes with non-hosts on late blight severity and tuber yield in organic production." *Plant Pathology* 57, no. 5 (2008): 916-927.

Briggs Helen. 2017. "Alarm over decline in flying insects." *BBC*, October 19, 2017. http://www.bbc.com/news/science-environment-41670472

Cardinale, Bradley J., J. Emmett Duffy, Andrew Gonzalez, David U. Hooper, Charles Perrings, Patrick Venail, Anita Narwani et al. "Biodiversity loss and its impact on humanity." *Nature* 486, no. 7401 (2012): 59-67.

Dacom. 2017. (http://haarden.dacom.nl/, http://www.dacom.nl/masterplan/index.php?pid=3)

Dainese, M., Luna, D. I., Sitzia, T., & Marini, L. (2015). Testing scale-dependent effects of seminatural habitats on farmland biodiversity. *Ecological Applications*, *25*(6), 1681-1690.

Denys, C., & Tscharntke, T. (2002). Plant-insect communities and predator-prey ratios in field margin strips, adjacent crop fields, and fallows. *Oecologia*, *130*(2), 315-324.

Elba, B., Suárez, S. A., Lenardis, A. E., & Poggio, S. L. (2014). Intercropping sunflower and soybean in intensive farming systems: Evaluating yield advantage and effect on weed and insect assemblages. *NJAS-Wageningen Journal of Life Sciences*, *70*, 47-52.

Fischer, J., Brittain, C., & Klein, A. M. (2013). Biodiversity-friendly farming.

Fischer, J., Lindenmayer, D. B., & Manning, A. D. (2006). Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes. *Frontiers in Ecology and the Environment*, *4*(2), 80-86.

Flint, M. L., & Dreistadt, S. H. (1998). *Natural enemies handbook: the illustrated guide to biological pest control* (Vol. 3386). Univ of California Press.

Fukai, S., and B. R. Trenbath. "Processes determining intercrop productivity and yields of component crops." *Field Crops Research* 34, no. 3-4 (1993): 247-271.

Gómez-Macpherson, H., Villalobos, F. J., & Fereres, E. (2016). Cropping and Farming Systems. In *Principles of Agronomy for Sustainable Agriculture* (pp. 515-525). Springer International Publishing.

Government of Netherlands. 2017." Regeling bestrijding schadelijke organismen- Phytophthora infestans regulation, De Minister van Landbouw, Natuurbeheer en Visserij,"
(http://wetten.overheid.nl/BWBR0013946/2015-07-14#Paragraaf5)

Guvenc, Ismail, and Ertan Yildirim. "Increasing productivity with intercropping systems in cabbage production." *Journal of sustainable agriculture* 28, no. 4 (2006): 29-44.

Hallmann, Caspar A., Martin Sorg, Eelke Jongejans, Henk Siepel, Nick Hofland, Heinz Schwan, Werner Stenmans et al. "More than 75 percent decline over 27 years in total flying insect biomass in protected areas." *PLoS One* 12, no. 10 (2017): e0185809.

Hirst, J. M., and O. J. Stedman. "The epidemiology of Phytophthora infestans." *Annals of Applied Biology* 48, no. 3 (1960): 489-517.

Hooper, David U., E. Carol Adair, Bradley J. Cardinale, Jarrett EK Byrnes, Bruce A. Hungate, Kristin L. Matulich, Andrew Gonzalez, J. Emmett Duffy, Lars Gamfeldt, and Mary I. O'Connor. "A global synthesis reveals biodiversity loss as a major driver of ecosystem change." *Nature* 486, no. 7401 (2012): 105-108.

Hothorn, Torsten, Frank Bretz, and Peter Westfall. "Simultaneous inference in general parametric models." *Biometrical journal* 50, no. 3 (2008): 346-363.

Kremen, C., & Miles, A. (2012). Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. *Ecology and Society*, *17*(4)

Landis, D. A. (2017). Designing agricultural landscapes for biodiversity-based ecosystem services. *Basic and Applied Ecology*, *18*, 1-12.

Liang, Jingjing, Mo Zhou, Patrick C. Tobin, A. David McGuire, and Peter B. Reich. "Biodiversity influences plant productivity through niche–efficiency." *Proceedings of the National Academy of Sciences* 112, no. 18 (2015): 5738-5743.

Lin, B. B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience*, *61*(3), 183-193.

Maisonhaute, J. É., Labrie, G., & Lucas, É. (2017). Direct and indirect effects of the spatial context on the natural biocontrol of an invasive crop pest. *Biological Control*.

Martin, E. A., Seo, B., Park, C. R., Reineking, B., & Steffan-Dewenter, I. (2016). Scale-dependent effects of landscape composition and configuration on natural enemy diversity, crop herbivory, and yields. *Ecological Applications*, *26*(2), 448-462.

McLaughlin, A., & Mineau, P. (1995). The impact of agricultural practices on biodiversity. *Agriculture, Ecosystems & Environment*, *55*(3), 201-212.

Mead, R., and R. W. Willey. "The concept of a ‘land equivalent ratio and advantages in yields from intercropping." *Experimental Agriculture* 16, no. 3 (1980): 217-228.

Möller, Kurt, Johann Habermeyer, Volker Zinkernagel, and Hans-Jürgen Reents. "Impact and interaction of nitrogen and Phytophthora infestans as yield-limiting and yield-reducing factors in organic potato (Solanum tuberosum L.) crops." *Potato Research* 49, no. 4 (2006): 281-301.

Naeem, S., Thompson, L. J., Lawler, S. P., Lawton, J. H., & Woodfin, R. M. (1994). Declining biodiversity can alter the performance of ecosystems. *Nature*, *368*(6473), 734-737.

NOS. 2017. “100.000 mensen tekenen petitie om insecten te redden.” *NOS*, December 7, 2017. https://nos.nl/artikel/2206217-100-000-mensen-tekenen-petitie-om-insecten-te-redden.html

Ofori, Francis, and W. R. Stern. "Cereal–legume intercropping systems." *Advances in agronomy* 41 (1987): 41-90.

Oliver, Tom H., Matthew S. Heard, Nick JB Isaac, David B. Roy, Deborah Procter, Felix Eigenbrod, Rob Freckleton et al. "Biodiversity and resilience of ecosystem functions." *Trends in Ecology & Evolution* 30, no. 11 (2015): 673-684.

Pinheiro, Jose, Douglas Bates, Saikat DebRoy, Deepayan Sarkar, and R. Core Team. "nlme: Linear and nonlinear mixed effects models." *R package version* 3 (2009): 96.

R version 3.4.2. "Short Summer" Copyright (C) 2017 The R Foundation for Statistical Computing Platform: x86_64-w64-mingw32/x64 (64-bit)

Riechert, S. E. (1999). The hows and whys of successful pest suppression by spiders: insights from case studies. *Journal of Arachnology*, 387-396.

Skelsey, P., G. J. T. Kessel, W. A. H. Rossing, and W. van der Werf. "Parameterization and evaluation of a spatiotemporal model of the potato late blight pathosystem." *Phytopathology*99, no. 3 (2009): 290-300.

Suresha, B. A., T. B. Allolli, M. G. Patil, B. K. Desai, and Syed Abbas Hussain. "Yield and economics of chilli based intercropping system." *Karnataka Journal of Agricultural Sciences* 20, no. 4 (2010).

Tscharntke, T., Bommarco, R., Clough, Y., Crist, T. O., Kleijn, D., Rand, T. A., ... & Vidal, S. (2007). Conservation biological control and enemy diversity on a landscape scale. *Biological control*, *43*(3), 294-309.

Tscharntke, T., Karp, D. S., Chaplin-Kramer, R., Batáry, P., DeClerck, F., Gratton, C., ... & Martin, E. A. (2016). When natural habitat fails to enhance biological pest control–Five hypotheses. *Biological Conservation*, *204*, 449-458.

Tschumi, M., Albrecht, M., Entling, M. H., & Jacot, K. (2015, September). High effectiveness of tailored flower strips in reducing pests and crop plant damage. In *Proc. R. Soc. B* (Vol. 282, No. 1814, p. 20151369). The Royal Society.

van Apeldoorn, D. F., W. A. H. Rossing, and Gerard Oomen. "Strokenteelt klaar voor de praktijk." *Ekoland* 5 (2017): 10-11.

Vandermeer, John H. *The ecology of intercropping*. Cambridge University Press, 1992.

Wagg, Cameron, S. Franz Bender, Franco Widmer, and Marcel GA van der Heijden. "Soil biodiversity and soil community composition determine ecosystem multifunctionality." *Proceedings of the National Academy of Sciences* 111, no. 14 (2014): 5266-5270.

Waggoner, Paul E. "Distribution of potato late blight around inoculum sources." *Phytopathology* 42 (1952): 323-328.

Zuur, Alain, Elena N. Ieno, and Erik Meesters. *A Beginner's Guide to R*. Springer Science & Business Media, 2009.

# Appendix

## Methodology

| strip | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|
| 1 | grass | spinach | potato | cabbage | carrot | grass |
| | grass | spinach | potato | cabbage | carrot | flowers |
| 2 | carrot | grass | grass | spinach | potato | cabbage |
| | carrot | flowers | grass | spinach | potato | cabbage |
| 3 | potato | cabbage | carrot | flowers | grass | spinach |
| | potato | cabbage | carrot | grass | grass | spinach |
| 4 | grass | grass | spinach | potato | cabbage | carrot |
| | flowers | grass | spinach | potato | cabbage | carrot |
| 5 | cabbage | carrot | grass | grass | spinach | potato |
| | cabbage | carrot | flowers | grass | spinach | potato |
| 6 | spinach | potato | cabbage | carrot | flowers | grass |
| | spinach | potato | cabbage | carrot | grass | grass |

Figure 6. Crop rotation plan for the period of 2017 till 2022

Table 3. Crop-wise list of pests and natural enemies (Flint and Dreistadt,1998).

| Crop | Pest/Pathogen of Interest | Other Pests | Natural Enemy |
|---|---|---|---|
| Potato | Late blight *(Phytophthora infestans)* | Colorado beetle (*Leptinotarsa decemlineata*) | Two-spotted stink bug (*Perillus bioculatus*),<br>Wasp (*Edovum puttleri)* |
| Cabbage | Cabbage flea (*Phyllotreta sp.*) | Aphids (O: Hemiptera) | Lady bugs (F: Coleoptera), Lace wings (O: Neuroptera),<br>Spiders (O: Araneae) |
| Carrot | Carrot fly (*Chamaepsila rosae*) | | Spiders (O: Araneae) |

Table 4. Crop-wise harvesting schedule

| Crop (In *Dutch*) | Variety | Sowing Date | Harvesting/ Sampling Date | Method of sampling |
|---|---|---|---|---|
| Spinach (Spinazie) | Boa | 19-06-2017 | 26-07-2017 | Machine |
| Potato (Consumptieaardappelen) | Ditta | 04-05-2017 | 28-08-2017/ 29-08-2017 | Machine |
| Carrot (Grove peen) | Kormano | 30-05-2017 | 15-10-2017/ 16-10-2017 | Hand |
| Cabbage (Spruitkool) | Martinus | 17-05-2017 | 14-11-2017<br>31-10-2017/ 02-11-2017 | Machine<br>Hand |

### *Method for assessing Infection*

#### Late blight of Potato

Visual inspection of the potato crop is done for *Phytophthora infestans*. The field is to be scouted for first detection of *Phytophthora infestans* visually as well as remotely using nationally available online tools. (http://haarden.dacom.nl/ & http://www.dacom.nl/masterplan/index.php?pid=3).

Field assessment days are every Monday, Wednesday and Friday during the months of July and August (potato late blight season in the Netherlands), 2017, starting from the first detection of *Phytophthora infestans* and ending when the potato fields need to be terminated due to sanitary regulations. Such a procedure would continue for at least 2 weeks or till the time the crop requires termination on account of Dutch regulations on *Phytophthora infestans* (http://wetten.overheid.nl/BWBR0013946/2015-07-14#Paragraaf5)

The legislation allows the maximum rate of infection to be:

- 1000 leaflets infected by living *Phytophthora infestans* within a semi-continuous area of 20 m2 or
- more than 2000 leaflets infected by living *Phytophthora infestans* on dispersed plants in an area of 100m2.

Further, an infected potato stem is to be counted equivalent to 5 infected leaflets. Following the legislation, the potato crop in an organic field must be defoliated, if the infection reaches the prescribed limits.

#### Scoring and recording the data

Each field assessment day consists of sampling for visual assessment of *Phytophthora infestans* in one of 3 strata (namely stratum 1,2,3).

32 potato plants per strip will be assessed in a single stratum across the 2 blocks and the control group.  Sampling within the strata for each field assessment day is randomised.  the sequence of strata to visit in the first week is randomized at the start, In the following weeks the same sequence will be kept

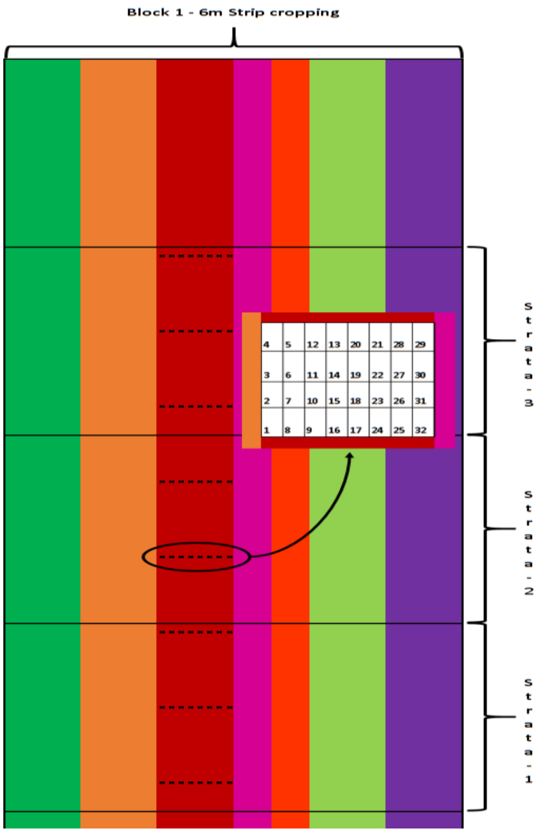



Figure 7a. Sampling positions of the observed plants in 6m potato strips (each number represents an observed potato plant)

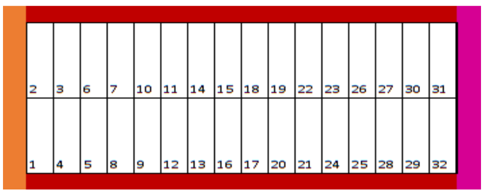



Figure 7b. Sampling positions of the observed plants in 12m potato strips (each number represents an observed potato plant)

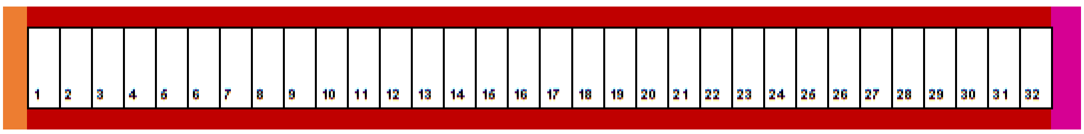



Figure 7c. Sampling positions of the observed plants in 24m potato strips (each number represents an observed potato plant)

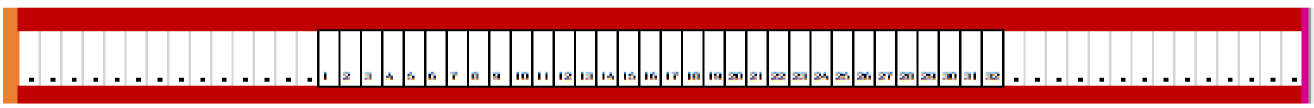


Figure 7d. Sampling positions of the observed plants in 48m (control) potato strips (each dot and number represents a potato plant; however, only numbered potato plants will be observed)

The following set of observations will be arrived at after each field assessment day;

Block 1 - 32 * 3 (6m, 12m, 24m) = 96 observations;

Block 2 - 32 * 3 (6m, 12m, 24m) = 96 observations;

Control - 32 * 1 (48m) = 32 observations;

**Total = 224** observations.

The scoring would be done as per the convention of *Nederlandse Voedsel en Warenautoriteit (*http://wetten.overheid.nl/BWBR0013946/2015-07-14#Paragraaf5). For every observed plant for assessment of *Phytophthora infestans*, the infected number of leaflets will be counted per potato cropping strip per field assessment day per selected stratum for that day.

### Colorado beetle

Visual inspection of the potato crop is done for Colorado beetle, during the same period as visual inspection for *Phytophthora infestans*. The same sample selection for *Pi* is used for Colorado beetle inspection. Thus 32 plants were selected for visual inspection and scoring according to the research guidelines (Wageningen University and Research 2017). Three composite leaves per sampled plant are observed and the number of Colorado beetles are scored. However, no sample of Colorado beetle was found on any plant part according to the sampling protocol at any stage.

### Spinach

For analysis of quality, five random samples of approximately 2-3 kg per sample from each strip were hand-picked in a bag from the mechanised harvester and were oven dried at 100°C for 48h. Each sample was assessed for dry matter (DM) ratio for leaves and stems.

For graphical representations violin plots were used multiple data distributions, besides boxplots and line and stacked graphs. Violin plots help to compare several distributions by placing them side by side. A violin plot is a kernel density estimate, mirrored so that it forms a symmetrical shape. They have narrow box plots overlaid, with a white dot for representing mean and black bar representing median (Chang 2012).

## Results

### *Pests/Pathogen*

Table 5. Potato- Model summary for treatment, number of *Phytophthora infestans* (Pi) infected leaflets

| Strip Width (m) | Estimate | Standard Error (SE) | Z value | Significance | Sig Codes |
|---|---|---|---|---|---|
| Count model coefficients (negbin with log link) | | | | | |
| (Intercept) | 4.84434 | 0.13264 | 36.522 | <2.00E-16 | *** |
| Strip24 | -0.39224 | 0.16378 | -2.395 | 0.0166 | * |
| Strip12 | -0.29252 | 0.16249 | -1.8 | 0.0718 | . |
| Strip6 | -0.71589 | 0.1733 | -4.131 | 3.61E-05 | *** |
| Log(theta) | -0.51939 | 0.05903 | -8.799 | <2.00E-16 | *** |
| Zero-inflation model coefficients (binomial with logit link) | | | | | |
| (Intercept) | -21.598 | 4997.71 | -0.004 | 0.997 | |
| Strip24 | 16.449 | 4997.711 | 0.003 | 0.997 | |
| Strip12 | 7.498 | 4998.591 | 0.001 | 0.999 | |
| Strip6 | 20.528 | 4997.71 | 0.004 | 0.997 | |

Model: Zero-inflated negative binomial- Count model coefficients (negbin with log link), significance level, ($P < 0.05$); Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

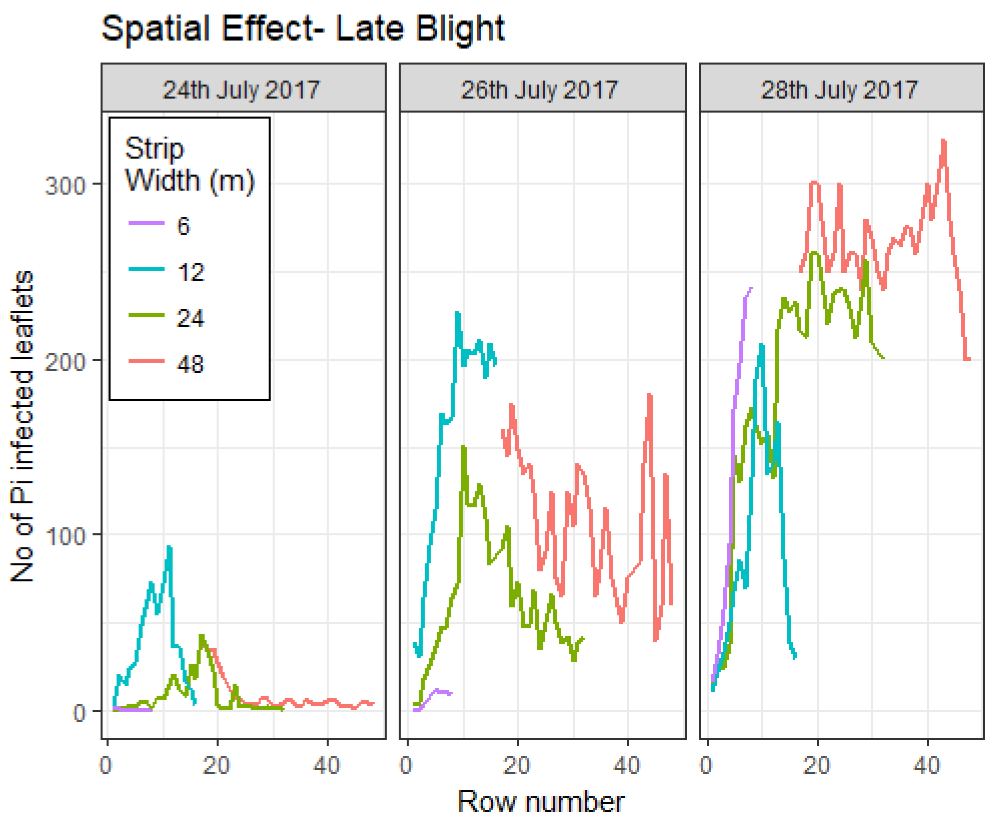



Figure 8. Line graph showing the spatial distribution of the *Phytophthora infestans (Pi)* across the rows within the Strip and for Strip-width (Treatments- 6, 12, 24m; Control-48m) with mean number of *Pi* infected leaflets per day of measurement per row number forming an edge to edge transact for treatments

Table 6. Cabbage (Sprout)- Model summary for treatment ~ number of Cabbage Flea per plant

| Strip Width (m) | Estimate | Standard Error (SE) | Z value | Significance | Sig Codes |
|---|---|---|---|---|---|
| (Intercept) | 1.9169 | 0.309 | 6.204 | 5.51E-10 | *** |
| Strip24 | 0.2578 | 0.374 | 0.689 | 0.491 | |
| Strip12 | 0.1243 | 0.3761 | 0.33 | 0.741 | |
| Strip6 | -0.3277 | 0.3859 | -0.849 | 0.396 | |

Model: Negative Binomial; link: log, significance level- ($P < 0.05$); Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 7 Cabbage (Sprout)- Model summary for treatment ~ number of Aphids per plant

| Strip Width (m) | Estimate | Standard Error (SE) | Z value | Significance | Sig Codes |
|---|---|---|---|---|---|
| (Intercept) | 2.8449 | 0.241 | 11.804 | <2.00E-16 | *** |
| Strip24 | -0.1435 | 0.2967 | -0.484 | 0.6285 | |
| Strip12 | -0.2348 | 0.2978 | -0.789 | 0.4303 | |
| Strip6 | -0.6366 | 0.3038 | -2.095 | **0.0361** | * |

Model: Negative Binomial; link: log, significance level- ($P < 0.05$); Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 8. Cabbage (Sprout)- Summary for treatment ~ affected sprouts (%), and damage mass ratio (w/w)

| Treatment/ Strip width (m) | Number of Observations (N) | Affected Sprouts (%) | Damage mass ratio, (w/w) |
|---|---|---|---|
| 48 (Control) | 6 | 62 [a] | 0.084 [a] |
| 24 | 6 | 57 (0.327) [a] | 0.088 (0.776) [a] |
| 12 | 6 | 53 (0.118) [a] | 0.082 (0.888) [a] |
| 06 | 6 | 61 (0.926) [a] | 0.090 (0.656) [a] |

For each treatment, means in the column are followed by P values; different superscripts are significantly different ($P < 0.05$)

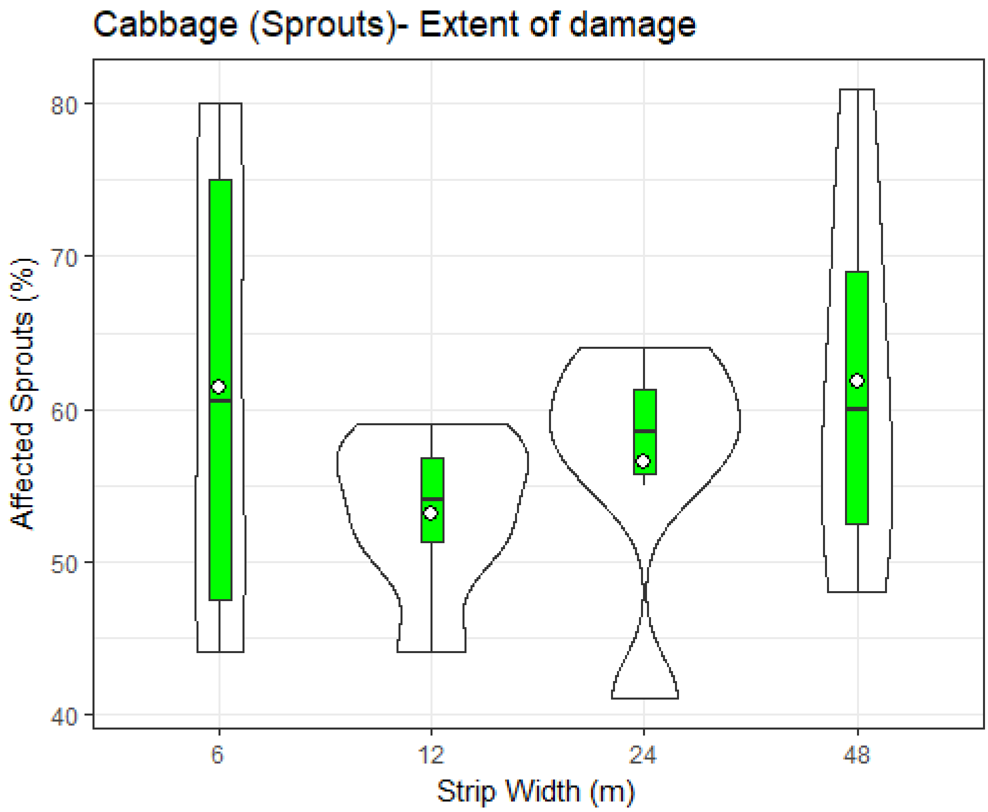



Figure 9. Strip-cropping for Cabbage- Violin plots showing results for Treatments- 24, 12, 6m strips and Control-48m strip ~ Affected sprouts (%), highlighting the extent of damage

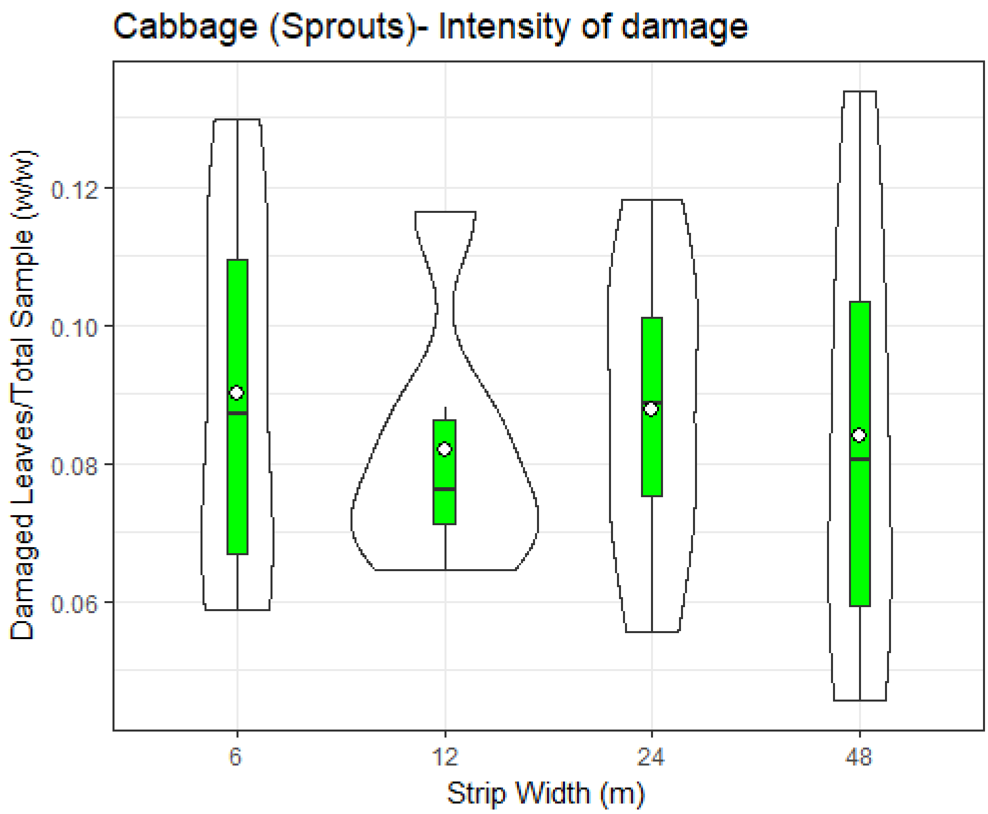



Figure 10. Strip-cropping for Cabbage- Violin plots showing results for Treatments- 24, 12, 6m strips and Control-48m strip ~ Affected sprouts (%), highlighting the intensity (severity) of damage

## *Yield and Quality*

### LER

Table 9. Statistics summary for treatment-wise LER (Land Equivalent Ratio) for fresh yields; Control-48m (Monocrop) LER taken as 1.0

| Treatment (Strip width) (m) | Number of Observations (N) | Land Equivalent Ratio (LER) | Standard Deviation (SD) | Standard Error (SE) | Confidence Interval (95%) (CI) |
|---|---|---|---|---|---|
| 24 | 3 | **1.00** | 0.08 | 0.05 | 0.21 |
| 12 | 3 | **1.01** | 0.10 | 0.06 | 0.24 |
| 6 | 3 | **0.95** | 0.11 | 0.06 | 0.26 |

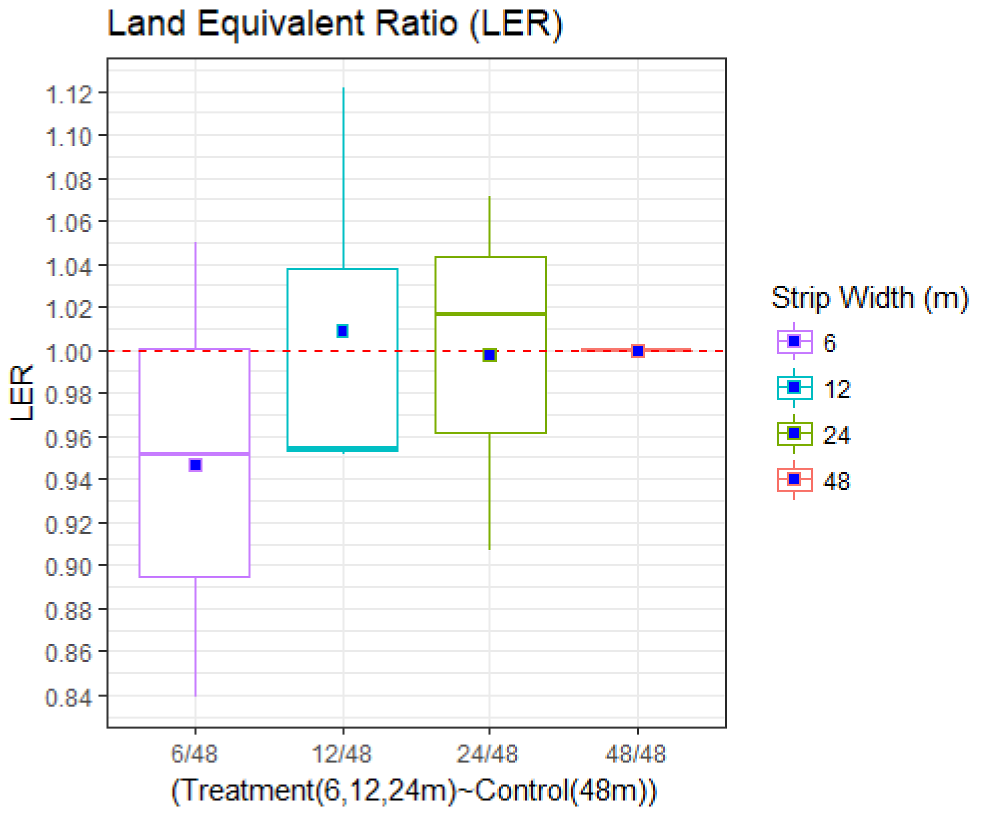



Figure 11. Boxplot showing LER (Land Equivalent Ratio) mean (square dots) and median (bar) values for: Control- 48m (Monocrop) and Treatments- 24, 12, 6m (Strip-cropping); Control (Monocrop) LER (red dotted line) taken as 1.0

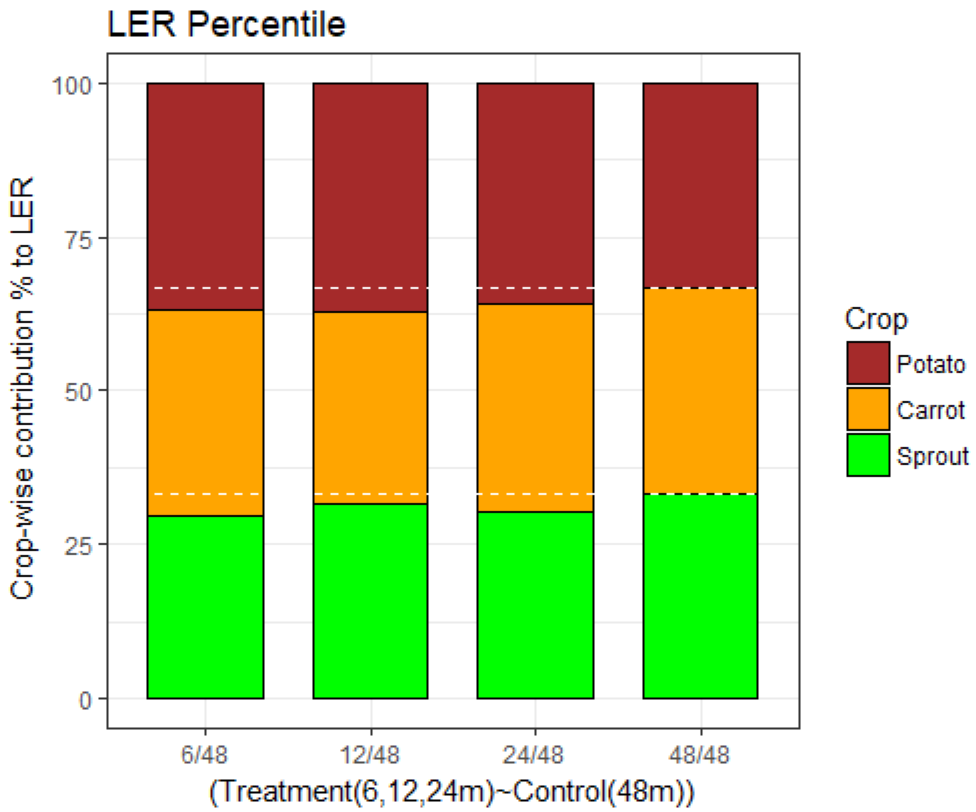


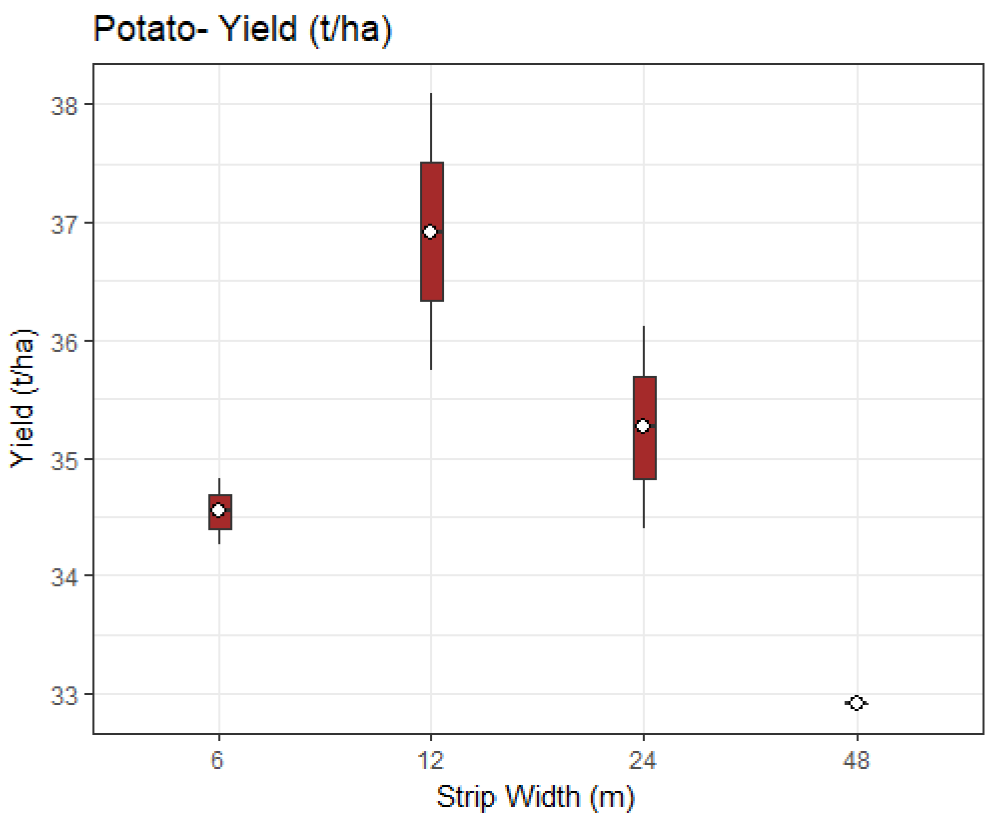

Figure 12. Plot showing crop-wise contribution to LER (Land Equivalent Ratio): Control- 48m (Monocrop) and Treatments- 24, 12, 6m (Strip-cropping); Control (Monocrop) LER taken as 1.0. White dotted line is the marker for the 33% (1/3 for each of the 3 crops) contribution, if there was no variation.

## Potato

Table 10. Effect of Strip-cropping on Potato, Results showing Treatment/Strip width (m)-wise- PLER, Yield, Dry matter (DM) ratio, DM yield; Control (Monocrop) PLER taken as 1.0

| Treatment/ Strip width (m) | PLER | Yield (t/ha) | DM ratio, (DM) | DM Yield (Yield*DM ratio) (t/ha) |
|---|---|---|---|---|
| 48 (Control) | 1.00 | 32.9 [a] | 0.166 [a] | 5.5 |
| 24 | 1.07 | 35.3 (0.046) [c] | 0.162 (0.302) [a] | 5.7 |
| 12 | **1.12** | **36.9** (0.004) [b] | 0.167 (0.678) [a] | **6.2** |
| 06 | 1.05 | 34.5 (0.137) [a] | **0.168** (0.597) [a] | 5.8 |

For each treatment, means (for Yield and DM ratio) in the column are followed by P values; different superscripts are significantly different ($P < 0.05$)



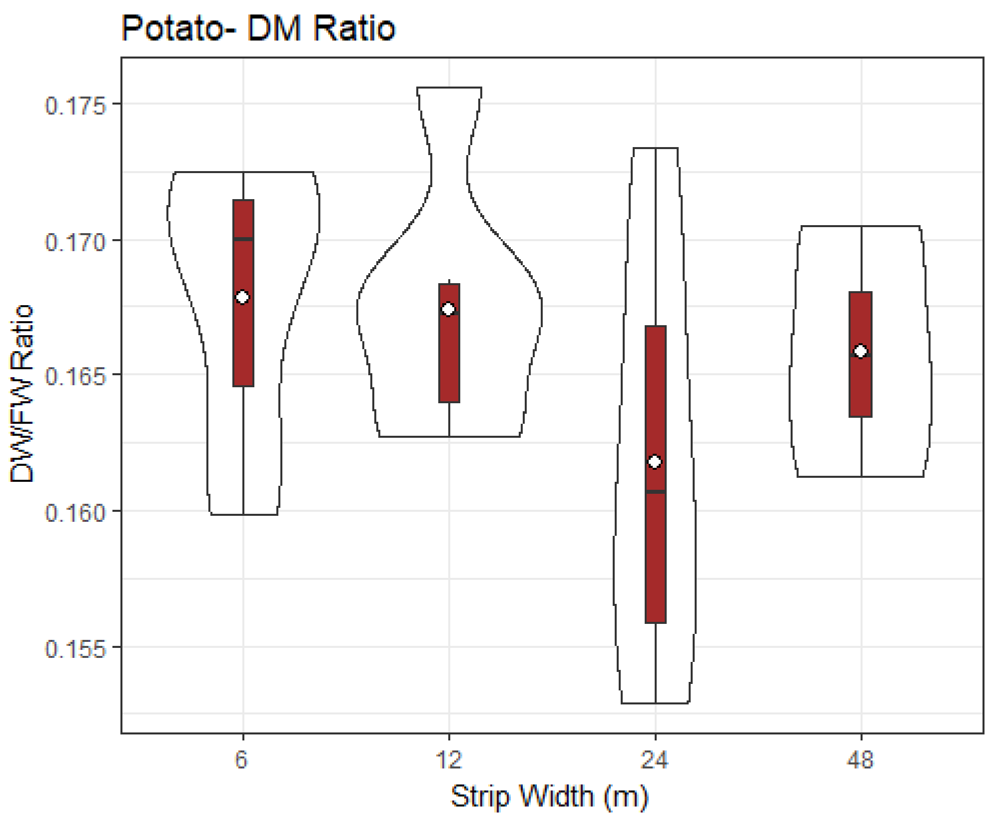




Figure 13. Strip-cropping for Potato- Top- Strip-width (m) ~ Yield (t/ha); Above- Strip-width (m)~DM ratio (Dry Weight/Fresh Weight); Violin plots showing mean (white dots) and median (black bar) values for DM ratios for Treatments-24, 12, 6m strips and Control-48m strip

## Carrot

Table 11. Effect of Strip-cropping on Carrot (hand-harvested), Results showing Treatment/Strip width (m)-wise- PLER, Yield, Dry matter (DM) ratio, DM yield; Control (Monocrop) PLER taken as 1.0

| Treatment/ Strip width (m) | PLER | Yield (t/ha) | DM Ratio | DM Yield (Yield*DM ratio) (t/ha) |
|---|---|---|---|---|
| 48 (Control) | 1.00 | 66.6 [a] | 0.107 [a] | 7.1 |
| 24 | **1.02** | **67.6** (0.854) [a] | 0.111 (0.496) [a] | **7.5** |
| 12 | 0.95 | 63.3 (0.502) [a] | 0.116 (0.067) [a] | 7.3 |
| 06 | 0.95 | 63.3 (0.497) [a] | **0.116** (0.053) [b] | 7.4 |

For each treatment, means (for Yield and DM ratio) in the column are followed by P values; different superscripts are significantly different ($P \leq 0.05$)


Figure 14. Strip-cropping for Carrot- Violin plots showing mean (white dots) and median (bar) values for Treatments- 24, 12, 6m strips and Control-48m strip; Top- Strip-width (m) ~ Yield (t/ha); Above- Strip-width (m) ~ DM ratio (Dry Weight/Fresh Weight)

## Carrot Machine Yield Graph

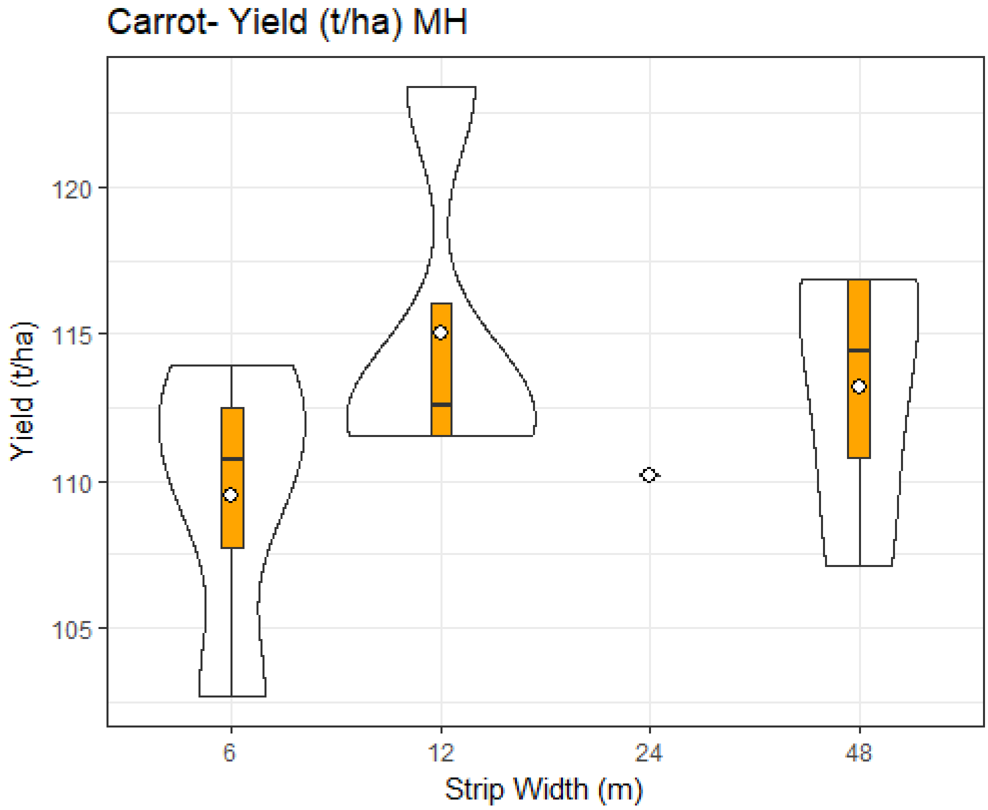


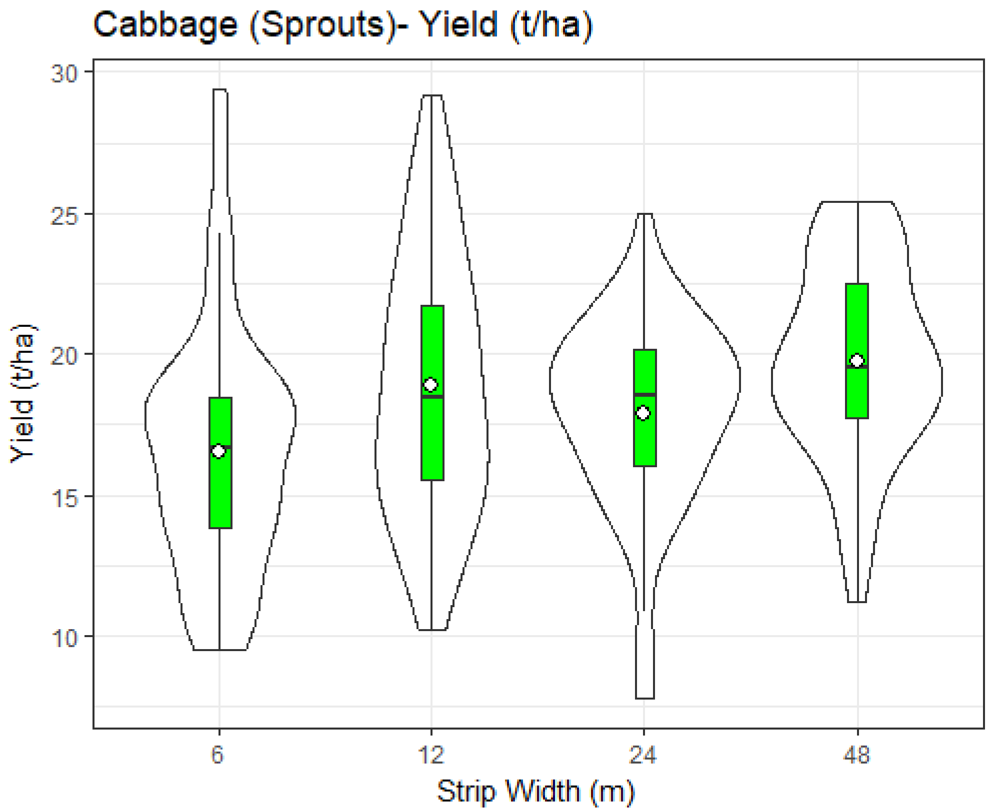

Figure 15. Strip-cropping for Carrot (Machine harvested)- Violin plots for Strip-width (m) ~ Yield (t/ha), showing mean (white dots) and median (bar) values for Treatments- 24, 12, 6m strips and Control-48m strip

## Cabbage (Sprouts)

Table 12. Effect of Strip-cropping on Cabbage (Sprouts), Results showing Treatment/Strip width (m)-wise- PLER, Yield, Dry matter (DM) ratio, DM yield; Control (Monocrop) PLER taken as 1.0

| Treatment/<br>Strip width (m) | PLER | Yield<br>(t/ha) | DM<br>ratio, | DM Yield<br>(Yield*DM ratio)<br>(t/ha) |
|---|---|---|---|---|
| 48 (Control) | **1.00** | **19.7** [a] | **0.153** [a] | **3.0** |
| 24 | 0.91 | 17.9 (0.036) [b] | 0.151 (0.729) [a] | 2.7 |
| 12 | 0.95 | 18.8 (0.289) [a] | 0.150 (0.544) [a] | 2.8 |
| 06 | 0.84 | 16.6 (0.001) [c] | **0**.147 (0.249) [a] | 2.4 |

For each treatment, means (for Yield and DM ratio) in the column are followed by P values; different superscripts are significantly different (P < 0.05)



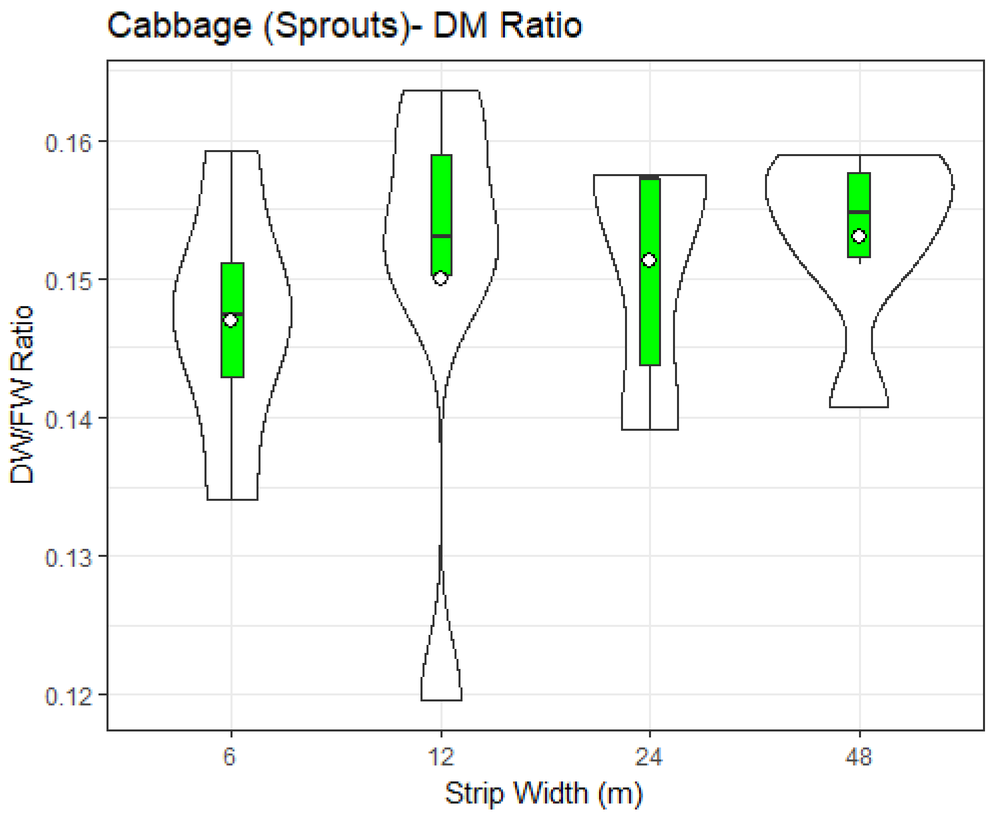




Figure 16. Strip-cropping for Cabbage (Sprouts)- Violin plots showing mean (white dots) and median (black bar) values for Treatments- 24, 12, 6m strips and Control-48m strip; Top- Strip-width (m) ~ Yield (t/ha); Above- Strip-width (m) ~ DM ratio (Dry Weight/Fresh Weight)

## Spinach

Table 13. Effect of Strip-cropping on Spinach. Results showing Treatment/Strip width (m)-wise, Dry matter (DM) ratio.

| Treatment/ Strip width (m) | DM ratio, |
|---|---|
| 48 (Control) | **0.87** [a] |
| 24 | 0.84 (0.512) [a] |
| 12 | 0.77 (0.011) [b] |
| 06 | **0**.85 (0.680) [a] |

For each treatment, means (DM ratio) in the column are followed by P values; different superscripts are significantly different (P < 0.05)

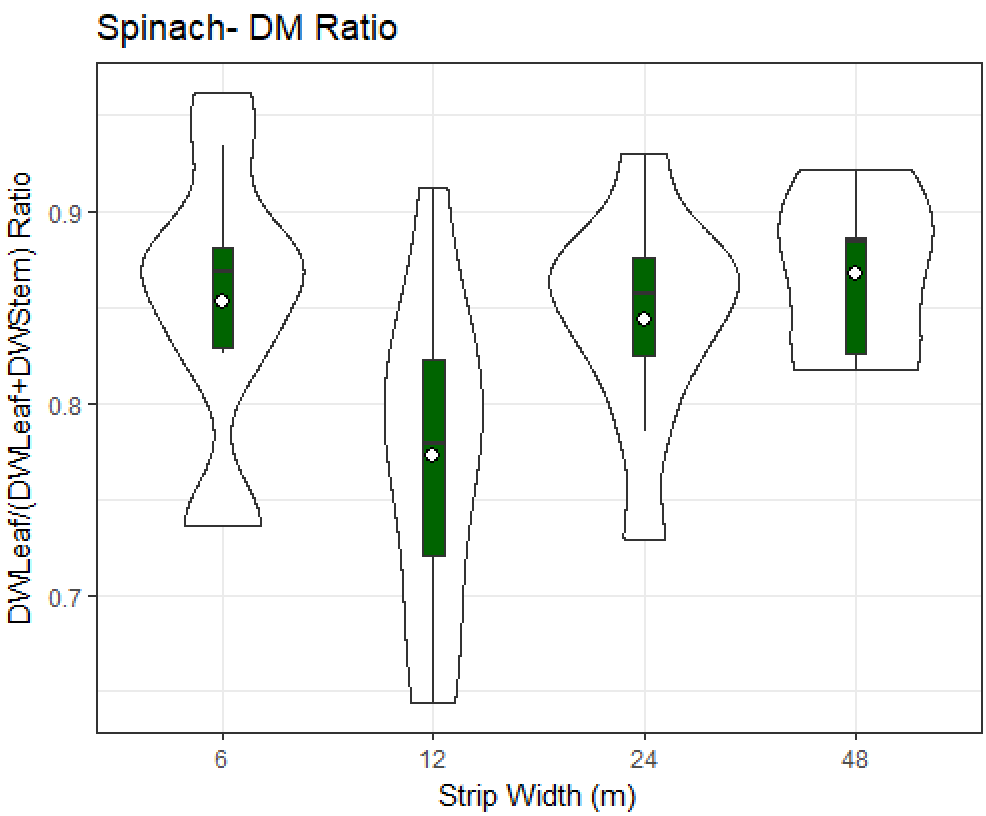



Figure 17. Strip-cropping for Spinach- Violin plots showing mean (white dots) and median (black bar) values for Strip-width (m) ~ DM ratio (DW Leaf / (DW Leaf + DW Stem) for Treatments- 24, 12, 6m strips and Control-48m strip

## References

Chang, Winston. *R Graphics Cookbook: Practical Recipes for Visualizing Data*. " O'Reilly Media, Inc.", 2012.

Wageningen University and Research. 2017.
(http://edepot.wur.nl/177641)