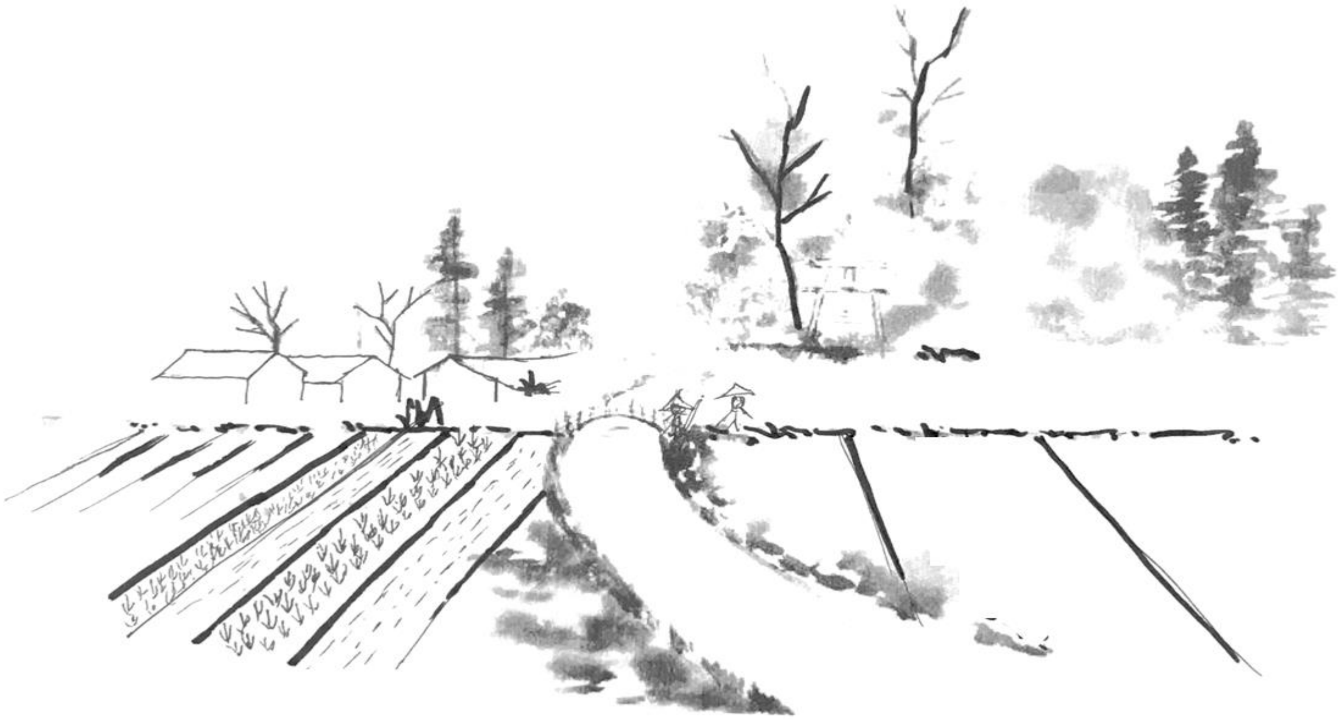
Effects of Strip Diversification on Crop Performance in Strip Cropping System in the Netherlands



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Content

Effects of Strip Diversification on Crop Performance in Strip-Cropping System in the Netherlands

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A B S T R A C T

Strip cropping, as a form of intercropping, allows sufficiently width to conduct separate machinery management on each component crop while remaining sufficiently close to influence each other. Regarded as one of the main diversification methods, strip cropping delivers ecosystem services such as nitrogen supply, yield increases and nutrient uptake in an input-sparse manner. The objective of this study was to evaluate the effects of spatial (strip width) and genetic (strip crop) diversification strategies on crop yield and quality in the strip cropping system. Experiments were conducted in 2018 at four organic farms in the Netherlands. In strip width study, strip cropping system of potato, carrot, and cauliflower was designed to study the influence of a variety of strips widths by 6m, 12m, 24m, and 48m (Control). Results show that potato obtained a significantly higher yield and nitrogen yield in the 12m strips. Carrot and cauliflower showed yield and dry matter yield benefits in the 24m strips. No significant differences were found in DMR of the three crops. In strip crop diversification study, potato and cabbage were treated as main crop species to evaluate diversification influences. Results show that crop yield was strengthened by Strip/Substitute treatment in potato strips, but Strip/Additive treatment was performing adversely on the yield results of potato, wheat, onion, and carrot. No influences were observed on DMR and N content by strip-crop diversification strategy. It is concluded that, in the organic strip cropping system, customizing strip design in terms of spatial (strip width) and genetic (strip crop) arrangements have the potential to strengthen strip crop performance, by selecting appropriate component crops and specific strip width.

1. Introduction

1.1 Problems with monoculture

The agricultural system has substantially benefited from the applications introduced in the last century such as mechanization, synthetic inputs, and biotechnology (Paarlberg and Paarlberg, 2008; Wieland T, 2006). Advanced techniques have extensively increased productivity but also caused other problems in the agricultural sector, such as soil degradation and biodiversity loss, as a direct result of chemical fertilizer and pesticide use. The decline in soil fertility and biodiversity undermined the potential of feeding the growing population in the future (Bruinsma, 2017). Additionally, concerns related to crop quality from monoculture production were also raised by the public (Thomas, 2007). An overall decrease on average mineral (Ca, P, Fe, etc.) and protein content were detected by studies on vegetable and fruit crops in the UK and US between 1930-1980 (White and Broadley, 2005; Davis *et al.*, 2004). The decrease possibly attributes to the extensive chemical uses, declined soil fertility

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and breeding selection towards high-yield hybrids (Murphy *et al.*, 2008).

1.2 Diversification and intercropping

To alleviate the negative effects brought by agricultural modernization and shift the paradigm from industrial agriculture to diversified agroecological farming, diversification of agricultural system is needed (IPES Food, 2016). A variety of new practices were developed from academia and producer-driven bottom-up initiatives (Grasseni, 2018; Fielke, 2015; IPES Food, 2015). Among those, agroecology was regarded as one of the effective means, due to its integration of various approaches to address current challenges in the production system (Wezel *et al.*, 2009). By applying ecological principals in management practices, agroecological designs strengthen ecosystem functions and increase resilience to the production system (Wezel *et al.*, 2014). Agroecology adds more components to the production system, commonly referred to as systematic complexity (i.e. species richness is increased with a favour in ecosystem services) (Loreau *et al.*, 2001). This diversification process is seen as one of the most important rationales in agroecological design to facilitate ecosystem functionality. This process is extensively reflected in agroecological practices, for example intercropping, growing cover crops, and living mulch, which received favourable attention from the scientific field owing to their promising advantages in facilitating ecological functioning (Lin, 2011; Vyas, 1996). Intercropping as the primary method of crop diversification is defined as growing two or more plant species simultaneously on the same plot. It has been reported as an effective way of increasing productivity (Nasri *et al.*, 2014), supporting pest control (Altieri and Nicholls, 2004; Labrie *et al.*, 2016), and contributing in soil fertility (Manna *et al.*,2003). The mechanisms that underpinned intercropping performance include inter and intra-specific plant competition, facilitation, and complementarity. When two plant species can share part of the common resources (radiation, mineral nutrients) in an intercropping system, inter-species competition is mostly lower than the intra-species competition, thus a higher yield index would be expected. Variations in plant architecture and niche differentiation affect resource partitioning at the spatial and temporal level and reduce competition between plants. These effects are suggested to be the primary reason for yield increases in the intercropping system (Hooper, 1998).

1.3 Strip cropping and spatial effects

Among all variations of intercropping, such as mixed cropping and row intercropping, strip cropping has been evolved as a collective practice, formed by the need of maintaining labour efficiency of modern agriculture while improving agrobiodiversity to support ecosystem services. Experiments conducted on strip-cropping showed a promising characteristic of machinery adaptability and facilitated crop interaction which has been regarded as the key to obtaining an increased yield while preserving environmental sustainability (Labrie *et al.*,2016). Within strip cropping systems, the overall crop yield is often the result of multi-factors including strip width, adjacent crop, fertilization scheme and irrigation sufficiency (Singh, 2007). The effects were referred as a strip or spatial effects in strip cropping studies. A review conducted on strip effects from spatial arrangement and crop diversification under the intercropping setups suggested that the individual factor which affects the collective consequences on the system level is not fully comprehended, in spite of the vast amount of studies carried out on crop combination and spatial composition. (Beaurepère, 2016).

The effect occurring on the outer rows in strips is referred to as edge effect, which significantly influences the overall strip effect. Evidence reveals that edge effect impacted on various aspects including pest control (Brandenburg and Kennedy, 1982), yield advancement, and microclimate make-ups at row level (Ghaffarzadeh *et al.*, 1994). In addition, crops grown on the border rows received greater direct influences from their adjacent crops than their fellow crop in the middle rows.

The influencing factors of strip effect were broadly investigated in many aspects. To further facilitate the synergy between agronomy and ecological functionality, the optimal strip width which could directly adapt to current machinery while giving the best crop performance was investigated. Yield production of soybean was improved on 18m width of strip compared to 36m and 180m (control) in a previous study (Labrie, 2016). A potential increase in the yield by adjusting was evidenced for some crops. However, a wide range of crop species has yet to be investigated. Moreover, there is a knowledge gap on the extent to which to strip width diversification may affect strip performance, and whether the influence would also make a difference on edge effect; therefore, further study should proceed in this topic (Beaurepère, 2016).

Besides strip width, diversifying crop composition within strips also plays a key role in co-shaping strip effects. Most researchers followed a diversification design suggested by Vandermeer (1989), which is an additive approach that supports niche differentiation, ultimately lowering inter-specific competition (Santos, 2002). By applying this diversification design, most studies tested two plant species with single cultivars as a substitute crop or additive crop (Jalilian, 2017; Ghaffarzadeh, 1994). Little studies have been conducted on a multi-species/cultivar diversification strategy. Therefore, there remains uncertainty as to whether adding cultivars in single species strips could improve crop performance by differentiating each cultivar's system functioning. Furthermore, the influences from constructed cultivars on modifying edge effects in strips should be further investigated by analysing the result on the row level. Through answering these questions, insights about crop diversification in strip cropping could significantly benefit farmers and even accelerate the promotion of strip cropping concept. Besides, via comparing crop yield on edge rows from varied strip width and crop species/cultivar construction, a general idea of crop competition level with neighbouring crop and influencing factor should be developed.

1.4 Objectives and research questions

This study focuses on both strip width influence and strip crop diversification strategy, by exploring primary crop species in the Netherlands, specifically, potato (*Solanum tuberosum* L.), cabbage (*Brassica oleracea* L. var. *capitata*), wheat (*Triticum aestivum* L.), carrot (*Daucus carota* L.), onion (*Allium* L.), cauliflower (*Brassica oleracea* L. var. *botrytis*), parsnip (*Pastinaca* L.) and leek (*Allium porrum* L.). These crops are of great importance, evidenced by the extensive growing area, and large consumer group (Potato Pro, 2019; Holland Food Trade, 2019). Going from the broader system influences of strip effect to lower level interaction of edge effect, this study tries to address the current knowledge gap in strip crop research. The primary objective of this research was to investigate the strip effects from spatial (strip width) and genetic (strip crop) diversification on crop yield and quality factors. In addition, the secondary focus was to evaluate edge effect on the row level as the reflection of crop competition to reveal the potential good companion crops for strip cropping system. Therefore, the research questions are: (1) What are the effects of strip width on crop performance for each crop species and is there a certain strip width which benefits crop the most in terms of yield and quality factors? (2) What are the effects of strip crop diversification (multi-species/cultivars) on strip crop performance in terms of yield and quality factors? (3) How do the edge effects affect crop yield by varied neighbouring crops?

2. Material and method

2.1. Site and climate conditions

This study was conducted in four organic farms in the Netherlands: the experimental field at Zeewolde (52°35'58.56" N, 5°49'12.24"E) from the entrepreneurial farm of B.V ERF, the Droevendaal experimental farm at Wageningen (51°59'33.06" N, 5°39'43.56" E), the Broekemahoeve experimental farm at Lelystad (52°32'23.70"N, 5°33'44.92"E) and the organic farm at Strijen (51°46'20.68" N, 4°29'14.25" E). With a temperate maritime climate, the normal annual average precipitation is 847.2 mm in the Netherlands (KNMI, 2017). In 2018, the annual precipitation is 675.3 mm (KNMI, 2018), reported as the top 5 percent driest year (Pieters, 2018). The annual weather description provided by KNMI (Royal Netherlands Meteorological Institute) is "Extremely warm, extremely sunny and very dry" (KNMI, 2019). Experimental and agronomic aspects of the field information are present in Table 1.

Table 1 Overview of farms involved in this study and crop rotation in each farm.

Farm	Type	Area	Soil type	Crop in the rotation in 2018	Experiment
ERF	Organic	50 ha	Clay	Grass, grass, spinach, potato, cauliflower, carrot	strip width
Droevendaal	Organic	6.18 ha	Sandy	Grass, grass, cabbage, leek, potato, wheat	Strip crop
Broekemahoeve	Organic	1.84 ha	Light clay	Grass, cabbage, onion, potato, wheat, carrot	Strip crop
Strijen	Organic	2.7 ha	sandy clay loam	Grass, pumpkin, parsnip, leek, cabbage	Edge effect

2.2 Experimental design

2.2.1 Strip width

The field experiment of strip width was carried out in Zeewolde, on the production land (500m*1000m) of B.V ERF. Two- year grass, spinach, potato, carrot, and cauliflower were grown in rotation on the field. Spinach (*Spinacia oleracea* L.) was not included in this study as it was prematurely yellowed due to the excessive heat and drought in 2018. For this study, three widths of strips were explored, the width of 6m (~8 rows), 12m (~16 rows), 24m (~32 rows), which could accommodate the tractor width commonly used in the Netherlands. The control treatment was designed in 48m (~64 rows) width. The distance between rows is 0.75m in each strip. The experiment followed a complete randomized design with three strip width treatments and two replicates. An extra 6m strip was sowed for the first year next to control plots. Next to cauliflower strips (*Brassica oleracea* L. var. *botrytis*), a 3-meter flower strips with mixed varieties were grown to provide a natural habitat for the beneficial insect. The first and last 100m strips were taken as a buffer zone to avoid border effects. Random sampling locations were generated by R studio 3.5.1 (R core team, 2018). The layout of experimental design can be found in Appendix A.

2.2.2 Strip-crop diversification

The field experiments of strip-crop diversification were conducted on Droevendaal and Broekemahoeve experimental farms. The experimental design followed the principles of diversification suggested by Vandermeer (1989), namely Strip/Additive and Strip/Substitute treatments. The mechanisms involved in the two designs provide potential benefits from niche differentiation and plant facilitation in strip cropping system (Vandermeer,2011). Strip/Additive treatment was designed as adding extra legume species in the strips, while Strip/Substitute was composed by replacing part of the primary crop cultivar with other cultivars. Strip/Mono was set as reference strip treatment with primary cultivar of each crop species to compare the performance of strip treatments. Monoculture of each crop cultivar was planted as Control to provide comparisons between strip cropping and monoculture system. Two study sites followed an incomplete randomized design with three strip-crop treatments (Strip/Mono, Strip/Additive, and Strip/Substitute) and one Control treatment. Control plots were planted only in Droevendaal farm. The experimental area from two sites was divided into four blocks (Droevendaal × 3 blocks and Broekemahoeve × 1 block) and each block was designed with three strip-crop treatments with two replicates (3 treatments × 2 replicates). The first and last 10m strips were taken as a buffer zone to avoid border effects. The detailed information on strip-crop treatments for each crop was shown in Table 2.

In potato strips (*Solanum tuberosum* L.), Strip/Substitute was planted with primary cultivar *Agria* in row 1 and 4 and substitute cultivar *Alouette* and *Carolus* in row 2 and 3, respectively. The substitute cultivars were selected due to their higher resistance of late blight and robustness (AHDB, 2019). In Strip/Additive treatment, red clover was used as green manure grown in grass strip next to potato. In cabbage strips (*Brassica oleracea* L. var. *capitata*), Strip/Substitute was planted with primary cultivar *Rivera* in row 1 and 4, with substitute cultivar *Christmas Drumhead* (CD) grown at 1:8 replacement ratio in row 2 and 3. Cultivar CD was treated as sacrificial cabbage, aiming to attract pest herbivores and thereby protect *Rivera* cabbages (Altieri 1994; Poelman 2009). The legume species in wheat and grass strips were chosen based on the resource capture complementarity (Vandermeer, 2011). The layout of experimental design can be found in Appendix A.

Table 2 Information of crop species and cultivars used in strip crop diversification experiment in Droevendaal and Broekemahoeve. Except for grass strips, all crop strips were provided by cultivar names.

Farm	Crop	Species/Cultivars				
		Reference	Strip/Mono	Strip/Additive	Strip/Substitute	Strip Width/ Rows
Droevendaal	Potato	Agria	Agria	Agria	Agria/Alouette/Carolus	3m/4 rows
	Grass	Ryegrass	Ryegrass	Ryegrass/Red clover	Ryegrass/Fescue	3m/4 rows
	Cabbage	Rivera	Rivera	Rivera	Rivera/Christmas Drumhead	3m/4 rows
	Wheat	Lennox	Lennox	Lennox/Fava	Lennox/Lavette	3m/4 rows
Broekemahoeve*	Potato	NA	Ditta	Ditta	Ditta/Carolus	3.15m/4 rows
	Grass	NA	Ryegrass	Ryegrass/Red clover	Ryegrass/Fescue	3.15m/4 rows
	Cabbage	NA	Rivera	Rivera	Rivera/Christmas Drumhead	3.15m/4 rows
	Wheat	NA	Lennox	Lennox/Fava	Lennox/Lavette	3.15m/4 rows

Onion	NA	Hylander	Hylander	Hylander/Hytech	3.15m/4 rows
Carrot	NA	Komarno	Komarno	Komarno/Yara	3.15m/4 rows

*Potato, onion, and carrot in Strip/Substitute treatment at Broekemahoeve site only had two cultivars on row 1, 2 and 3, 4 respectively.

2.2.3 Strip edge effect

Data collected for each crop in strip width experiment and strip-crop experiment was used for edge effect comparison. Edge rows (Strip/Edge) and middle rows (Strip/Middle) were taken as two treatments for each crop, analysed on effects of varied neighbouring crops. Strip cropping experiment conducted at Strijen was included in this analysis. Crop species included parsnip (*Pastinaca* L.), leek (*Allium porrum* L.), and cabbage (*Brassica oleracea* L. var. *capitata*), which were planted with grass in two alternating strips. Strip width in this site was 3m with 4 rows in between. Two strips for each crop were measured 6m on each row.

2.3 Yield

In the strip width experiment, the yield of strip width treatments was measured by 6m harvesting on two edge rows and one middle row (6 m × 0.75 m × 3 rows). Control plots were measured by 6m harvesting on three middle rows for each crop (6 m × 0.75 m × 3 rows). In the strip-crop experiment, except for cabbage in Broekemahoeve, yield was measured by the whole strip length on each row (Strip length × 0.75 m × 4 rows) for each crop. Control field was measured by whole strip length with four middle rows for each crop (Strip length × 0.75 m × 4 rows). Cabbage in Broekemahoeve was measured by the sum of 10 cabbages' head weight, harvested by every 10th cabbage. Detailed harvest schemes can be found in Appendix B. Fresh yield of each crop was evaluated by a pull scale or portable car scale on site. Additionally, the yield of a crop within the strip cropping system divided by crop yield of monoculture was defined as yield ratio (YR) in this study to compare crop productivity on an independent crop of interest in a strip cropping system. The equation (1) below showed the calculation of YR, where *Yi* represents the yield of a species within the strip and *Ym* represents the yield of monoculture. Yield Ratio higher than 1.0 indicates that strips provide higher yields than sole crop.

$$Yield\ Ratio = \frac{Yi}{Ym} \qquad (1)$$

2.4 Grading

Potato, onion, carrot, parsnip, and leek were graded into different classes according to local market standards. Only potato's sample amount was sufficient to be assessed and thereby included in this study. Information of classification for other crops can be found in Appendix C. Potato tubers were graded into four categories by diameter: category C1 for potatoes below 35mm; C2 for sizes between 35mm and 50mm; C3 for those between 50mm and 70mm and C4 for those above 70mm. The yield of categories C2-C4 was considered as marketable yield. Potato grading was done by sorting machine

2.5 Dry matter ratio

Subsamples of 5-10 kg per row in each experiment were taken from total harvest for crop quality assessments. Crops (400-500 g) from each subsample were cleaned and weighted for fresh weight (*FW*). After slicing into small pieces, samples were oven-dried at 70 °C for 72 hours to a constant dry weight (*DW*). Dry Matter Ratio (DMR) was calculated by equation (2).

$$Dry\ Matter\ Ratio = \frac{DW}{FW} \qquad (2)$$

2.6 NPK content

Samples were also analysed by nitrogen, phosphorus, potassium (NPK) content as quality assessment in this study to describe the influence of treatments on nutrition content in each crop type. Total nitrogen, phosphorus, and potassium were measured in the lab after DMR was measured. The oven-dried samples were ground in a milling machine with a 2 mm sieve. The milled samples were further processed in the lab, followed crop chemical analysis protocol presents in Appendix I. Total NPK content was present by percentage of total weight of the processed sample (%).

2.7 Data analysis and statistics

Statistical analysis in this study was conducted in R Studio 3.5.1 (R core team, 2018). Yield, marketable yield, grading, DMR, NPK content were analysed by Linear mixed-effects model (LMMs) with *lme4* package (Bates *et al.*, 2014). Treatments in each experiment were selected as the fixed effects, while blocks, cultivars were selected as random effects according to context. Response variables were set to each measured factor in each experiment. Multiple comparisons was conducted with *multicomp* package by Tukey's method as a post-hoc test (Bretz *et al.*, 2010). Normality of data was assessed by Shapiro-Wilk Normality Test (Shapiro and Wilk, 1965). The result of analysis focused on potato (*Solanum tuberosum* L.), carrot (*Daucus carota* L.), and cauliflower (*Brassica oleracea* L. var. *botrytis*) in strip width experiment, and potato (*Solanum tuberosum* L.), cabbage (*Brassica oleracea* L. var. *capitata*) in strip crop diversification experiment. Other crops from four sites were used as explorative data which explained briefly. The statistical model used is provided in Appendix D

3. Result

3.1 Strip width

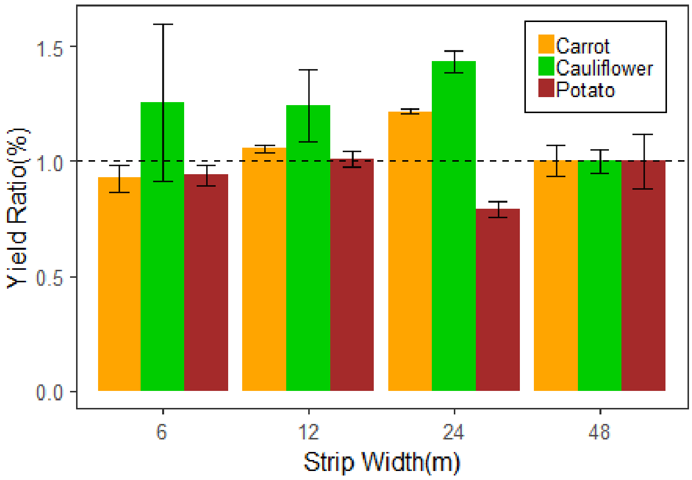

Figure 1 Yield Ratio of potato (purple), carrot (orange) and cauliflower (green) in 6m, 12m, and 24m strips. Yield ratio of crops was calculated by samples collected on the middle rows in 6m, 12m, 24m strips, divided by the yield of mono(48m) strip. Yield Ratio ± standard error was calculated and presented by error bar in the figure.

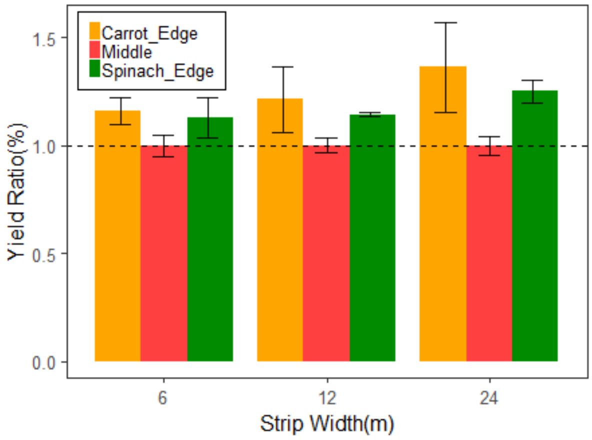

Figure 2 Yield ratio of carrot edge (orange), spinach edge (green), and middle rows (red) in potato strips at 6m, 12m, and 24m treatments. Yield ratio was calculated by taking yield at middle rows of each treatment as the reference and divided by yield in carrot edges and spinach edges.

In potato strip, tuber fresh yield for 6m, 12m, 24m, and 48m (Control) strips corresponded to (2.85 ± 0.11 kg/m^2), (3.13 ± 0.16kg/m^2), (2.63 ± 0.19 kg/m^2) and (2.76 ± 0.32 kg/m^2), respectively. No significant differences were found in potato' fresh yield between treatments. With the increased strip width, the yield difference between edge rows and middle rows in potato strips increased, indicating an influence caused by the strip width (Figure 2). A similar potato response was found on DMR, as no significant differences were found between treatments. However, for the 48m (19.64 ± 0.34 %), and 6m (19.59 ± 0.41 %) strips, DMR tended to be higher than 12m (19.00 ± 0.24 %), and 24m (18.85 ±

0.21 %) strips. Dry matter yield (DMR × Fresh yield) varied between 0.50 and 0.59 kg/m2. N and K content had no significant difference across treatments. The nitrogen yield (N content × Fresh yield) was significantly higher in 12m (0.046 ± 0.0023 kg/m2) strips compared to 24m strips (0.039 ± 0.0027 kg/m^2), which were corresponded to the highest and the lowest nitrogen yield found. All strip treatments (6m, 12m,24m) had significantly higher P content in potato tuber compared to the Control strip (48m). Tables of detailed results of potato, carrot, and cauliflower can be found in Appendix E

Carrot had no significant differences in yield result between treatments. The yield tended to be higher in the 24m (6.19 ± 0.31 kg/m^2), followed by 48m (5.80 ± 0.39 kg/m^2), 6m (5.20 ± 0.16 kg/m^2) and 12m (4.37 ± 0.56 kg/m^2) strips. No significant differences in the DMR was found between treatments. Nitrogen content for 6m, 12m 24m and 48m treatments corresponded to 1.36 ± 0.039 %, 1.40 ± 0.038 %, 1.39 ± 0.061 % and 1.49 ± 0.10 % respectively, and no significant differences were observed. Dry matter yield and nitrogen yield tended to be higher in the 24m strips, with 0.74 ± 0.033 kg/m^2 and 0.086 ± 0.005kg/m^2 correspondingly. P and K content was tended to be higher in the 48m strip, by 0.28 ± 0.0097 % and 3.72 ± 0.16 % respectively, whereas no significant differences were observed between treatments.

Significant differences in cauliflower strips were observed between the 24m treatment (2.04 ± 0.20 kg/m^2) and the 12m treatment (1.28 ± 0.13 kg/m^2), which corresponded to the highest and the lowest yield obtained. Other treatments showed no significant differences. DMR was varied between 8.15 and 8.91% showing no differences. Dry matter yield was significantly different between the highest treatment of 24m (0.18 ± 0.020kg/m^2) and the lowest of 12m (0.10 ± 0.010 kg/m^2). Nitrogen content was ranged from 3.16 to 4.40 % and tend to be higher in the 12m treatment and lower in the 48m. No significant differences were observed on N, P, content, while the K content was significantly higher in the 12m strip (4.32 ± 0.099 %) when compared with the 6m (4.02 ± 0.065 %) and the 24m (3.95 ± 0.150 %) strips.

3.2 Strip-crop diversification

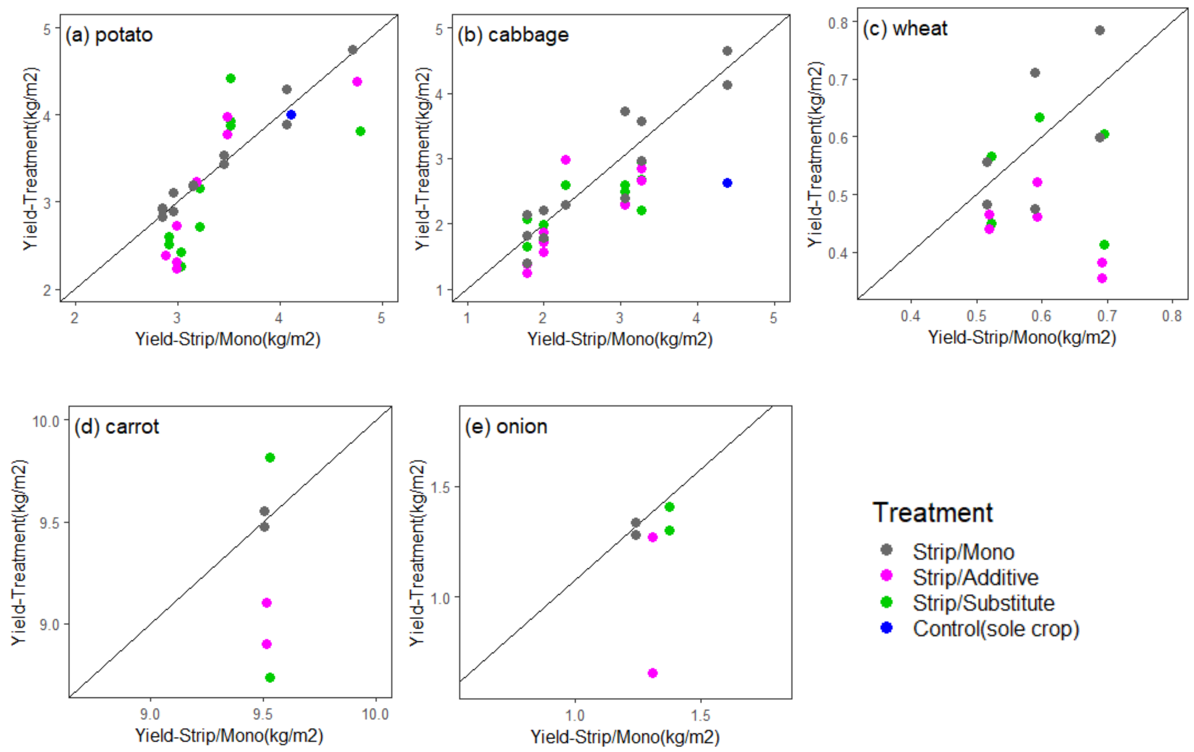

Figure 3 The fresh yield of (a) potato, (b) cabbage, (c) wheat, (d) carrot, and (e) onion grown in strip crop diversification experiments. X axis used Strip/Mono treatment yield as reference compared with other treatments in the same field to remove field variance. Lines (x=y) in the graphs represent the performance boundary where treatment yield equal to yield at Strip/Mono treatments. Points located above the line means other treatments yield is higher than Strip/Mono treatment.

In potato strips, significant higher yield was found on Strip/Substitute (3.30 ± 0.16 kg/m^2) and Strip/Mono treatments (3.09 ± 0.10 kg/m^2) compared with Strip/Additive treatment (2.86 ± 0.14 kg/m^2), whereas Control (3.03 ± 0.16 kg/m^2) showed no significant difference with other strip treatments. No difference was found on marketable yield (class C2-C4) of potato tuber between treatments, but Strip/Substitute (45.72 ± 3.93 %) and Strip/Mono (43.61 ± 1.92 %) had a significantly higher amount of class C3-C4 (tuber size >50mm) than Strip/Additive (30.05%). Dry matter ratio (DMR) was in the range of 21.29-22.05%, which had no significant differences. As for dry matter yield, a significant difference was found between Strip/Substitute (0.70 ± 0.033kg/m^2) and Strip/Additive (0.60 ± 0.028 kg/m^2), which corresponded to the highest and the lowest dry matter yield obtained. The nitrogen content in treatments was in the range of 1.32-1.39%, showing no significant differences. Likewise, P content (%), and K content (%) showed no significant differences between strip treatments, while P content was significantly higher in the Control field than strip treatments. Tables of detailed results of potato and cabbage can be found in Appendix F.

Cabbage yield was significantly lower in Reference (1.05 ± 0.05 kg/m^2) compared with strip treatments. Though no significant difference was found, Strip/Mono (2.70 ± 0.17 kg/m^2) showed higher yield than Strip/Substitute (2.54 ± 0.12 kg/m^2) and Strip/Additive (2.31 ± 0.14 kg/m^2). DMR was in the range of 9.47-9.61%, with no significant difference. As for dry matter yield, Control (0.11 ± 0.006 kg/m^2) was significantly lower than Strip/Mono (0.26 ± 0.017 kg/m^2), Strip/Substitute (0.24 ± 0.010 kg/m^2) and Strip/Additive (0.23 ± 0.012 kg/m^2). A significant higher N content was observed on Strip/Additive (2.62 ± 0.052 %), compared with Strip/Substitute (2.42 ± 0.042 %), Strip/Mono (2.34 ± 0.046 %), and Control (2.22 ± 0.12 %). Due to the significant lower fresh yield in the Control field, total nitrogen yield was also lower (0.024 ± 0.003 kg/m^2) compared to other strip treatments, ranging from 0.059 to 0.062 kg/m^2. P content was found higher in Strip/Mono (0.43 ± 0.0064 %) treatment compared to Strip/Additive (0.40 ± 0.0061 %), while no significant differences were found on K content between treatments.

Figure 3 showed potato, cabbage and other crops investigated in strip-crop diversification experiment. The figure presents the fresh yield of Strip/Mono treatment on X-axis and other treatments on Y-axis to compare strips performance. The yield of each treatment was calculated by the mean yield of on each field to remove field effect. After standardised result on each field, the yield of Strip/Substitute had similar performance with Strip/Mono in each crop. For Strip/Additive, lower yield was found in wheat, onion, and carrot strips. The points on the reference line (x=y) indicates the same performance between treatments and Strip/Mono. The points above/below the line indicates treatment provide a higher/lower yield than Strip/Mono treatment.

3.3 Strip edge effect

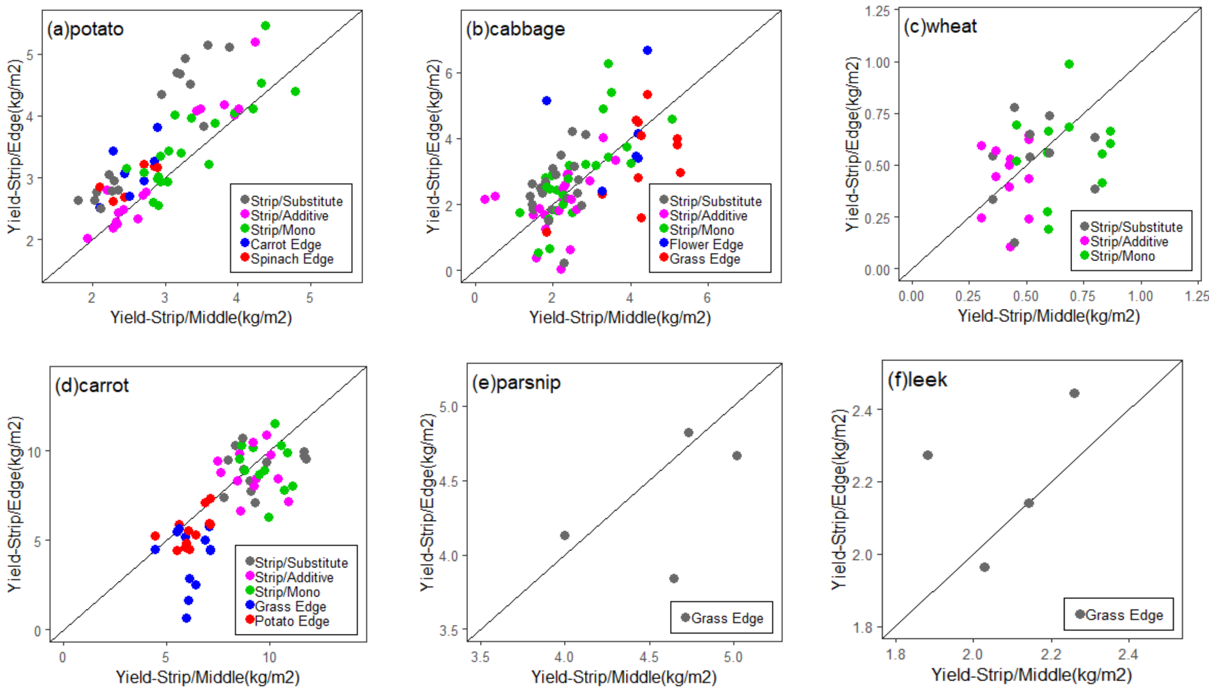

Figure 4 Yields of (a) potato, (b) cabbage, (c) wheat, (d) carrot (e) parsnip and (f) leek, at Strip/Edge and Strip/Middle with different neighbouring crops. Strip/Middle is the middle rows in the strips and Strip/Edge is the edge rows in a strip. Strip/Substitute (grey), Strip/Additive (pink) and Strip/Mono (green) were subtracted from strip-crop experiment. “X Edge” indicated neighbouring crop of the investigated crops. Lines (x=y) in the graphs represent the performance boundary where the yield of Strip/Edge equal to the yield of Strip/Middle. Points located above the line represent the yield at Strip/Edge is higher than yield at Strip/Middle.

The fresh yield of Strip/Edge and Strip/middle of each crop with different neighbours is shown in Figure 4. Strip/Middle represented the middle rows in strips and Strip/Edge represented the edge rows in a strip. In potato strips, edge rows, regardless of its neighbouring crop, showed higher yield than middle rows. Strip/Substitute and Strip/Mono showed 35.26% and 5.35% significant higher yield in edge rows than middle rows, respectively. Edge rows in Strip/Substitute were 3.4% higher than the edges in Strip/Mono. Strip/Substitute had significant higher DMR on the edge rows (22.26%) compared to the inner ones (21.08%). Nitrogen content also significantly different in Strip/Substitute by 1.25% on the edge and 1.50% on the middle. In ERF experimental field, both carrot edge (3.11 ± 0.17 kg/m^2) and spinach edge (2.95 ± 0.11 kg/m^2) in potato strips showed significantly higher yield compared to the middle ones (2.54 ± 0.11 kg/m^2). DMR and total nitrogen content had no significant differences on the row level. Tables of detailed results of potato, carrot, cauliflower and cabbage can be found in Appendix G.

In cabbage species (*Brassica oleracea* L.), white cabbage showed less differences on edge and middle rows, as only Strip/Substitute showed significantly higher yield on edge (2.49 ± 0.20 kg/m^2) than the middle (2.08 ± 0.10 kg/m^2). Other neighbours showed no significant differences between the edge and middle. The cauliflower strips tended to have a higher yield on grass edge (2.06 ± 0.25 kg/m^2) but not significantly different with the flower edge (1.80 ± 0.27 kg/m^2) and middle rows (1.77 ± 0.19 kg/m^2).

The carrot strips consistently showed a higher yield in the middle rows with varied neighbours. Strip/Substitute had significant higher DMR on the edge rows (13.30 ± 0.22 %) than the inner ones (12.49 ± 0.20 %). No significant difference was observed in N content. In ERF, carrot yield on the row level had no significant difference between grass edge (4.02 ± 0.49 kg/m^2), potato edge (5.56 ± 0.27 kg/m^2) and middle rows (6.18 ± 0.23 kg/m^2). DMR was higher in grass edge (12.40 ± 0.12 %) than potato edge (11.77 ± 0.19 %), but no significant differences between the middle (11.88 ± 0.18 %) and edges. N content showed no difference.

Wheat had no difference in yield between the border and middle rows with varied neighbours. N content was significantly higher in edges of

Strip/Substitute (edge: 2.73%, middle: 2.46%) and Strip/Additive (edge:2.31%, middle: 2.02%). No differences in yield or quality factors were showed in Strip/Mono neighbouring setting. Parsnip had a lower yield on the edge rows (4.37 kg/m^2) compared to the middle ones (4.60 kg/m^2). N content was significantly different on middle rows (1.11%) and edge rows (0.96%). Leek shown higher yield obtained on edge rows (2.20 kg/m^2) whereas the difference with middle rows (2.08 kg/m^2) was not significant.

4. Discussion

4.1 Strip width

The highest potato yield was found on the 12m strips. This was in accordance with the study of Sondh (2018), the same experiment conducted in 2017 in ERF. With the increased strip width, an increasing difference of edge-middle yield in potato strip was observed, indicates presents of strip effect. The similar range of dry matter yield suggests a roughly equal dry matter accumulation in different strips, which comes from the total radiation interception.

Strip width affects total water uptake of crops on the strip level indicated by varied DMR value. The 12m and 24m had lower DMR which possibly contributes to yield benefits. Low DMR is corresponded to more water content in potato tuber which mostly attributes to the higher soil moisture content. As reported widely, potato yield and quality are highly dependent on soil moisture which affects the water uptake (Onder *et al.*, 2005). Potato yield can decrease proportionally to water uptake according to Costa *et al.* (1997). The reasons for water-dependent potato yield are often attributed to its shallow and sparse root zone (Opena and Porter, 1999; Rud *et al.*, 2014). However, due to the limited research on strip width effect in potato strip cropping system, the difference in soil moisture occurred by strip width cannot be fully answered. The neighbouring crop strip can also affect soil moisture content in potato strips. Researches conducted on soil water competition and compensation in the intercropping system show that the differences in soil water were highly related to sowed species, as the greatest difference is found in wheat-maize intercropping and lowest in soybean–wheat intercropping (Chen *et al.*, 2014). No researches have been conducted on a similar topic in potato strips yet. Therefore, further researches are suggested on this topic which could help in revealing hidden mechanisms of yield benefit of 12m strips. As researchers suggest soil N is more readily exploited by crops in high soil moisture (Denmead and Shaw, 1962; Costa *et al.*, 1997, Chen *et al.*, 2014), the higher N content found in the 12m and 24m strips confirmed the assumption of higher soil water, which should be the main reason for yield and N content differences between treatments.

Carrots' fresh yield, dry matter yield, and nitrogen yield are consistently tended to be higher in the 24m strips, which accords with the findings of Sondh (2018). No significant difference of DMR was discovered while a decrease was observed with increased width of carrot strip. This confirmed the result obtained last year (Sondh, 2018). P and K content had no significant difference in strips, but both measured the highest on reference strip (48m). The carrot grown in ERF served the industrialized production purpose and would be further processed into carrot chips according to the information from management staff in ERF.BV (J. Swagmakers, personal communication, November 16, 2018). A higher DRM can contribute to better *Carrot-taste* perception in the sensory study, which may lead to a higher liking rate from consumer perception (Haglund *et al.*, 1998). The DMR result was found highest on 6m, 12m in Sondh's study in 2017 and 12m in this study (2018), a small strip of carrot might contribute to higher DMR value.

In cauliflower strips, fresh yield and dry matter yield were significantly higher in the 24m strips compared to the lowest result on the 12m strips. No significant differences were found in other quality factors. The insignificant results were highly attributed to the field variances, mis-conducted field management, and limited sample sizes. Field variances include a significant variation in mature time of cauliflower. When samples were harvested on 18th of October 2018, cauliflowers in the 6m strips were still in the early head formation stage. Only 24m strips showed filled head. The reason for late maturation in the 6m strip may include the influence of first-year cauliflower planting in block 3, as other blocks and strips were grown in the rotation for years. In addition, field variance also displayed by smaller plant sizes in the southern part of the experimental area, which was observed by management personnel. A flower strip near the 24m strips was miss-sowed, as the cauliflower strip was extended to 27m, thereby contributed in an inconsistent experimental setting. Sample sizes were limited due to the rush harvest in sampling date, so no replicates on each row were harvested.

Cauliflower results also affected by the 3-meter flower strips planted adjacently. The flower strips were planted to sustain the benefits of natural pest control as sugar source and habitat were provided for parasitoid wasps and other predators of pest affecting *brassica* crops. However, an observation found mostly higher insect damage and smaller plant size on the cauliflower crops near flower strips. The higher insect damage may have been caused by herbivorous species which were favoured by flower strips (Géneau *et al.*, 2012). The smaller plant size is presumably due to the inter-specific plant competition between flowers strip and neighbouring cauliflowers, as a certain degree of shading provided by higher flower plants. Less radiation interception caused by shading influences plant dry matter accumulation. The effect of soil water competition between flower strips and cauliflower was not studied previously. It is possible that there was a lowered soil moisture on cauliflower strips exerted by flower strips, and lead to a lowered growth rate (Denmead and Shaw, 1962). There was no clear conclusion about the effects of flower strips on the cauliflowers in this study. Therefore, further study can be conducted to explore the effects of flower strips and varied strip width on cauliflowers.

Overall, there was limited research conducted on strip width effects in potato, carrot, and cauliflower intercropping system. No clear conclusion about the impacts of strip width can be made. A strip width experiment conducted on soybean-wheat-corn intercropping system confirmed that soybean aphid abundance was lowered in strips (18m and 36m) compared to control plots (180m), while no clear conclusions are made on strip width effects (18m and 36m). The climate in 2018 was extreme compared to the previous year. Though the irrigation was applied regularly during the study period, the field may still be under water stress and influenced results reliability. A study shows the different timing of water stress in potato growing period result in different Water Use Efficiency and total N uptake (Costa *et al.*, 1997). It should be considered that environmental influence may alter the plant interactions and change the inter/intra-specific competition balance in the strip cropping system (Brooker *et al.*, 2015). In addition, the higher reference evaporation rate of grass strip may even increase the water stress on the strips grown adjacently (carrot and cauliflower in this case) (Allen *et al.*, 1998). Due to the large growing area (500m×1000m) and field differences, the variance in results should be expected and thereby the absolute value of yield might be skewed by the local heterogeneity.

4.2 Strip crop diversification

Potato yields and the number of class C3-C4 (tuber size > 50mm) were found higher in Strip/Substitute and Strip/Mono treatments, while lower in Strip/Additive treatment. Other quality factors like DMR and NPK content showed no significant differences between treatments. The reasons for the higher yield in Strip/Substitute may attribute to cultivar differences. The potato cultivar designed in Strip/Substitute was *Agria* on the border rows and *Alouette* and *Carolus* grown in the middle ones. *Agria* is recorded as the highly productive cultivar in potato database. However, the productivity of *Alouette* and *Carolus* are relatively low as reported (AHDB, 2019).

Strip/Additive treatment was designed as intercropped with red clover and ryegrass strip. The fertilization scheme included mowed grass-clover material as the green manure. Previous research shows that potato and red clover share specific associations of bacterial endophytes which provide, to some extent, in vitro antibiosis to the potato pathogen *Rhizoctonia solani* (Sturz *et al.*, 1998). Additionally, experiments show potatoes could potentially gain benefit from residual clover due to higher nitrogen content and more soil organic matter added (Sturz *et al.*, 1998). However, the yield and tuber size obtained on Strip/Additive was reported as the lowest. This should be caused by fertilization difference. Strip/Mono and Strip/Substitute strips were fertilized with 35 ton/ha Farm Yard Manure (FYM), whereas Strip/Additive only fertilized with mowed grass-clover (GC) from its adjacent strip. Total NPK consent was different in the two fertilizers, as higher NPK content was contained in FYM, associated with a little Ca and Mg content (UniFarm, 2019), and only little NPK in grass-clover material. A study shows that a deficiency of certain mineral nutrient could limit the uptake of another mineral nutrient (Almeida *et al.*, 2000). In this case, limited P and K content in green manure could potentially lead to a reduced mineral uptake and yield reduction. One thing should be pointed is that, although potatoes have a lower yield in Strip/Additive treatment and smaller tuber sizes, which were possibly caused by fertilization differences, the NPK content showed no significant difference between treatments, which implied the proportional nutrient uptake in tuber is approximately the same. Previous studies show that clover species are highly competitive and often lead to yield loss on associated crops (Theunissen *et al.*, 1995; Lotz *et al.*, 1997). However, the differences in inter-specific plant competition between potato-grass and potato-grass clover were remained unclear. It is hard to correspond to the yield reduction with clover species added.

As the fresh yield and amount of class C3-C4 were both higher and larger in Strip/Substitute and Strip/Mono treatment, no significant benefits could be confirmed by substitute design. Additionally, Strip/Substitute strips need individual harvest for each cultivar due to the different price and market channel. Thereby, more labour should be considered as a holdback to suggest benefits. However, Strip/Substitute showed slightly higher *Agria*'s yield on the edge rows (3.43%) than Strip/Mono's edges. By replacing inner rows with high late blight resistance cultivars, a potential of improved crop performance was shown on row level, which indicates a promising direction worth further exploration.

Cabbage yield was significantly lower in Control as it was almost reduced to 50% of strips yield. The reasons might include higher damage level in sole crop system (Lithourgidis *et al.*, 2011), and variation in soil conditions. The range of soil organic matter (SOM) in Droevendaal is 2.5-4.4% (Appendix H), which is wide and may potentially lead to the varied yield result. It was also observed that during two-round harvests of cabbages, cabbage head in Control field was smaller than the ones from other treatments. The late mature could be explained by excessive heat and drought in 2018 which caused an irreversible impact on plant growth. Though no difference was found on yield and DMR between strip treatments, N content in Strip/Additive treatment was significantly higher than other treatments. The reason could be fertilizer application from farm management. In Strip/Additive treatment, cabbage received Organic Plant Fertilizer (OPF) before harvest while in Strip/Substitute and Strip/Mono treatments, Farm Yard Manure (FYM, 20 ton/ha) was applied in early season. Excessive N availability during the head fill stage could potentially contribute to higher total N content.

Wheat, onion, and carrot all showed lower yield in Strip/Additive treatment which accord with the results of potato and cabbage. The reason could be the same, as the fertilization was applied differently in additive design. Though the yield result was consistently lower on Strip/Additive in all crops, it is insufficient to conclude that additive design affects adversely on crop yield. For other studies followed Vandermeer diversification design, bean and potato are tested suitably to be inter-cultivated with broccoli in additive design, but less suitable for substitute design with cabbage and cauliflower (Santos *et al.*, 2002). Similarly, for forage sorghum, research showed forage sorghum in additive design with lima bean obtained the best result (Reza *et al.*, 2012). Therefore, it is possible that fertilization differences affected greatly on the effects of additive design. Also, due to the legume species added, Strip/Additive may sustain benefits on soil fertility and nutrient cycling which were not included in this study.

Overall, field heterogeneity was observed both in Droevendaal and Broekemahoeve. When statistical analysis was conducted on the block level, each block (Droevendaal × 3 blocks and Broekemahoeve × 1 block) suggested the opposite result for the treatments that contained the higher yield. Field difference might cause by planting history and varied soil organic matter (SOM) content. The plant stress caused by warm and dry weather was confirmed by data of Near-Infrared (NIR) and Weighted Difference Vegetation Index (WDVI) captured by drone camera in the same experimental area (C. Fernández, personal communication, March 18, 2018). Control treatment of potato and cabbage, were both lower than strip treatment, confirming the benefits from strip cropping system. Together with extreme climate conditions and field heterogeneity, this preliminary study should be further confirmed by following researches.

4.3 Edge effect and plant competition

The potato was found to have a mostly higher yield on edge rows regardless of its adjacent crop species, which showed significant benefits from niche differentiation like canopy structures, and good adaptability with varied crops. Strip/Substitute showed higher yield (3.43%) on edge rows (*Agria*) rows than edges in Strip/Mono strips, indicating a benefit from substitute design. Higher N content was found in middle rows in Strip/Substitute and Strip/Mono without significant difference. When considered the total nitrogen yield on the row level, the differences were neutralized due to the higher yield obtained on edge rows. Therefore, the total N uptake was the same found on edge and middle rows, but N content was diluted in edge rows due to the higher yield.

Potato grown next to carrot showed higher yield compared to the ones next to spinach. Spinach strip was suffered from excessive heat and drought in summer which should be less competitive. However, yield result suggested more benefits were received by potato when it was grown with carrots. Root types which directly decide the below-ground partitions of nutrients may be the dominant factor which affects the inter-specific competition (Thorsted, 2006). Carrot with a taproot system has less rhizosphere area which should be less competitive than the species with a fibrous root system (Gruber, 2013). Though spinach has a deep taproot system, the shallow but extensive branching root (Trujillo and Gardener, 2003), which could possibly lead to the yield reduction of potatoes when they are grown nearby.

Cabbage showed less difference on the edge and middle rows. The only significant difference on yield result was obtained on Strip/Substitute. However, the reason for significant difference should mostly be 1 in 8 of sacrificial cultivar (*Christmas Drumhead*) was excluded in the fresh yield. Other strip treatments showed no significant differences in yield. Cabbage edge yield of Strip/Mono is 6.45% higher than Strip/Substitute, showing a negative effect brought by substitute design. DMR and N content had no different by strip treatments. The cauliflower had a higher yield on grass edge compared with flower edge and middle rows. Flower strip adversely affects the cauliflower yield. The reason could be explained by favoured herbivores activity from flower strips, and inter-specific competition between flower species and cauliflower, like radiation and water competition (Géneau *et al.*, 2012).

Carrot yield was found consistently higher in the middle rows, showing a negative influence on edge effect regardless of bordering crop species (onion, potato, grass in this case). The inter-specific competition should be higher than intra-specific competition for carrot intercropping system in this study. Carrot's taproot system with less rhizosphere area should be the main reason for less competitiveness than other species, as root types directly influence on the below-ground partitions (Gruber, 2013). Potato edge of carrot strips sustained higher yield than grass edges, which proved the assumption of root type, as grass has a fibrous root system which could potentially lead to high competitiveness. Some studies conducted on carrot intercropping system obtain higher yield when intercropping with onion (Błażewicz-Woźniak and Wach, 2011), and chili pepper (Suresha et al, 2007) compared to monoculture. However, these yield benefits are on strip level of an intercropping system, when considered crop performance on the row level, onion and chili pepper may still lead to yield reduction on edge rows of carrot strips.

5. Conclusion

As a part of the long-term project on diversified cropping system, this study demonstrated that spatial and genetic diversification in strip cropping system can substantially influence crop performance, which answered our research questions. Potato showed significantly higher yield and nitrogen yield in the 12m strips. With the increase in strip width, potato yield differences between edge and middle rows increased accordingly, indicating effects of strip width. Carrot and cauliflower showed higher yield and dry matter accumulation in the 24m strips. The 12m strip for potato, 24m strips for carrot and cauliflower was found to be the strip widths provide the most benefits on yield. No significant differences were found in DMR of three crops, while lower DMR was found correspond to the higher yield obtained. Effects of strip-crop diversification on crop performance need further exploration. The fresh yield was slightly strengthened by Strip/Substitute treatment in potato strips, but Strip/Additive treatments lowered the crop yield in potato, wheat, onion, and carrot strips. No influences were observed on DMR and N content by strip-crop diversification strategy. Strip/Substitute showed possibilities to further strengthen crop yield and quality factors by selecting more suitable complementary cultivars. Considered fertilization differences, negative results in Strip/Additive treatment were not concluded. Effects on pest control and nutrient cycling should be considered as potential benefits from the Strip/Additive design. Edge effects present in strip cropping can potentially benefit strip crop performance by selecting appropriate neighbouring crop. In this study, potato showed promising characteristics as edge yield is consistently high, regardless of neighbouring species. On the contrary, carrot shows lower yield on edge rows, with varied bordering crops. The behaviour differences for each crop could help in identifying suitable species grown next to each other. Results accountability in this research was limited by extreme weather condition, field variance, mis-conducted managements, and sample sizes. To conclude, in organic strip cropping system, customising strip design in terms of spatial (strip width) and genetic (strip crop) arrangements has the potential to strengthen strip crop performance, by selecting appropriate component crops and specific strip width. However, more studies are required to confirm the findings in this study.

6. Limitation and recommendation

In this study, impacts from water stress on the experimental results were not neglectable. The drier weather and higher temperature could lead to higher soil water competition and therefore influence the crop yield. The following research is suggested on soil water competition and compensation effect in the strip cropping system.

Water soil content could help in understanding water availability and plant uptake which contribute to revealing the mechanisms involved in varied crop performance. As the part of a long-term project, this study can not explain the mechanisms of yield increases/decrease by treatments but could be at least, partly explained by the studies of soil water competition and compensation in strips. For carrot strip, a higher DMR may be preferred by industrialised processing requirements. The analysis of soil water interaction between strips could alter the DMR of carrot towards a preferred value. Irrigation strategy could also be improved by soil water studies, as more water should be applied to less competitive crops for soil water, which could potentially improve Water Use Efficiency (WUE) and N uptake at the same time.

Mostly sampling sizes in this study were limited due to rush harvest and labour availability, which may highly influence the accuracy of result and conclusion. The field variance was both observed on a broad level like block/strata effect and local level for each sampling location. Even though the sampling locations were randomized, the variances in local conditions were not reduced if sample sizes are not big enough. For each experiment, samples should be taken at least three locations per row (middle/edge) to reduce the variance, which was not achieved in this study. Bias was also introduced in the experiments by field design. ERF farm was designed with Control field on block 3 and treatments field on block 1 and 2. Even though an extra 6m treatment was planted next to Control field in Block 3, the variances can not mitigate the bias in the system level, as results would highly rely on the accountability of the extra 6m. In this case, the block effects could not be estimated properly, as treatments design are separated from Controls plot. Same for Droevendaal farm, the Control field was planned in block 5 without Strip/Substitute and Strip/Additive treatment. The comparison may be skewed by the only link of Strip/Mono strips. As for Broekemahoeve, it does not have Control treatment planted in 2018, which even introduced higher bias.

By applying participatory research method, a constant update with local farmers and management personnel should greatly improve the sampling method itself and research design as a whole. The local knowledge should be respected since it may be experiences gathered outside the scientific scope but should greatly improve scientific research at large. The information about field history, local management, gradient soil conditions, and even local market preferences, for which could potentially lead to non-representative results and influences on experimental conclusions, should be discussed and considered into experiment design. Other sectors could also, to some extent, be involved in the research process. For example, the decision of component crop could be made together with breeding companies or local agents/groups. In this case, component crop/cultivar could be tested more effectively and in line with market demand, which possibly contributes to greater impacts of agricultural research and the society as a whole.

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Appendices

Appendix A. Experimental layouts

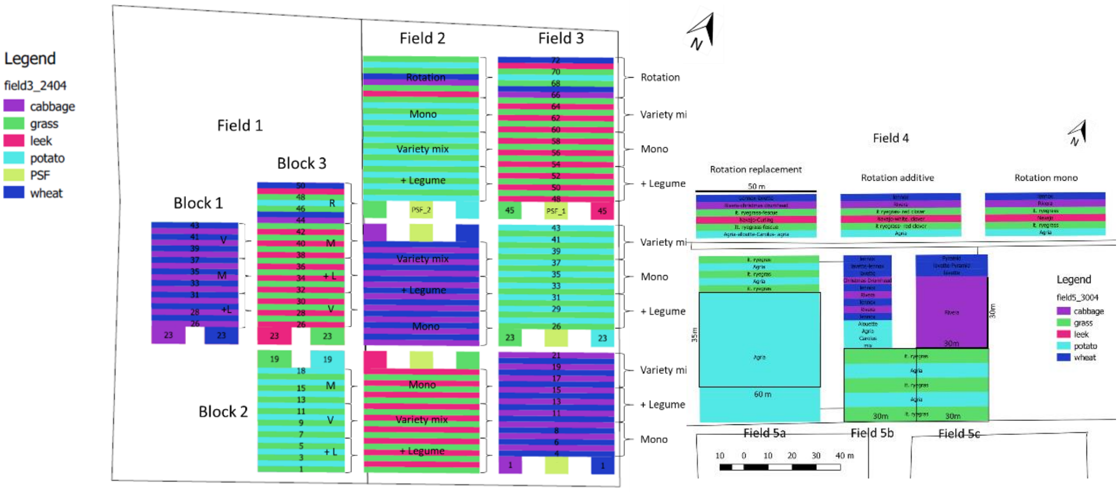

Figure A1 The incomplete block experimental design with three replicates of each strip diversification treatment (indicate by “Mono”, “Legume” and “Variety mix”) on field 1, 2 and 3 in 6.18ha land at Droevendaal. Control in Field 5 was grown with sole crop, as reference to strip cropping. Cabbage (purple), wheat (dark blue) and potato (light blue) were investigated in this study.

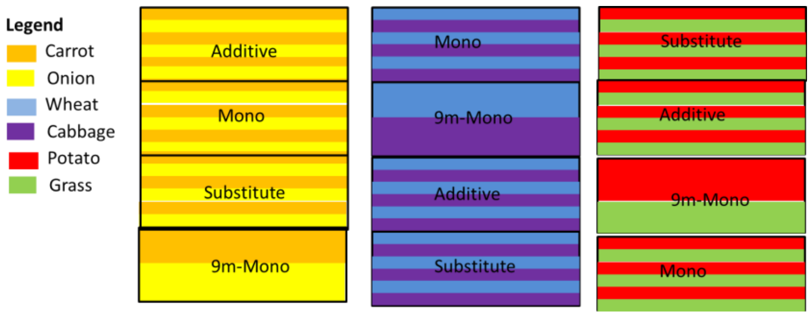

Figure A2 The incomplete block design in 1.84ha field in Broekemahoeve, Lelystad – representation of 3.15m wide strips of crops with their respective treatments. Strips/Mono, Strips/Additive and Strips/Substitutive were applied on cabbage-wheat, onion-carrot, and potato-grass crop combination. 9m-Mono (9m) was not used in this study.

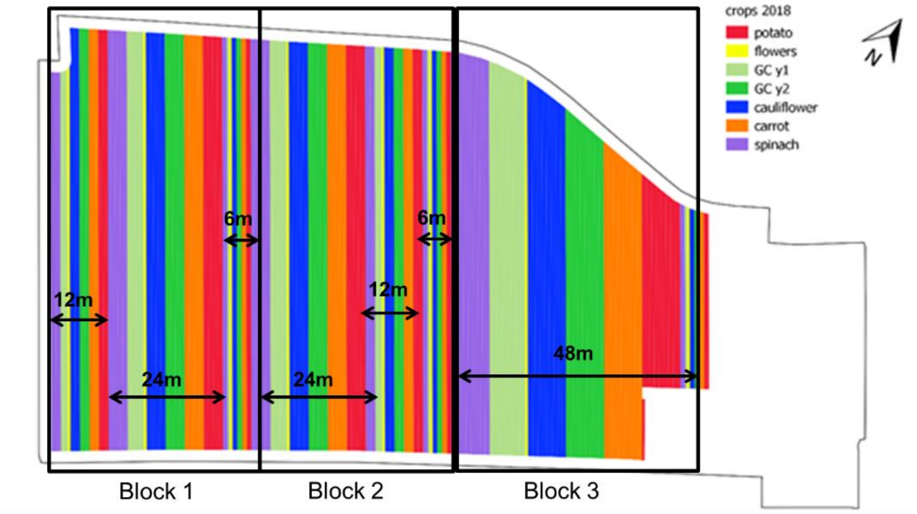

Figure A3 The complete block experimental design for strip width experiment, with 2 replicates in 50ha farmland in ERF BV, Zeewolde. Potato (red), carrot (orange), and cauliflower (blue) were investigated in this study and grown in rotation of 6m, 12m, 24m strips and 48m (Control), a 3m-wide flower strip (yellow) on the left side of the cauliflower strip (blue) was planned for pest control..

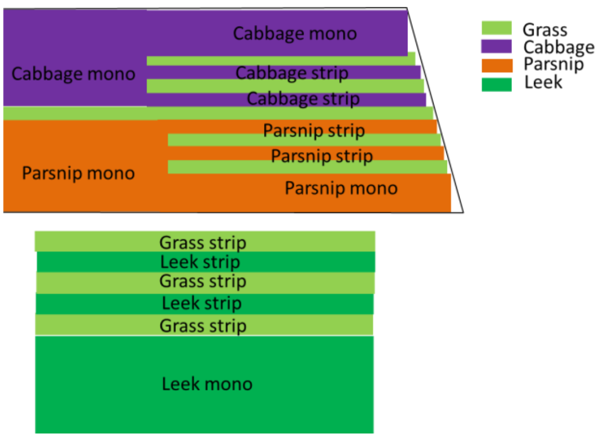

Figure A4 The complete block experimental design in 2.7ha field at Strijen. Cabbage (purple), leek (dark green) and parsnip (brown) were studied by strip edge effects.

Appendix B. Harvest schemes

As samples from each farm were collected on different harvesting scale, harvest method was depending on the machine type and availability. When machine was not capable to conduct the row-wise or plot-wise harvest, sampling was done manually by shovel with the reference to market standard. In ERF.BV, data of three rows per strip were measured (two edge rows and a middle row) on row level to determine strip performance and edge effects (Figure B1). In Droevendaal, samples were collected at each row in the strips, but in Broekemahoeve only cabbage data was available on the row level. Potato, carrot and onion in Broekemahoeve were collected with two-row type harvester, so each sample representing two rows. After measuring the weight, the total harvest of hand-sampling or a subsample of 5-10kg from the machine-harvesting was collected in mesh bags and stored in refrigeration for further measurements of DMR and NPK content.

Table B1 Sampling and yield determination method of each crop.

Farm	Crop	Sampling method	Harvest size	Subsample
	Potato	Machine	One row	5-10kg/row
Droevendaal	Cabbage	Hand	One row*	4 heads/row
	Wheat	Hand	6×0.5m×0.5m/strip	Whole sample
	Potato	Machine	Two rows	5-10kg/two rows
	Cabbage	Hand	10 heads/row	2 head/row
Broekemahoeve	Wheat	Hand	6×0.5m×0.5m/strata	Whole sample
	Onion	Machine	Two rows	5-10kg/two rows
	Carrot	Hand	5×1m/row	1m/row
	Potato	Hand	6m/row	Whole sample
B.V Erf	Carrot	Hand	2×3m/row	5-10kg/row
	Cauliflower	Hand	6m/row	2head/row
	Cabbage	Hand	6m/row	2head/row
Strijen	Leek	Hand	6m/row	1kg/row
	Parsnip	Hand	6m/row	5-10kg/row

*The first harvest of cabbage was occurred on 1st Nov, when the subsamples were collected. The cabbages estimated to be > 1 kg were harvested. On 27th Nov, all remaining heads (that had at least developed until firm) were harvested.

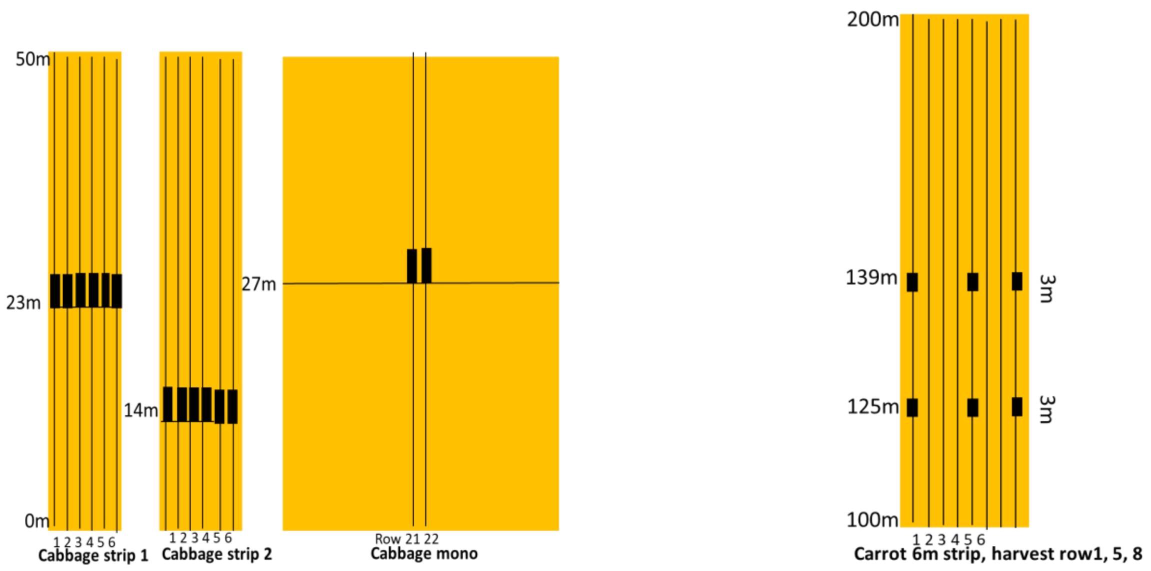

Figure B1 Demonstrations of random sampling location in Strijen (left) and ERF (right). Sampling in Strijen farm taken each row in the strips and followed random location generated by R studio. Sampling in ERF only taken two edge rows and one middles representing the strip performance. The 6m strip in ERF was taken as an example here.

Appendix C. Classification of other crops

Table C1 Classification conducted in this study for quality assessment of potato, onion, carrot, parsnip, and leek.

Crop	Size	Class	Marketable size
Potato	Diameter of unit	<35mm	35-70mm
		35-50mm	
		50-70mm	
		>70mm	
Onion	Diameter of unit	<40mm	>40mm
		40-60mm	
		>60mm	
Carrot	Head diameter of unit	<35mm	35-80mm
		35-80mm	
		>80mm	
Parsnip	Head diameter of unit	<30mm	30-80mm
		30-80mm	
		>80mm	
Leek	Diameter of unit	>1cm	>1cm

Appendix D. Linear Mixed-Effects Models (LMMs) and Multiple Comparison for Statistical Analysis in R

As experiments were conducted on different farms variable “field” was include as random effects which contained all the field variances caused by site conditions. “Variety” influence in strip crop experiment are also included as a random effect. The variable “Treatment” (Strip/Substitute, Strip/Additive, Strip/Mono and Control) was treated as the fixed effect for strip crop experiment; the “Treatment” for strip width experiment (6m, 12m,24m, 48m) was treated as the fixed effect in the model. “Positions” was treated as the fixed effect for edge effect analysis

Models selection was based on the Akaike Information Criteria (AIC). (Taken potato as the example)

A. Fresh yield
Droevendaal: lmer (Yield ~ Treatment, random= (1|Field) + (1|Variety), potato, method= “REML”)
Broekemahoeve[a]: lmer (Yield ~ Treatment, random= (1|Field) + (1|Variety), potato, method= “REML”)
ERF: lmer (Yield ~ Treatment, random= (1|Block) + (1| Position), potato, method= “REML”)
Strijen[b]: lmer (Yield ~ Position, random= (1|Strip), potato, method= “REML”)

B. DMR
Droevendaal: lmer (DMR ~ Treatment, random= (1|Field) + (1|Variety), potato, method= “REML”)
Broekemahoeve[a]: lmer (DMR ~ Treatment, random= (1|Field) + (1|Variety), potato, method= “REML”)
ERF: lmer (DMR ~ Treatment, random= (1|Block) + (1| Position), potato, method= “REML”)
Strijen[b]: lmer (DMR ~ Position, random= (1|Strip), potato, method= “REML”)

C. NPK
Droevendaal: lmer (N_tot ~ Treatment, random= (1|Field) + (1|Variety), potato, method= “REML”)
Broekemahoeve[a]: lmer (N_tot ~ Treatment, random= (1|Field) + (1|Variety), potato, method= “REML”)
ERF: lmer (N_tot ~ Treatment, random= (1|Block) + (1| Position), potato, method= “REML”)
Strijen[b]: lmer (N_tot ~ Position, random= (1|Strip), potato, method= “REML”)

D Multiple comparison
library(multcomp)
glht(model, linfct=mcp(Treatment="Tukey"))
# where Treatment is the under tested varied factors in each experiment.

a: Potato and cabbage data were combined from Droevendaal and Broekemahoeve to conducted statistical analysis, therefore “field” was taken as a random effect also in Lelystad.
b: Strijen result only was taken for edge effect analysis, therefore only “Position” was used as fixed effect.

Glossary of variable terms:
“Field”: Land which was divided in the experimental farm for experimental purpose. There were 5 fields in Droevendaal, 1 in Lelystad, Strijen and Lelystad.
“Block”: Land which was subdivided in the field, where a certain crop combination was growed. There were 3 blocks in Droevendaal, 1 in Lelystad and Strijen, and 3 in ERF.
“Strip”: A set of rows of a crop grown adjacently with another strip of another crop.
“Treatment”: Varied factors of strip experimental designs.

Appendix E. Results of strip width experiment

Table E1 Effects of strip width treatments (6m, 12m, 24m, 48m) on fresh yield, Dry matter ratio, and NPK content of potato in the ERF experimental site in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Potato	**Strip width(m)**			
	6	**12**	**24**	**48**
Fresh Yield(kg/m2)	2.85 ± 0.11a	3.13 ±0.16ab	2.63 ± 0.19ac	2.76 ± 0.32a
P-value	<0.001	0.113	0.221	0.849
Dry matter ratio (%)	19.59± 0.41a	19.00± 0.24a	18.85± 0.21a	19.64± 0.34a
P-value	<0.001	0.211	0.118	0.936
Dry matter yield (kg/m2)	0.56±0.027a	0.59±0.033a	0.50±0.037a	0.54±0.073a
P-value	<0.001	0.374	0.128	0.859
N content (%)	1.44±0.058a	1.47±0.047a	1.49±0.018a	1.42±0.10a
P-value	<0.001	0.661	0.494	0.865
Nitrogen yield (kg/m2)	0.041±0.0023a	0.046±0.0023ab	0.039±0.0027ac	0.039±0.0018a
P-value	0.001	0.069	0.444	0.788
P content (%)	0.23±0.0087a	0.23±0.0052a	0.23±0.0038a	0.19±0.0060a
P-value	<0.001	0.982	0.952	0.011
K content (%)	2.57±0.047a	2.65±0.026a	2.68±0.030a	2.52±0.12a
P-value	<0.001	0.203	0.076	0.579

Table E2 Effects of strip width treatments (6m, 12m, 24m, 48m) on fresh yield, Dry matter ratio, and NPK content of carrot in the ERF experimental site in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Carrot	**Strip width(m)**			
	6	**12**	**24**	**48**
Fresh Yield(kg/m2)	5.20 ± 0.16a	4.37 ±0.56a	6.19 ± 0.31bc	5.80 ± 0.39ab
P-value	0.008	0.04	0.016	0.691
Dry matter ratio (%)	11.92± 0.22a	12.08± 0.17a	12.04± 0.16a	11.34± 0.39a
P-value	<0.001	0.559	0.675	0.281
Dry matter yield (kg/m2)	0.62±0.018a	0.52±0.066a	0.74±0.033bc	0.66±0.052ab
P-value	0.006	0.049	0.014	0.807
N content (%)	1.36±0.039a	1.40±0.038a	1.39±0.061a	1.49±0.10a
P-value	<0.001	0.593	0.689	0.148
Nitrogen yield(kg/m2)	0.071±0.0032a	0.060±0.0074a	0.086±0.0050bc	0.085±0.0037ab
P-value	0.01113	0.05	0.008	0.541
P content (%)	0.28±0.0058a	0.26±0.0067bc	0.27±0.0072ab	0.28±0.0097a
P-value	<0.001	0.008	0.171	0.617
K content (%)	3.41±0.066ab	3.25±0.053a	3.38±0.074a	3.72±0.16b
P-value	<0.001	0.136	0.766	0.016

Table E 3 Effects of strip width treatments (6m, 12m, 24m, 48m) on fresh yield, Dry matter ratio and NPK content of cauliflower in the ERF experimental site in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Cauliflower	**Strip width(m)**			
	6	**12**	**24**	**48**
Fresh Yield(kg/m2)	1.62 ± 0.22ab	1.28 ±0.13a	2.04 ± 0.20b	1.55 ± 0.072ab
P-value	0.021	0.24	0.153	0.868
Dry matter ratio (%)	8.33± 0.29a	8.15± 0.21a	8.91± 0.34a	8.78± 0.78a
P-value	<0.001	0.647	0.125	0.342
Dry matter yield (kg/m2)	0.13±0.017ab	0.10±0.010a	0.18±0.020b	0.14±0.017ab
P-value	0.017	0.289	0.048	0.704
N content (%)	4.13±0.26a	4.40±0.22a	3.87±0.25a	3.16±0.52a
P-value	0.016	0.41	0.388	0.018
Nitrogen yield(kg/m2)	0.063±0.0090a	0.053±0.0043a	0.074±0.0063a	0.061±0.0038a
P-value	<0.001	0.339	0.329	0.874
P content (%)	0.62±0.023a	0.64±0.022a	0.60±0.026a	0.58±0.022a
P-value	0.004	0.481	0.439	0.278
K content (%)	4.02±0.065a	4.32±0.099bc	3.95±0.150a	4.02±0.097ab
P-value	<0.001	0.015	0.513	0.997

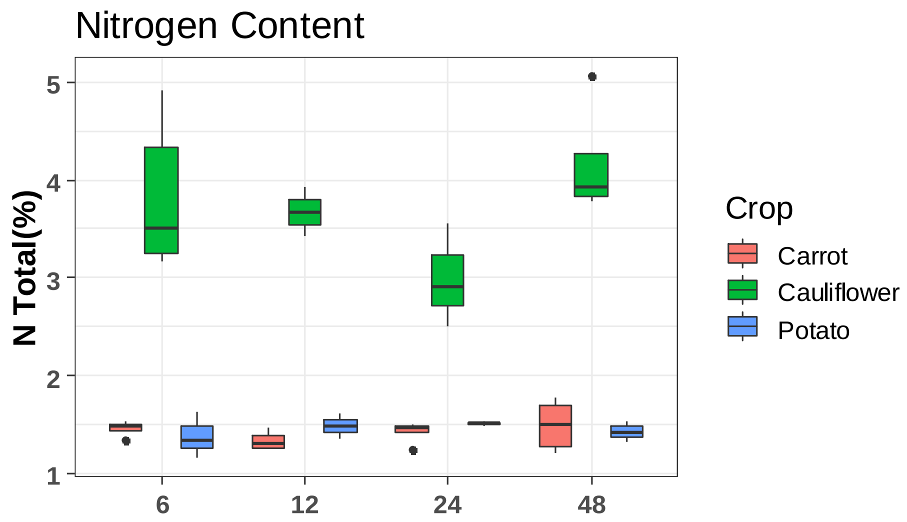

Figure E1 Nitrogen content of potato (blue), cauliflower (green) and carrot (red), represented by total weight percentage (%) in strip width experiment in ERF farm.

Appendix F. Results of strip crop diversification experiment.

Table F1 Effects of strip crop diversification treatments (Strip/Additive, Strip/Substitute, Strip/Mono) and Control treatment on fresh yield, Dry matter ratio, NPK content and marketable yield of potato in the Droevendaal and Broekemahoeve experimental sites in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Potato	**Strip treatment**			
	Strip/Mono	**Strip/Additive**	**Strip/Substitute**	**Control**
Fresh Yield(kg/m2)	3.09 ± 0.10a	2.86 ±0.14b	3.30 ± 0.16a	3.03 ± 0.16ab
P-value	<0.001	0.009	0.059	0.781
Dry matter ratio (%)	21.29± 0.22a	21.65± 0.32a	21.50± 0.23a	22.06± 0.79a
P-value	<0.001	0.217	0.538	0.304
Dry matter yield (kg/m2)	0.65±0.019ab	0.60±0.028b	0.70±0.033a	0.68±0.057ab
P-value	<0.001	0.0372	0.063	0.624
N content (%)	1.33±0.022a	1.39±0.017a	1.34±0.027a	1.31±0.66a
P-value	<0.001	0.056	0.681	0.88
Nitrogen yield(kg/m2)	0.041±0.0013a	0.040±0.0018a	0.044±0.0020a	0.040±0.0042a
P-value	<0.001	0.473	0.108	0.705
P content (%)	0.25±0.0040a	0.25±0.0038a	0.24±0.0043a	0.28±0.0023b
P-value	<0.001	0.942	0.442	0.006
K content (%)	2.32±0.030a	2.28±0.040a	2.26±0.040a	2.32±0.020a
P-value	<0.001	0.217	0.141	0.961
Marketable yield (%)	94.38± 0.27a	93.91± 0.30a	94.51± 0.92a	94.09± 0.64a
P-value	<0.001	0.411	0.858	0.841
Class C2 (%)	56.39± 1.92b	69.95± 2.44a	54.28± 3.93b	57.98± 4.82ab
P-value	0	<0.001	0.467	0.795
Class C3-4 (%)	43.61± 1.92a	30.05± 2.44b	45.72± 3.93a	42.02± 4.82ab
P-value	0.008	<0.001	0.467	0.795

Table F2 Effects of strip crop diversification treatments (Strip/Additive, Strip/Substitute, Strip/Mono) and Control treatment on fresh yield, Dry matter ratio, and NPK content of cabbage in the Droevendaal and Broekemahoeve experimental sites in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Cabbage	**Strip treatment**			
	Strip/Mono	**Strip/Additive**	**Strip/Substitute**	**Control**
Fresh Yield(kg/m2)	2.70 ± 0.17a	2.31±0.14a	2.54 ± 0.12a	1.05 ± 0.05b
P-value	<0.001	0.014	0.374	<0.001
Dry matter ratio (%)	9.56± 0.11a	9.51± 0.11a	9.47± 0.12a	9.62± 0.24a
P-value	<0.001	0.729	0.551	0.852
Dry matter yield (kg/m2)	0.26±0.017a	0.23±0.012b	0.24±0.010ab	0.11±0.006c
P-value	<0.001	0.013	0.132	<0.001
N content (%)	2.35±0.046b	2.62±0.052a	2.42±0.042b	2.22±0.12b
P-value	0.002	<0.001	0.204	0.351
Nitrogen yield(kg/m2)	0.062±0.0039a	0.059±0.0037a	0.060±0.0032a	0.024±0.0030b
P-value	0.01	0.472	0.783	0.002
P content (%)	0.43±0.0064a	0.40±0.0061b	0.42±0.0062ab	0.41±0.0166ab
P-value	<0.001	0.002	0.169	0.376

K content (%)	2.73±0.048a	2.69±0.055a	2.63±0.043a	2.52±0.075a
P-value	<0.001	0.386	0.027	0.078

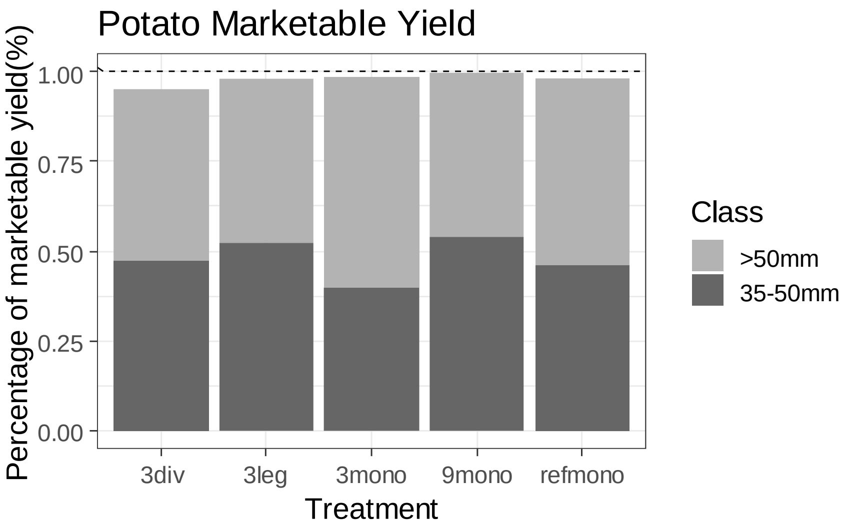

Figure F1 Percentage of marketable yield with total harvest of strip diversification experiment, including potato from Droevendaal and Broekemahoeve. The minimum size for marketable potato tuber is 35mm in 2018 from buyer's information. Data extracted from subsamples taken from each strip. "3div" represents Strip/Substitute strips, "3leg" represents Strip/Additive treatment and "3mono" represents Strip/Mono treatments. "9mono" mean 9-meter Strip/Mono setting which was not included in this study.

Appendix G. Results of edge effects

Table G1 Effects of Strip/Edge and Strip/Middle on fresh yield, Dry matter ratio, and NPK content of potato in the Droevendaal experimental site in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Potato	**Position**	
	Strip/Edge	**Strip/Middle**
Strip/Mono		
Fresh Yield(kg/m2)	3.73 ± 0.16a	3.54±0.14b
P-value	>0.001	0.042
Dry matter ratio (%)	21.84± 0.32a	21.45± 0.33a
P-value	>0.001	0.338
N content (%)	1.21±0.030a	1.26±0.037a
P-value	>0.001	0.279
Strip/Additive		
Fresh Yield(kg/m2)	3.37± 0.26a	3.12 ±0.19a
P-value	0.007	0.064
Dry matter ratio (%)	22.38± 0.59a	21.96± 0.41a
P-value	>0.001	0.368
N content (%)	1.32±0.025a	1.31±0.022a
P-value	>0.001	0.729
Strip/Substitute		
Fresh Yield(kg/m2)	3.68 ± 0.25a	2.72 ±0.17b
P-value	0.00312	>0.001
Dry matter ratio (%)	22.26± 0.37a	21.08± 0.25b
P-value	>0.001	0.0024
N content (%)	1.25±0.023a	1.50±0.033b
P-value	>0.001	>0.001

Table G 2 Effects of Strip/Edge and Strip/Middle on fresh yield, Dry matter ratio, and NPK content of cabbage in the Droevendaal and Broekemahoeve experimental sites in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Cabbage	**Position**	
	Strip/Edge	**Strip/Middle**
Strip/Mono		
Fresh Yield (kg/m2)	2.93 ± 0.28a	2.65±0.19b
P-value	<0.001	<0.001
Dry matter ratio (%)	8.99± 0.22a	9.60± 0.15b
P-value	<0.001	<0.001
N content (%)	2.56±0.056a	2.34±0.067b
P-value	<0.001	<0.001
Strip/Additive		
Fresh Yield(kg/m2)	2.15± 0.21a	2.22 ±0.18a
P-value	0.001	0.754
Dry matter ratio (%)	9.14± 0.22a	9.38± 0.14a
P-value	<0.001	0.068

N content (%)	2.79±0.022a	2.76±0.086a
P-value	<0.001	0.591
Strip/Substitute		
Fresh Yield(kg/m2)	2.49 ± 0.20a	2.08 ±0.10b
P-value	<0.001	0.053
Dry matter ratio (%)	9.16± 0.18a	9.75± 0.13b
P-value	<0.001	0.002
N content (%)	2.64±0.062a	2.38±0.047b
P-value	<0.001	0.003

Table G3 Effects of Strip/Edge and Strip/Middle on fresh yield, Dry matter ratio, and NPK content of carrot in the Broekemahoeve and ERF experimental sites in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Carrot	**Position**	
	Strip/Edge	**Strip/Middle**
Strip/Mono		
Fresh Yield(kg/m2)	9.20 ± 0.40a	9.82 ± 0.26a
P-value	<0.001	0.205
Dry matter ratio (%)	12.58 ± 0.49a	12.46 ± 0.15a
P-value	<0.001	0.832
N content (%)	1.16 ± 0.063a	0.88 ±0.065b
P-value	0.023	0.009
Strip/Additive		
Fresh Yield(kg/m2)	8.86 ± 0.37a	9.14 ± 0.30a
P-value	<0.001	0.565
Dry matter ratio (%)	12.32 ± 0.37a	12.57 ± 0.41a
P-value	0.003	0.126
N content (%)	0.99 ± 0.056a	1.11 ± 0.117a
P-value	<0.001	0.371
Strip/Substitute		
Fresh Yield(kg/m2)	9.05 ± 0.34a	9.49 ±0.42a
P-value	<0.001	0.386
Dry matter ratio (%)	13.30± 0.22a	12.49± 0.20b
P-value	0.008	0.006
N content (%)	1.03±0.064a	1.02±0.047a
P-value	0.002	0.868

Table G4 Effects of Strip/Edge and Strip/Middle on fresh yield, Dry matter ratio, and NPK content of cauliflower in the ERF experimental site in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Cauliflower	**Flower edge**	**Grass edge**	**Middle**
Fresh Yield(kg/m2)	1.80 ± 0.27a	2.06±0.25a	1.77±0.19a
P-value	0.001	0.329	0.822
Dry matter ratio (%)	7.88± 0.21b	8.77± 0.16a	8.59± 0.36a
P-value	<0.001	0.012	0.136

N content (%)	4.46±0.30a	3.70±0.22ab	3.49±0.20b
P-value	0.004	0.177	0.042

Table G5 Effects of Strip/Edge and Strip/Middle on fresh yield, Dry matter ratio, and NPK content of Potato in the ERF experimental site in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Potato	**Carrot edge**	**Middle**	**Grass edge**
Fresh Yield (kg/m2)	3.11 ± 0.17a	2.54±0.11b	2.95±0.11a
P-value	<0.001	0.002	0.355
Dry matter ratio (%)	18.98± 0.16a	19.13± 0.46a	19.45± 0.35a
P-value	<0.001	0.751	0.348
N content (%)	1.49±0.024a	1.44±0.063a	1.45±0.047a
P-value	<0.001	0.452	0.504

Table G 6 Effects of Strip/Edge and Strip/Middle on fresh yield, Dry matter ratio, and NPK content of Potato in the ERF experimental site in 2018. Means (± standard error) followed by same letter in same row are not significantly different, suggested by Tukey HSD test, $p < 0.05$ at 0.95 confidence level. *P*-values were provided by Linear mixed-effects model (LMMs) with *lme4* package.

Carrot	**Grass edge**	**Middle**	**Potato edge**
Fresh Yield (kg/m2)	4.02 ± 0.49a	6.18 ± 0.23b	5.56 ± 0.27a
P-value	0.007	<0.001	<0.001
Dry matter ratio (%)	12.40 ± 0.12a	11.86 ± 0.18a	11.77 ± 0.19a
P-value	<0.001	0.034	0.014
N content (%)	1.38 ± 0.061a	1.40 ± 0.031a	1.37 ± 0.043a
P-value	<0.001	0.704	0.857

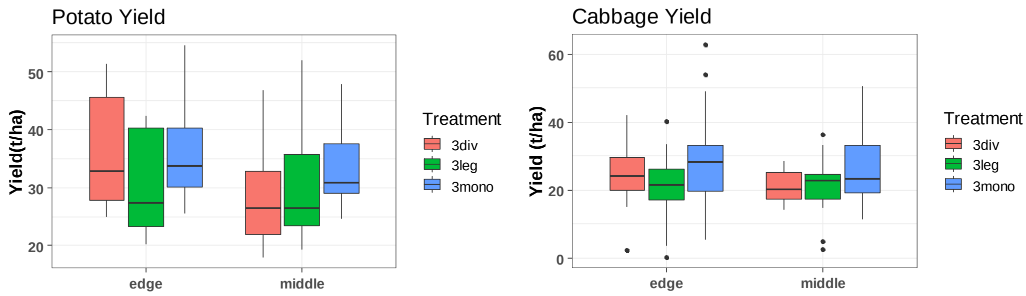

Figure G1 Yield of potato (left) and cabbage (right) on edge and middle rows in each strip treatment. Yield result extracted only from Droevendaal farm because no samples were taken on the row level at Broekemahoeve. “3div” represents Strip/Substitute strips, “3leg” represents Strip/Additive treatment and “3mono” represents Strip/Mono treatments.

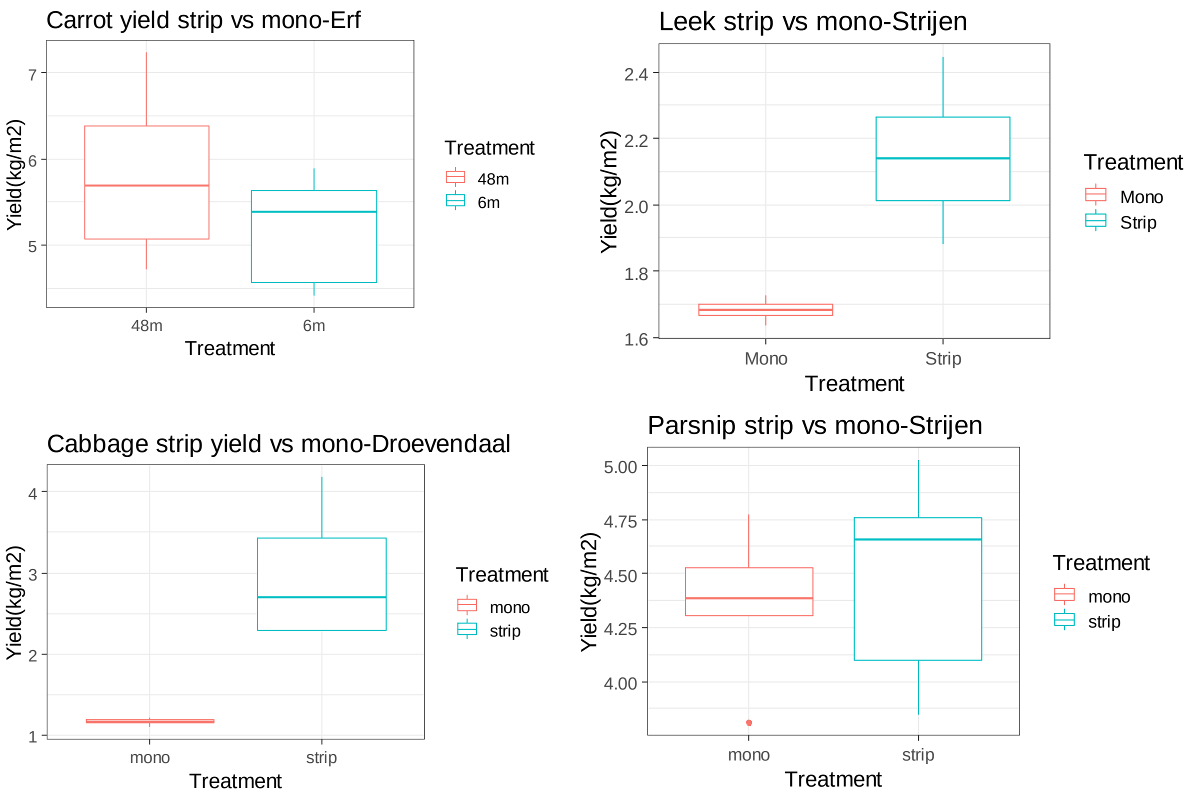

Figure G2 Carrot (top left), leek (top right), cabbage (bottom left) and parsnip (bottom right) results at strip cropping setting (blue) and monoculture setting (red). Experimental sites where crops were collected are presenting in the title of each figure.

Appendix H. Soil organic matter of Droevendaal and Broekemahoeve.

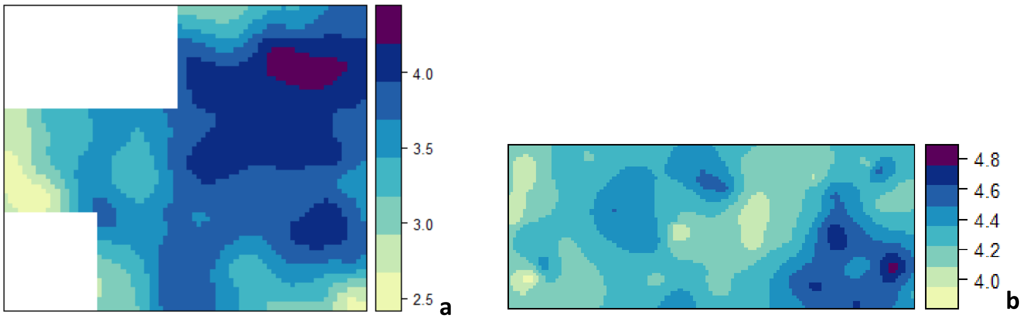

Figure H1 Using ordinary kriging, a prediction for SOM content has been made for each 3x3m (Droevendaal (a)) or 3.15x3.15m (Broekemahoeve (b)) pixel. As the scales show, the range of SOM percentage is wider for Droevendaal (2.5 - 4.4) than the Broekemahoeve (3.9-4.8).

Appendix I. Crop chemical analysis protocol

Chemical analysis for plant/soil samples.

Samples were digested with a mixture of H_2SO_4–Se and salicylic acid (Novozamski et al., 1983). The actual digestion is started by H_2O_2 and in this step most of the organic matter is oxidized. After decomposition of the excess H_2O_2 and evaporation of water, the digestion is completed by concentrated H_2SO_4 at elevated temperature (330°C) under the influence of Se as a catalyst. In these digests total N and P was measured spectrophotometrically with a segmented-flow system (Skalar San++ System).

In the same digests K was measured with aVarian AA240FS fast sequential atomic absorption spectrometer. (Terneuzen, the Netherlands).

Remark: Salicylic acid is added to prevent loss of nitrate-N. This is done by coupling the nitrate to salicylic acid, a reaction which proceeds easily in the acid medium. In this way, 3-nitrosalicylic acid and/or 4-nitrosalicylic acid are formed. These compounds are reduced to their corresponding amino forms by the plant organic matter. In this study, chemical analysis was done by technician of FSE (Farming System Ecology Group).