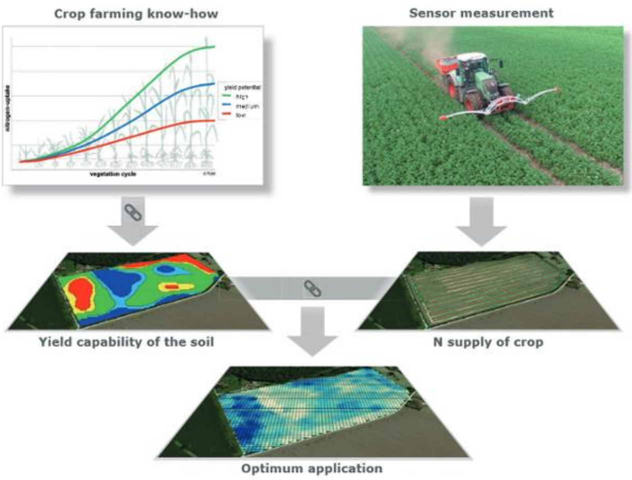
Spatial and temporal analysis and explanation of potato variability

MSc. Thesis Plant Production Systems



Rick Rasenberg
MSc-student Plant Sciences

Master Thesis Plant Production Systems
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Photo: Variable fertilizer application based on Fritzmeier sensor (Fritzmeier, 2016)

Name Student:	*Rick Rasenberg*	
Registration Number:	*940202-680-040*	
Study:	*MSc Plant Sciences – Specialization Crop Sciences*	
Chair group:	*Plant Production Systems (PPS)*	
Code Number:	*PPS-80436*	
Date	*20, August 2018*	
Supervisors:	*Dr. P. Reidsma*	*(Plant Production Systems)*
	Prof. Dr. E.R. van den Heuvel	*(TU/e)*
Examiners:	*Dr. J. van Heerwaarden*	*(Plant Production Systems)*

Contact office.pp@wur.nl for access to data, models and scripts used for the analysis

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Rick Rasenberg

Summary

Potato yields vary across and within fields in the Netherlands. Until recently, data was limited to understand this yield variability across and within fields. For this research, four years dataset was used that is obtained by Van den Borne. The number of fields that Van den Borne uses annually for the cultivation of around 500 hectares of ware potatoes on around 150 fields. The collection of the data started in 2012. In 2012 only one or two observations were sampled in the fields. This number did increase over years, in 2016 six observations were sampled. The observation spots were chosen based on the median electro conductivity of the field that was determined by the dualem 38 from Van den Borne. The majority of the fields was planted with the variety Fontana.

The aim of this study was to investigate the influence of soil characteristics, crop management and weather conditions on plant characteristics, determined by Van den Borne. The first smaller subject was to investigate which factors together could explain the variability in growth curves of the plant characteristics. The relationships between the plant characteristics during the growing season and the underlying factors (soil, crop management and weather) were investigated. Plant characteristics that were analysed include tuber weight, shoot weight, root weight, underwater weight, number of leaves, number of tubers, number of stems, nitrate content, flavonoid content and chlorophyll content of the leaves. The relationship between each plant characteristic and factor (management, soil, etcetera) was analysed separately. For the different characteristics, different growth curves and therefore different mixed models were used (proc MIXED, GLIMMIX and NLMIXED). The second subject was to investigate the relation between the plant characteristics and to estimate the most optimal curve, with a generalized linear model (HP GENSELECT).

The fit of the models was good except for root weight, underwater weight and flavonoid had a R-square less than 0.512. Especially those results need to be interpreted carefully. Postponing the haulm killing had a positive influence on the tuber growth curve and stem length, due to an increase of radiation duration, but negative on underwater weight. The amount of rainfall positively influenced the yield and number of tubers, but negatively influenced underwater weight. Fertilizer application was very important, in particular potassium and nitrogen. The overall applied potassium fertilizer increased the underwater weight and stem length but had a negative effect on the number of stems. The K50 potassium fertilizer had a positive influence on the tuber growth curve and root weight, which was applied only on fields in 2013. K60 had a positive effect on the number of stems, which was only applied in 2014, 2015 and 2016. Nitrogen application had a positive influence on the root growth, underwater weight, number of tubers and a negative impact on shoot weight. Only sulfasote had a negative impact on the stem length and shoot weight, but positive on the number of stems. KAS had a positive effect on underwater weight, number of tubers, but a negative effect on nitrate content, stem length and compound leaves. Urea resulted in a lower underwater weight, number of stems, but had a positive effect on the nitrate content and yield. A mix of different nitrogen formulated (nitrate, ammonia and urea) fertilizers was better. Planting distance was negatively correlated to tuber weight, so planting the potatoes closer to each other resulted in an increase of tuber weight. There is an optimum for planting distance and seed size. Clay fraction represents the soil type of the fields. More yield is achieved on a heavier soil (more clay) but negatively affected the root weight. A sandy soil contains less water and therefore according to the results the amount of nitrogen in the plant increases. A lower soil conductivity suggested a higher number of tubers. A higher nitrogen content in the soil did cause a decrease in flavonoid. On soils with a low phosphate content, a higher stem density was obtained. Beside the macronutrients boron (micronutrient) caused a reduction in stem length.

Different plant characteristics were related to each other. All the results are therefore related not only for that particular plant characteristic but also for others. To obtain a high yield a high shoot weight and therefore a high stem length, compound leaves and nitrate content were important to intercept radiation and therefore for the yield. The number of stems was important to intercept radiation and a higher stem density implies more tubers. More stems imply also more roots which lead to a higher flavonoid level. A high stem density also results in more tubers, which implies smaller tubers. More shoot weight was related to a higher number of compound leaves and a higher root weight was negatively related to the nitrate content in the leaves and compound leaves. For the management, soil and weather variables an HPGENSELECT procedure is performed. The parameters that were important to obtain the optimal growth curve were: seed distance, total potassium, variety, field wetness, KAS and sulfasote. The most optimal curve was estimated at 133 ton/ ha, based on parameters that were inside the range that were used.

Based on this report, the importance of the radiation, plant available water content (GHG and rainfall) in the soil and plant available nutrients (soil nutrients and fertilizer) showed to be the main factors influencing the potato yield. Further research is needed to investigate the influence of the different fertilizer application, different mixes of fertilizer (also manure), soil conditions and their effect on the potato yield. A higher number of tubers was related to a lower amount of nitrate content in the leaves and compound leaves. Because more stems indicated more tubers and therefore more intraspecific competition. According to the findings flavonoid increases if the plant experiences more stress due to water and or nutrients (less nitrate in the leaves). So, to obtain a high yield with a relatively high underwater weight, a high stem density should be obtained by planting bigger seed potatoes, so the number of tubers would be relatively high.

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List of acronyms, special terms and abbreviations

Plant characteristics

AGB	:Aboveground Biomass	
DAP	:Days After Planting	
GDD	:Growing Degree Days	
GWK	:Tuber weight	(Gewicht knollen)
LGW	:Shoot weight	(Loof gewicht)
WGW	:Root weight	(Wortel gewicht)
OWG	:Underwater weight	(Onderwater gewicht)
AST	:Number of stems	(Aantal stengels)
ASB	:Number of compound leaves	(Aantal samengestelde bladeren)
AKN	:Number of tubers	(Aantal knollen)
STL	:Stem length	
PPM	:Nitrate content (PPM)	
CHL	:Chlorophyll	
Flav	:Flavonoid	
NBI	:Nutrient Balances Index	
Yield	:Fresh weight of potatoes in kilogram per hectare	

Results

p	: Value of significance level
R^2	: Goodness of fit measurment
SSA	: Subject Specific Analysis

Sign

ns	: Not significant
-	: No observation
na	: Not applicable
***	: P value <0.001
**	: P value <0.01
*	: P value <0.05

1 Introduction

1.1 Potatoes as an important crop

Potato is a very important source of energy for all humans around the world. The average consumption in 2011 was 96 gram/capita/day (FAO, 2014). It is the fourth most important crop of the world, after maize (1), wheat (2) and rice (3) in terms of production (net ton) (Birch *et al.*, 2012; FAO, 2012). The potato (Solanum tuberosum L.) crop is an economically important crop in the Netherlands. The crop is mainly grown for seeds, starch and consumption. The total area of potatoes was around 180.000 in 2000; in 2016 the area was decreased to 157.540 hectares (Anonymous, 2017a). Potatoes are mainly cultivated in the Northern Hemisphere (figure 1.1). The yield that is obtained ranges a lot, due to climate, soil conditions, etcetera. The yield that is obtained in the Netherlands fluctuates over years, this is due to that the yield gap and potential yield varies over the years. Globally the yield differences due to different potential yield and those yield gaps (figure 1.2). On average an actual yield of 43.8 ton/ha was harvested in the Netherlands (seed, starch and consumption potatoes) in the period from 1994 until 2016 (Anonymous, 2017a), which are relatively high (Licker *et al.*, 2010; Monfreda *et al.*, 2008).

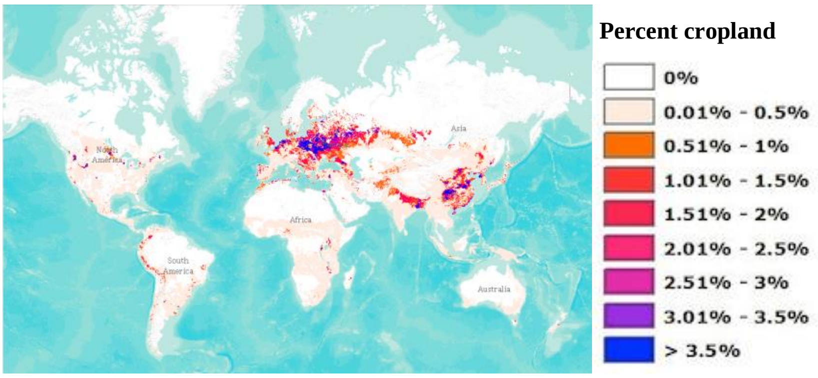


Fig. 1.1 Area of potato (% of total cropland in a region) across the globe (RTBMaps, 2017).

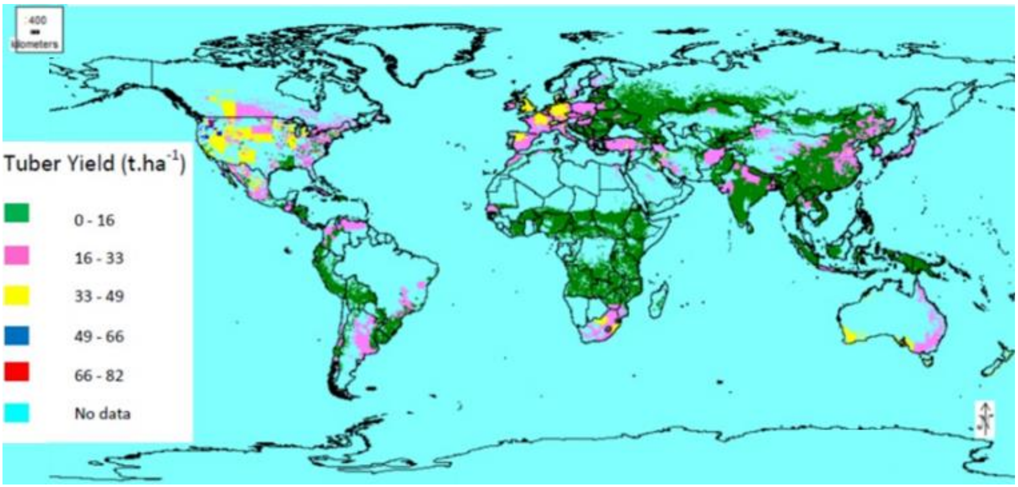


Fig. 1.2 Actual potato yield at global level by Monfreda et al. (2008).

1.2 Yield gap analyses in potatoes

Yield gap analysis can provide insights into the scope for sustainable intensification (Van Ittersum *et al.*, 2013). The gap is identified as the difference between the actual and potential yield, based on reducing, limiting and defining factors (figure 1.3). Silva et al. (2017) showed that the yield gap of ware potatoes in the Netherlands is 29%. Rietema (2015) analysed potato yields at Van den Borne based on data from 2013 and 2014, but a large part of the yield gap could not be explained. Soil conditions (e.g. nematode pressure, soil nutrients and structure) and other yield decreasing factors such as blackleg and insects seemed to be very important. Soil conditions were however unknown, but seemed to have a larger impact than the crop management characteristics. Rietema (2015) results showed that the following variables were influencing the actual yield:

- Planting window
- Irrigation capacity
- Lack of information on field history
- Bad field quality (soil properties)

The correlations (R^2) that were obtained with multiple regression analyses to explain yield were 0.17 for 2013 and 0.23 for 2014. Those correlations are very weak (Mukaka, 2012). Another research that is related to potato yield gaps is the research of Machakaire *et al.* (2016). The crop model LINTUL-POTATO-DSS was used. LINTUL-POTATO-DSS is a model that is widely used to predict the dry matter production for potatoes, which is based on the amount of intercepted light by potatoes and by the radiation-use efficiency under nitrogen and water-limiting circumstances. Machakaire et al. (2016) forecasted the yield and tuber size in South Africa. After calibration of the model, an R square of 0.635 was obtained (Machakaire et al., 2016). Besides the quantitative studies also a qualitative study was performed on potato yield gap analysis. Hengsdijk and Langeveld (2009) did research for Central, Eastern, Western Europe and the CIS countries (Belarus, Russia, and Ukraine). Based on the expert assessment they identified five key yield gap components: (1) water; (2) nutrients; (3) pests; weed; diseases; (4) mechanisation and (5) knowledge systems. The experts assessed the importance of these components in percentages. The outcome was that 80 % of the yield gap is due to water, ten per cent due to knowledge and ten per cent due to pest, weeds and diseases. All those analyses did not explain the variation in yield in relation to the soil and crop management factors in the Netherlands. A crop model would potentially be a good tool to predict the potato yield. However, it does not include all the limiting and reducing factors influencing yield. Only weeds, pests, diseases and pollutants are included as reducing factors, while the soil structure also reduce the yield. Other reducing factors like pests and diseases, and the quality of the seed tubers are also not included in crop models (figure 1.3). To reduce the yield gap, precision farming can be used to reduce the environmental impact and maximize the yield (Van den Brande, 2015). Traditionally, a fertilizer application differs not within a field. By using precision farming different amounts of fertilizer and irrigation can be applied within the field to the crop to maximize the efficiency.

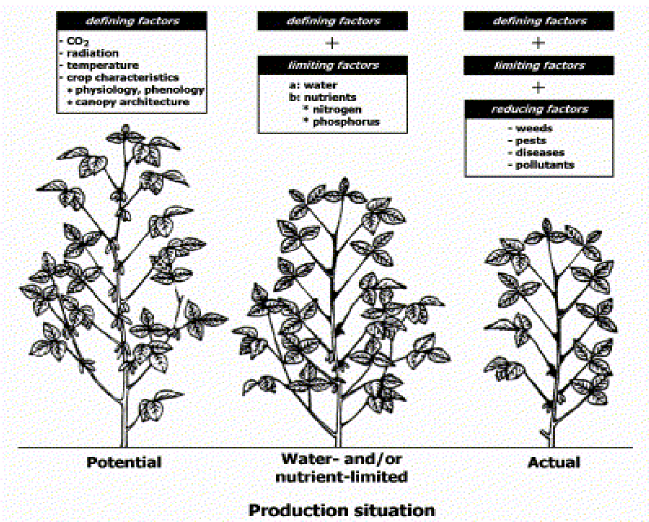


Fig. 1.3 Defining, limiting and reducing factors for crop production (Van Ittersum *et al.*, 2003).

1.3 Precision farming

In the Dutch agricultural sector, precision farming becomes more important, especially for high-value crops. This is due to the relatively high land prices and decreasing nutrient amounts, restricted by the government. These restrictions are a result of an overdose of nutrients and chemical protection agents, which caused negative effects on the environment (Dietz and Hoogervorst, 1991). It is important for farmers to exploit their fields as optimal as possible and to minimize the environmental impact, by making use of precision farming. Precision farming makes it possible to vary doses of nutrients and chemical agents within fields (Atherton *et al.*, 1999; Stoorvogel *et al.*, 2015). Precision farming makes it possible to monitor fields more closely, by looking at the different soil and crop circumstances at specific locations. The possibility to adapt management based on these varying conditions depends on the machines (Van den Borne, 2015). All fields have varying soil characteristics; the picture below (figure 1.4) shows an example of the variability in soil conductivity in a field (Cambouris *et al.*, 2006). Liebig's "Law of the minimum" showed the concept that a particular minimum element determines the final yield (Thomas, 1929). Figure 1.4 shows that a limiting element related to soil conductivity (e.g. water availability) varies in a field. In the agricultural sector, data analysis becomes more important, as precision farming requires more understanding of the data that is collected and new sensors allow for more data collection to analyse (Haverkort *et al.*, 2006). The main question with such large datasets is: "how to make those datasets useful for advice on the farm?" (Janssen and Andeweg, 2015). The amount of data is quickly expanding and the techniques to analyse that data are still limited, which limits useful advice based on the obtained data. Some people mentioned that the data is big data. But this is not the case in this report and in many other cases .

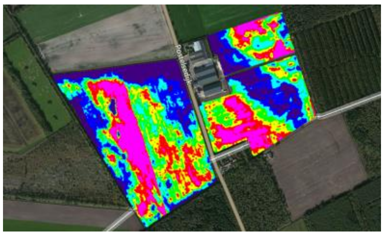


Fig. 1.4 An example of a soil conductivity map (Van den Borne, 2015).

1.4 Big data

There is no big data set used in this study. The concepts that are used in bigdata can give more inside in how to analyse and get information to give advice based on the data. The definition of big data is: "Big data is a term describing the storage and analysis of large and or complex datasets using a series of techniques including, but not limited to NoSQL, MapReduce and machine learning" (Stoorvogel et al., 2015). An easier definition according to Oxford dictionary is: "sets of information that are too large or too complex to handle, analyse or use with standard methods"(Oxford_Univeristy, 2013). To analyse big datasets and to get wisdom from it, is very difficult. The first step is to get information about the (big) dataset. For example, to know the relations between the variables. The second step is to obtain knowledge from the information. So how the information from the large dataset can be implemented in the farm, so decisions can be made based on the knowledge that is obtained from that information. The last step is to get wisdom from the knowledge. So, the trade-offs and associated risk with the implication (figure 1.5). The figure indicates the different disciplines and difficulties to get practical implication from the datasets. The dataset that Van den Borne obtained is not a big data set, but it is a large dataset, due to all the measurements and information that are collected by the farmer.

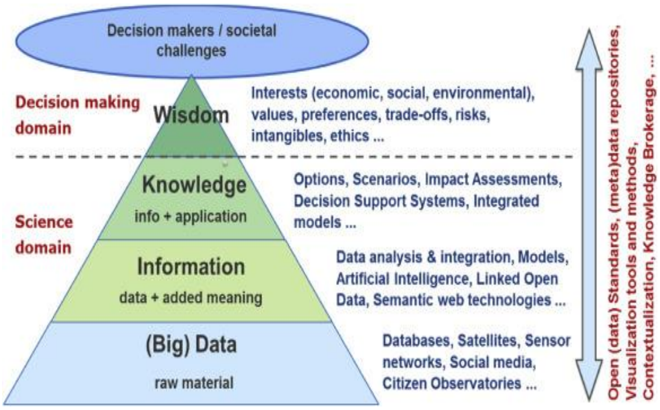


Fig. 1.5 DIKW hierarchy, from Big Data to decision making for societal challenges (Lokers *et al.*, 2016)

1.5 Van den Borne Aardappelen

For this study, the focus is on analysing data that is obtained with precision farming at Van den Borne potato in Reusel. The farm is located in the South of the Netherlands. Van den Borne cultivates more than 500 hectares of French fries potatoes. The fields that the farm cultivates are on average 3 hectares and therefore around 130 fields are cultivated every year with potatoes (Van den Borne, 2017). The reason why the farms are using precision farming is because the soil characteristics and crop rotation of all fields are not always known on the farm of Van den Borne (Rietema, 2015; Van den Borne, 2017). All the different aspects of precision farming are collected for nearly all fields; this is shown in figure 1.6. The opportunity of the data is to analyse which factors influence the yield and quality of the potatoes. A quality parameter that is measured in the dataset was underwater weight. The research question in this study focus on those aspects. The yield of potatoes in the Netherlands is mainly limited by water, especially the sandy soils (less water holding capacity). The soil of van den Borne is mainly sand. Clay soils will provide more water, due to capillary raise from the groundwater (Zhmud *et al.*, 2000).

1.6 Research questions

The aim of the study is to investigate: **"What is the influence of soil characteristics, crop management and weather conditions on plant characteristics and what is their effect on the final potato yield?"**

For answering the main research question, several sub-questions were formulated:

1) " *What are the relationships between the plant characteristics (growth curves) and the underlying factors (soil, crop management and weather) and the output variable potato yield over 4 years?*" Plant characteristics that are analysed include tuber weight, shoot weight, root weight, underwater weight, number of leaves, number of tubers, number of stems, nitrate content, flavonoid content and chlorophyll content of the leaves. The outcome of the mixed models were compared between fields to analyse significant differences between the each plant characteristic and factor (management, soil and weather condition).

2) "*Which factors together can explain the potato plant growth and final potato yield in different years?*" First the interactions are tested between the plant characteristics. Secondly, multiple factors are combined in a generalized linear model to explain the combination of factors how these influences the yield.

2 Material & Methods

2.1 Data source

To analyse and explain potato yield variability at Van den Borne Potatoes, a few materials were gathered. These materials are:

- Dataset of Van den Borne Potatoes from 2013 till 2016 (paragraph 2.1.1)
- Soil data (Appendix 3)
- Weather data (Anonymous, 2017b) in Appendix 2
- Results and method of Mulders (2017) (section 2.7)

2.1.1 Precision farming data (2013-2016)

The data was collected by Van den Borne Potatoes from 2012 to 2016 in Reusel. In the dataset of 2012, a lot of data is missing, for example the data from the dualex (plant measurement) and dualem 38 (soil conductivity), and therefore these data were not used for analysis. A summary of the data is inserted in appendix 3. During the growing season, the farmer collects destructive plant measurements to assess the growth (table 2.1). This number of destructive measurements to assess growth in plant characteristics increased over the years: 3 in 2013, 4 in 2014, 5 in 2015 and 8 in 2016. Besides that the number of observations differed per year, also per field measurements were differed. Plant characteristics were not always measured at the same moment, due to lack of time. Until now the importance of gathering different parameter during the season was not proven to be helpful to get a complete picture about the potential of the fields. The amount of dry matter weight of potatoes is expressed in this report as underwater weight. Simmonds (1977) showed that, underwater weight and other dry matter approaches were correlated to the dry matter content. Besides the plant characteristics, also the management and some soil variables were measured and collected per field. In appendix 3.3 a summary of the management practices are presented. The applied nutrients were summed together because during the year multiple fertilizations were applied on the field with different contents of nutrients and different dosages. Finally, the yield that is obtained ranges a lot per field, but also within a field and within years. The yield ranges from above 100 ton/ha to less than 10 ton/ha (figure 2.1). The average yield over the years is nearly 60 tonnes per hectare. So, there is still a lot of yield to gain.

Table 2.1 Overview of plant characteristics and how they were obtained (Bartelen, 2016).

Acronym	Data variable	Unit	Description
ASB	Stems / 3 plants	# 3 plants -1	Number of stems per meter row
STL	Stem length	cm	Average stem length in the plot
ASB	Number of leaves	# stem-1	Average number of compound leaves per stem
LGW	Foliage weight	g 3 plants-1	Total fresh foliage weight of the measured plants per plot
WGW	Root weight	g 3 plants-1	Total root weight of the measured plants per plot
AKN	Number of tubers	# 3 plants-1	Number of tubers per meter row
GWK	Tuber weight	g 3 plants-1	Total tuber weight of the measured plants per meter row
OWG	underwater weight	g g-1	Final underwater weight in gram per 5050 gram fresh potatoes weight
PPM	Nitrate content	PPM	Nitrate content average of 3 measurements
CHL	Chlorophyll content	$\mu g/cm^2$	Chlorophyll content measured on 1 leave
FLAV	Flavonoïd	g/cm2	Flavonoïd content measured on 1 leave
NBI	Nutrient Balance Index	Chl/flav	The ratio between Chlorophyll and flavonoid

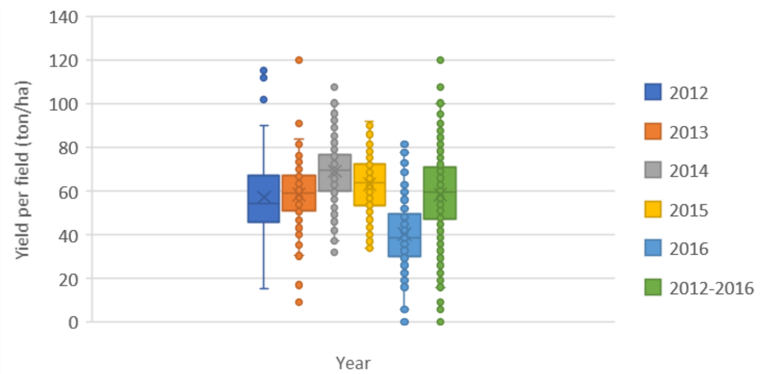


Fig. 2.1 Potato yield variability at field level at Van den Borne in the south of the Netherlands from 2012 to 2016 (Van den Borne, 2017).

2.1.2 Weather

To compare datasets that are obtained in different years, multiple weather variables will be used in the report. There is a weather station placed on the farm at Van den Borne. The data will not be used due to errors and a lot of missing weather data. The daily measured data that is used is obtained by the KNMI weather station in Eindhoven. KNMI weather station in Eindhoven is only 22 kilometres located from the farm. The weather patterns (especially rainfall patterns) are similar to the data obtained by Van den Borne (figure 2.2). Besides this data in 2015 and 2016, a rain metre is placed in different fields. Those results will also be used and compared with the results from KNMI, because Yan (2015) showed that there is a large variation between locations. During the samples measurements (shoot weight, tuber weight, etcetera), also the rain meter was checked and recorded, and those data will be used for the analysis. The pitfall of those data is that the data is only measured during spraying (ones every five days). To have verified data (table 2.2), the data from Eindhoven was used from the KNMI in Eindhoven.

Table 2.2 Overview of weather variables

Weather variables	Unit
Temperature (min, max, average)	ºC
Sunshine duration	hour
Global radiation	J/cm2
Precipitation duration	hour
Daily precipitation amount	mm
Daily mean relative atmospheric humidity	%
Potential evapotranspiration (Makkink) (Van der Schrier *et al.*, 2011)	mm

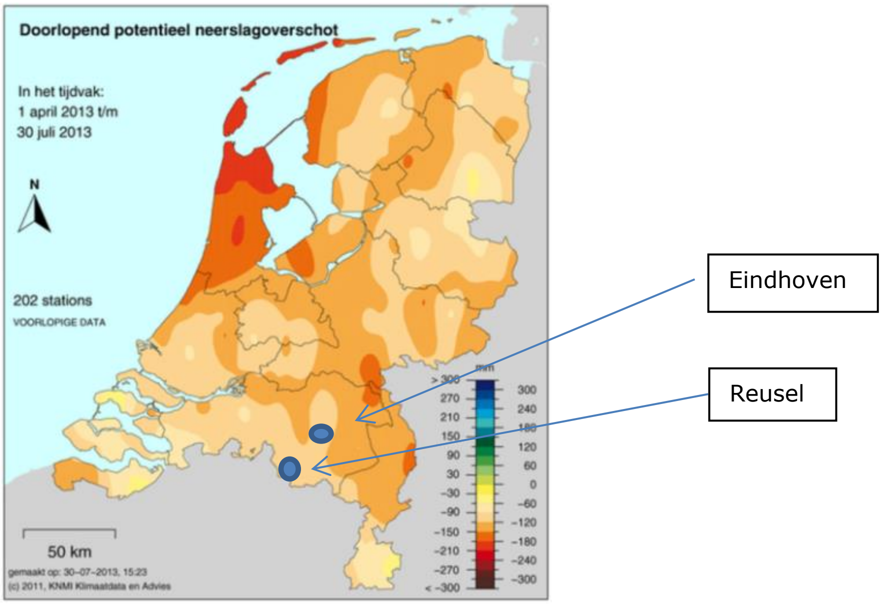


Fig. 2.2 Rainfall surplus from 1 April 2013 till 30 July 2013 KNMI (Anonymous, 2017b)

In the Netherlands on average, the yearly rainfall was 745 mm (in Eindhoven). The timing and intensity of the rain are very important. In 2014 the rainfall was in total 805 mm in 546 hours, while in 2015 681 mm in 670 hours. The intensity was therefore quite different (~1.5 mm/hour in 2014 vs ~1 mm/hour in 2015). For diseases, especially Phytophthora, a less intense rainfall causes a longer time of wetness of the leaves and that is beneficial for the disease; also for the potatoes less intense rain is beneficial for the water-limited yield of potatoes in the Netherlands (Skelsey, 2008; Yuan *et al.*, 2003). Besides the rainfall also the minimum and maximum temperatures during the growing season are important (appendix 2). The amount of radiation intercepted determines the potential yield obtained by potatoes. Radiation is related to rainfall, so if radiation is high, the amount of rainfall is low. Rainfall causes clouds that hinders the radiation to enter the surface of the earth. For example, in June 2016 the amount of radiation intercepted was 150 J/cm^2/month and in 2015 245 J/cm^2/month, while the rainfall amount in June 2016 was ~200 mm and in 2015 only ~30 mm. The hours of sunshine differ not much compared with intercepted radiation and rainfall. The largest difference was between 2016 and 2015 (5000 vs. 6400 hours/ month) according to appendix 2 (figure A.2).

The Relative Humidity (RH) is very important because the yield of potatoes is limited by rain. A relatively high RH is beneficial for the growth due to less stress. The period in August is the most important month for the yield. In 2014 the RH was the highest in August, this is one of the reasons why the average yield was so high compared with other years (2013, 2015 and 2016). A high RH is accompanied by a relatively low temperature and high rainfall (June 2016). During the year the RH is decreasing until May- June in Eindhoven. This implies an overall lower RH (~70%) during the growing period (April-September).

2.1.3 Soil maps

According to Yan (2015) the soil type and related water holding capacity are important, therefore the soil maps were used from Belgium and the Netherlands. Every field contains different soil types, according to Finke (1993). That spatial variability in the soil will have a different impact on the plant growth. So, for every field, the average clay, loam and sand content was determined, together with the soil water table depth: GLG =Ground water table in the summer (low) and GHG groundwater table during winter (high). To obtain those data, data is used from both countries: Belgium and the Netherlands. The soil type of Belgium was determined based on the map that can be viewed in Lambert (1990). The explanation of the data can be reviewed in Van Ranst and Sys (2000). The locations of the fields are presented in Appendix 6. In the Netherlands, the soil map can be found on paper that is provided by Wageningen (Steur *et al.*, 1985). The chart provides the soil type and groundwater measurements. That information combined with the rainfall gives an indication of the water circumstances of the fields, according to the findings of Yan (2015).

2.1.4 Variables

The different variables are separated according to Van Ittersum et al. (2003) hierarchy of growth factors, production situation and associated levels. The main category with capital letters is defining (D), limiting (L) and reducing (R) factors. The subcategories of variables are made based on soil (s), management (m) and weather variables (w). In Appendix 3.2 the variables that were used in this study are separated based on Van Ittersum et al. (2003) and with a subcategory with crop, management and weather variables. The **defining** factors are all the weather variables except the rainfall, only the temperature, relative humidity and radiation. The defining weather characteristics were the radiation amount and duration and temperature sums. The **limiting** factors only imply the water and nutrient associated growth factors, so for the management, all the fertilizer variables were included, besides this also irrigation and soil variables were included. For the **reducing** factors only previous crop, groups of spraying and granule were included. In Appendix 3.2 an overview is presented how the measurements were taken and according to which protocol.

2.2 Data handling

Mulders (2017) performed an explanatory study analysing potato yield variability at Van den Borne in 2016 (Mulders, 2017). This study is used as a starting point for further improvements.

2.2.1 Software

Mulders (2017) used Python, R and SAS. To continue the study those programs and codes were used and the data analysis is extended for multiple years (2013 till 2016), instead of only for the data from 2016. SAS 9.4 was used to analyse the data, with different procedure such as: proc mixed, proc glimmix, Hpgenselect and the logistic and one-way ANOVA analyses. The visualization was performed using R version 3.4.0 in RStudio 1.0.143. Python 3.6 was used to standardize the dataset and calculate the growing and growing degree days using Pycharm 2016.3.2. The most important scripts from the analyses are presented in Appendix 1.

2.2.2 Data handling, error correction and standardization

I. The plants were measured per 3 plants by the farmer. Equation one is used for the recalculation to hectares based on the planting distance setting by the farmer in centimetre.

$$(\text{Plant characteristic}) *13333 *0.85) / ((\text{plant distance} *3) /100) \qquad (1)$$

II. The data contained a lot of errors and grammatic errors. To tackle this problem all data were checked on grammar, string, float and integer cell properties. Also, the maxima and minima were checked and if necessary removed.

III. All the data is plotted to detect the outliers, which are visualized in the supplementary materials.

2.3 Growth curves

For estimating the growth curves a few methods were used to determine the curves. Different plant characteristics follow different growth curves in time. In Appendix 4 a literature overview is inserted for the different growth curves for the individual plant characteristics.

2.3.1 Time variables

For the growth curves, two time variables were used: days after planting and growing degree days. For growing degree days (GDD) the cumulative daily mean air temperature is used. This method is discussed by Buwalda and Freeman (1987) and Tei *et al.* (1996) (Yuan and Bland, 2005). Days after planting is calculated from the day that the field is finished with planting.

2.3.2 Statistical background

Mulders (2017) analysed potato yields of Van den Borne potatoes in growing season 2016. Characteristics that were found to be significantly different between clusters in Mulder (2017) are included in Appendix 7.1. The method that was used is summarized in a few steps:

I. Fit with mixed model the growth functions (table 2.3) of change over time for every plant characteristic (e.g. haulm weight, tuber weight, nitrate in leaves) for every field.
II. Cluster the fields for every plant characteristic, based on the random growth curve parameters α_{ik}, β_{ik}, γ_{ik} and U_{ik} of the mixed model (table 2.3).
III. Average the alfa, beta, gamma and scale factor of the functions for the fields inside the clusters and make a graph of the functions.
IV. Conduct a one-way ANOVA for continuous variables and for nominal variables a logistic regression analysis to show whether clusters of a plant characteristic are significantly different regarding soil, crop management and weather characteristics ($p < 0.05$).
V. Use the one-to-one relationships found to develop a model including interactions, which best explains yield (HP GENSELECT procedure).

There are a lot of methods for analysing datasets. To start with the analysis, it is important to know whether the data is qualitative (do not contain any number) or quantitative (data that is numerical). The data that is provided by Van den Borne is quantitative, and consists of measured (continuous) and counted data (discrete) (Gibbons *et al.*, 2010). To identify the correct statistical method, it is important to consider the purpose of the study and the type of data available. Datasets can have two forms (Belli, 2008; Cohen *et al.*, 2007; Gingery, 2016):

1. Cross-sectional (data obtained on one point in time)
2. Longitudinal data (data obtained in multiple moments in time):
    a. Prospective or trend (track the same general population)
    b. Retrospective or cohort (track same specific population)
    c. Panel (track same sample over time)

The data that is obtained by Van den Borne potatoes is longitudinal data (retrospective data). For analysing longitudinal data there are a lot of methods developed. The two popular types of longitudinal statistical models are (a) population-averaged models which model the behaviour of the population and (b) subject-specific models; which will model the individual behaviour (Azari *et al.*, 2006; Davidian, 2006). Szmaragd et al. (2013) studied the difference between a subject-specific model and a population average model using the British Household Panel (Jenkins, 2010). According to them, a subject-specific model tracks the characteristics better in time compared to the population average model. For estimating the growth curves of potato, a mixed model for longitudinal data is used. The model is based on a biological parametric growth function. For the different plant characteristics, different growth functions were used. These are specified in the next section. Every field has parameters that are field specific. The parameters have fixed and random effect according to Johnson *et al.* (2013).

A quadratic function was used to estimate the growth curves for shoot weight, root weight, Underwater weight, number of tubers, number of compound leaves, nitrate in the leaves, chlorophyll, flavonoid and nitrogen balance index. For leaf-, root weight and compound leaves no intercept was estimated. For estimating the number of stems a linear model was used and for stem length and tuber weight an S-shaped curve is estimated. The formulations are presented in the next section.

For estimating the growth functions (curves) different mixed models were used. The models were used to model the individual behaviour of the fields in relation to the plant characteristics. In other words, it is assumed that the plants on the different fields have different growth functions. The models that were used to model those individual functions are mixed model programmes in SAS. The different mixed models were chosen based on the distributions of the data that was used. For linear normal distributed data PROC MIXED was used. If the data was not normally distributed such as with stems per hectare a Poisson distribution was used; for this type of data, PROC GLIMMIX was used. The last model that was used is PROC NLMIXED. This procedure is used when the growth curve had to fit a scale parameter based on a certain formula. This statement could be done more easily in NLMIXED than in the GLIMMIX procedure. The NLMIXED procedure is therefore used for tuber weight, stem length and underwater weight. For clarification, the different models are summarized in the next section.

2.3.3 Function formulas

For estimating the growth curves different mixed models were used to analyse the longitudinal data, to allow field variation. The models are based on a biological parametric growth function. For the different plant characteristics, there were different growth function used (table 2.3). The model statements for the above-mentioned formulas in SAS are inserted in Appendix 1. For every individual plant characteristic and for every field, a function is estimated. For all functions, a quadratic function is estimated, except for stem number, tuber weight and stem length. For underwater weight, nitrate content and flavonoid level, this function includes an intercept, for the other plant characteristics no intercept is estimated (table 2.3). The random and fixed variables are estimated for all the parameters that are individual estimated for the fields and years.

Table 2.3 Overview of type of functions and SAS procedures for the plant characteristics.

Plant characteristics	Type of function	Type of curve	Intercept (yes/no)
Tuber yield	NLmixed	S-shaped	No
Root weight	Mixed	Quadratic	No
Shoot weight	Mixed	Quadratic	No
Underwater weight	NLmixed	Quadratic	Yes
Number of tubers	Mixed	Quadratic	No
Number of stems	Glimmix	Linear	Yes
Number of compound leaves	Mixed	Quadratic	No
Stem length	NLmixed	S-shaped	No
Nitrate content	Mixed	Quadratic	Yes
Flavonoid level	Mixed	Quadratic	Yes

2.3.3.1 Quadratic curve with intercept

For every individual plant characteristic and for every field, a function was estimated (Institute, 2009; Johnson et al., 2013). For all functions, a quadratic function was estimated (equation 2), except for number of stems, tuber weight and stem length. For nitrate content in the leaves, number of tubers and flavonoid an quadratic function with an intercept is fitted. For underwater weight only one parameter is fitted, because α, β and γ were correlated. The α_{ik}, β_{ik} and γ_{ik} of the regression coefficients of the quadratic function are the fixed effects for the different years and random for the different fields and t_{ijk} is the time j in normalized growth days for field i and year k. The ε_{ijk} is the error term in the formula. Y is the result of the plant characteristic of field i at time j in year k.

$$y_{ijk} = \alpha_{ik} + \beta_{ik} \cdot t_{ijk} + \gamma_{ik} \cdot {t_{ijk}}^2 + \epsilon_{ijk} \quad (2)$$

2.3.3.2 Quadratic curve without intercept

For root weight, shoot weight, number of tubers and number of compound leaves, the quadratic function without intercept was fitted. The β_{ik} and γ_{ik} were the regression coefficients of the quadratic function and t_{ijk} was the time in growth days. For field i and year k. The ε_{ijk} is the error term in the formula (equation 3). For this analysis the data was not normalized, due to no intercept (with normalized day, the mean of t is equal to 0).

$$y_{ijk} = \beta_{ik} \cdot t_{ijk} + \gamma_{ik} \cdot {t_{ijk}}^2 + \epsilon_{ijk} \quad (3)$$

2.3.3.3 Quadratic curve with an intercept but only with one parameter

For underwater weight it was found in the research that the α, β and γ were correlated between the fields. Therefore, only one random variable was fitted for underwater weight (U_{ik}). The $α_k$, $β_k$ and $γ_k$ are the fixed variables of the quadratic function for the individual years and t_{ijk} is the time j in normalized growth days for field i and year k (equation 4). The $ε_{ijk}$ is the error term in the formula. The U_{ik} is the scale parameter and was calculated for i observations and k years. S and Q were fixed parameters and did not vary between years.

$$y_{ijk} = \alpha_k + U_{ik} + (\beta_k + S \cdot U_{ik}) \cdot t_{ijk} + (\gamma_k + Q \cdot U_{ik}) \cdot t_{ijk}^2 + \epsilon_{ijk} \tag{4}$$

2.3.3.4 Linear curve

The $α_{ik}$ and $β_{ik}$ were the regression coefficients of the linear function and t_{ijk} is the time j in normalized growth days for field i and year k (equation 5). $α_{ik}$ and $β_{ik}$ were the random variables for j observations and k years. The $ε_{ijk}$ is the error term in the formula.

$$y_{ijk} = \alpha_{ik} + \beta_{ik} \cdot t_{ijk} + \epsilon_{ijk} \tag{5}$$

2.3.3.5 S-shaped curve

For stem length and tuber weight it was found in the research that b1, c, b2 and S were correlated. Therefore, only one parameter was fitted for those variables (U_{ik}). The fixed parameters for year k are the regression coefficients of the logistic function for the individual years and t_{ijk} is the time j in normalized growth days for field i and year k (equation 6). The $ε_{ijk}$ is the error term in the formula. The U_{ik} is the scale parameter and will be calculated for j observations and k year.

$$y_{ijk} = \frac{(B1_k + U_{ik})}{(1 + \exp(-c \cdot (t_{ijk} - B2 - S \cdot U_{ik})))} + \epsilon_{ijk} \tag{6}$$

2.3.4 Normality of data

The data that was used is not always normal distributed. For the analysis it was assumed that the data was normally distributed, and therefore transformations were performed to obtain normally distributed data. Depending on the data first a log transformation was performed (Stroup, 2015). In this report only a log transformation was used. During the years different distributions were used due to the different amounts of sampling per year. Nearly all the variables are continuous, except the number of tubers, number of stems and number of compound leaves. For example, in figure 2.3.a an overview of the residuals is plotted, this figure indicated clearly a heteroscedastic dataset. After transformation (figure 2.3.b) this data shows to be homoscedastic.

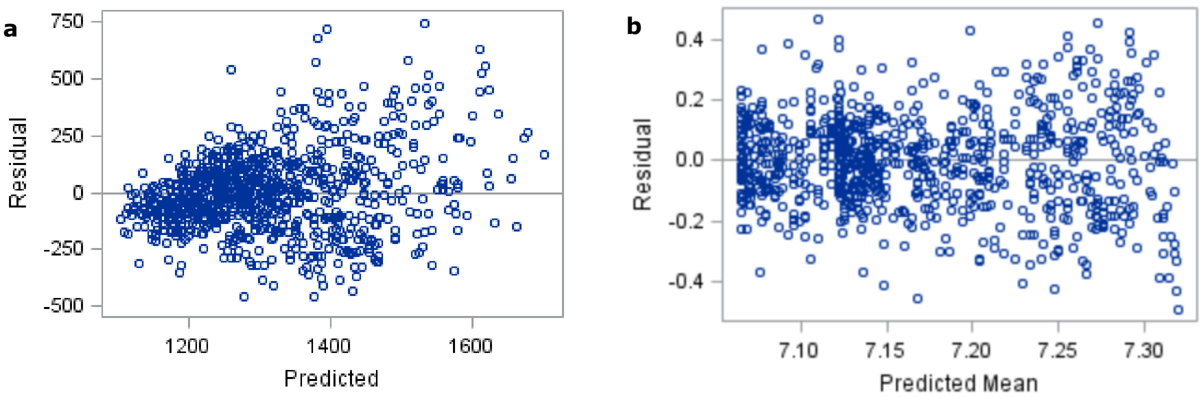


Fig. 2.3 Residual plot before (a) and after transformation (b) of flavonoid content fitted for growing days on data from 2013,2015 and 2016.

2.4 Number of clusters

For clustering, the parameters (αi, βi γi and uj) from the growth curves were used. In this report, the focus will be on the analyses over all the years (2013-2016), not the individual years. The number of clusters for the individual years and time variables (days after planting and degree days) were included in an additional report besides this study (supplementary materials).

2.4.1 Clustering method

For the analysis, a K-mean clustering method was applied (Hartigan and Wong, 1979; Mulders, 2017). The goal of the function is to minimize the equation 7. The $\vec{X}$ is the vector of the individual field and $\vec{\mu}$ is the vector of the average of a cluster. An observation (x) will be added to the closest K cluster. The next step is that the mean will be updated from the cluster where the observation has been added. This continues until all observation are assigned to the clusters. This will lead to the minimization (argmin) of the equation in equation 7 with k clusters. The distance between the clusters and observation were calculated with the Euclidean distance function, according to equation 8. N is the number of dimensions of the vector and $\underset{x}{\rightarrow}$, $\underset{\gamma}{\rightarrow}$ are the vectors were the distance is calculated between. X_i and Y_i are the clusters for i clusters. The goal of this step is to cluster fields in clusters with similar growth curves.

$$argmin \sum_{i=1}^{k} \sum_{x\epsilon i} ||\vec{X} - \vec{\mu}||^2 \quad (7)$$

$$\boldsymbol{d}\left(\underset{x}{\rightarrow}, \underset{\gamma}{\rightarrow}\right) = \sqrt{\sum_{i}^{n}(\boldsymbol{Xi} - \boldsymbol{Yi})^2} \quad (8)$$

2.4.2 Optimal cluster method

The reason why clustering methods were used is because the number of clusters is very hard to determine. If there was only a focus on finding the maximum likelihood model and the number of clusters would not matter, then the outcome would be that all the observations will have their own cluster. Therefore the increase of a number of clusters must give a penalty to generate the most optimal number of clusters. There are several methods to calculate the optimal number of clusters, therefore the selection criterium to determine the best clustering method was that the maximum number of clusters would be less than 25 if the total maximum cannot exceed 50 clusters. The numbers of clusters that were used are arbitrarily, but the ranges that were used are quite large for a dataset of around 500 fields. The methods that were compared are summarized in Appendix 5.

All the methods were compared and validated based on the data that was used to do the analysis. The methods that outperformed other methods were the functions of Scott and Symons (1971) and Krzanowski and Lai (1988). Due to the robustness of the analysis, the KL method was used to calculate the optimal number of clusters (equation 9, 10 & 11). This was calculated over all the 497 fields (Dumenci and Windle, 2001; Sekula, 2015). Krzanowski and Lai optimal cluster equations 10 represent the ratio between diff G+1 (equation 9) and diff G (Charrad *et al.*, 2012; Zhao, 2012).

$$DIFF(g) = (g-1)^{2/p} * S_{(g-1)} - g^{2/p} S_g \quad (9)$$

$$C_g = \frac{DIFF(g)}{DIFF(g+1)} \quad (10)$$

$$S = \sum_{i=1}^{n} ||x_i - c_{pi}||^2 \quad (11)$$

G is the number of clusters and p the number of variables included in the model. S is the within-group sum of squares. The optimum value of the number of clusters (g) is the value that maximises C_g in the equation. During the use of the method it is taken into account for the size of the sum of squares within clusters (equation 11), this is due that a small SSW divided by a much smaller SSW in a next cluster will results in a high Cg value, what not represent the most optimal cluster number (Krzanowski and Lai, 1988).

2.4.3 Collinearity

During the analysis of the data, it was reported that in some cases there was collinearity between the parameters in the different models that were used. For example, in underwater weight, it was noticed that the intercept, slope and square were highly correlated. Therefore, a scale parameter was used to track the individual behaviour of the field regarding underwater weight. Before the clustering, it had to be checked if there was collinearity between the parameters that were used as input for the cluster analysis. The effect of multicollinearity in data has been explained in detail for example by Grapentine (1997) and Sambandam (2003). Those examples show the importance to check the assumption of independent variables during cluster analyses.

2.5 Differences among plant characteristic clusters

For all the plant variables the outcome at 100 days after planting and 2000 growing degree days for all the clusters were presented. This can be used to compare fields and to know what can be expected from those fields in relation to previous years. Those values also represented the outcome of the clusters in relation to the crop, management and weather variables. To analyse the variability among cluster in yield, and in explaining variables like soil, weather and crop management variables, ANOVA and logistic regression were used. ANOVA was used if the variable was a continuous variable (for example: 0,1,2) and logistic regression was used where the was a nominal variable (for example size of seed potatoes: small, average, big).

2.5.1 Continuous variables

The differences between plant characteristics clusters and soil, crop management, weather conditions and yield were assessed by making a one-way ANOVA test for continuous variables. For continuous variables, the model in equation 12 was used.

$$y_{ij} = \mu + \alpha_i + \epsilon_{ij} \quad (12)$$

Y_{ij} is the outcome of the j^{th} measurement of the i^{th} field, μ is the overall mean and α is the effects of the cluster and ϵ is the standard error term. The F-statistic is calculated by calculating the mean squares within and between the clusters. From the F-statistic a p-value was calculated, and when the p-value is smaller than 0.05 between the clusters, this variable is significantly influencing the plant characteristic (Heiberger and Neuwirth, 2009).

2.5.2 Nominal variables

For the nominal variables, a logistic regression analysis was used, because such a variables has more than two possible responses. A generalized logit model (GLM) was fitted (equation 13). The GLM model compares the non-referenced categories to a reference category. The reference category is, for example, small tuber size when the seed potato size is compared.

$$\eta_{ij} = log\frac{\pi_{ij}}{\pi_{iJ}}\alpha_i + \beta_i\alpha, \quad i = 1, \dots , k \quad (13)$$

In equation 13 and 14, J is a reference category and i the response and j the other categories. K is the number of non-reference categories, α and β are vectors of regression coefficients. ∏ij will give a probability that i will fall in j (equation 14). In this equation the probability function is presented, so what the chance is that a certain variable fit in the reference category j (Kleinbaum and Klein, 2010).

$$\pi_{ij} = \Pr(Y_i = j) \quad (14)$$

2.5.3 Analyse individual years of the subject specific analyses

After the analysis of the one-to-one relationships, those results were combined in a table, which shows the p-values obtained from the analysis over the years 2013, 2014, 2015 and 2016 and all years together this is presented in chapter 3. The obtained significant relations (p<0.05) are compared for the different years, to observe certain similarities and differences between the years. An overview of the results of the time variable growing degree days was inserted in appendix 8.

2.6 Optimal yield

To explain the yield variability, a model is made for the most optimal curve. The model predicts yield based on the soil, crop management and weather condition from data from 2013 to 2016.

2.6.1 Interaction between plant characteristics

The interaction between plant characteristics is presented by using Spearman correlation between the field clusters. There is a green and red line for a positive and negative correlation and a small (0.3-0.6) and thick line (0.6-1.0) for the correlation (Mukaka, 2012).
The interaction between years for the individual plant characteristics was performed by taking the average cluster number for the individual years. The years were organized based on high to low average cluster number, with visual pattern scanning.

2.6.2 Optimal curves

The final question is how the soil, management and weather variables relates to the yield. This question was answered by performing a high performance procedure (HP GENSELECT) for tuber weight based on the parameter "U" in equation 5. The model that explains the optimal plant growth was made to predict the optimal plant growth for potato plants. When the optimal curve function was made, the variability in growth was derived from the model. The validation of this model could not be done, because there is no validate observation to determine those outcomes. For this purpose, different experiments need to be performed. For this procedure, a selection was made of variables which determine the optimal curve for tuber weight. The final output is the explanation of the potato yield variability over all the years.

The variables that were selected are the individual variables and all the interactions between the variables (soil, crop and weather conditions). The procedure was a forwards stepwise selection. First an intercept was fitted. After the first step, variables with the highest F statistics were added to the model. This step was continued until there were no variables that reach the cut off level (p-value less than 0.05). The final step was to calculated the AICC for the individual models. The variables that had the lowest AICC were fitted with the generalized linear model, with an Newton-Raphson with ridging optimization technique (Institute, 2015).

2.7 Study on data from 2016

Mulders (2017) conducted an explanatory study on data from 2016. In that study a quadratic function as presented in equation 2 and a linear function was fitted as presented in equation 6, with the proc MIXED and proc GLIMMIX were used. Beside the mixed models also a k mean clustering method was used. For the determining of the number of cluster a hierarchical clustering method was used. According visual scanning the number of cluster were chosen. ANOVA and logistic regression was also applied. For building an optimal model for shoot weight an HPGENSELECT procedure was used. An overview of literature that argue those results and an comparison between those results and from this study was inserted in appendix 11. The difference between the study of Mulders (2017) and the method in this report is the use of biological function for estimating the growth curves of the different plant characteristics. Beside the mathematical functions also another method was used for determining the number of clusters. Instead of hierarchical clustering the method of Krzanowski and Lai (1988) was used.

3 Results

The next paragraphs (3.2-3.11) will give an overview of the results for the individual plant characteristics. Relationships between the plant characteristics are reported in section 3.12. The optimal curves for the different plant characteristics are summarized in section 3.13. For information about the fit of the individual fields, a recommendation is to review the supplementary materials. All the plant characteristics significantly influence the yield of the harvester and weighbridge.

3.1 Modelling plant characteristics

The R-square represents the fit of the curve through the data points. The R-squares that were obtained for the functions that were fitted are visualised in table 3.1 with time variable days after planting (DAP) and for growing degree days (GDD). The fit of shoot weight, root weight and flavonoid level were not high, it ranges from 0.344 to 0.504 for days after planting. Beside the R-square, the residuals were important, for example for overfitted or normality. For more understanding about the fitting, in the supplementary materials the regression line with the datapoint are presented. An example of those pictures was inserted in figure 3.1. Besides the fit also for all the plant characteristics from every individual field were visualized. One of the fields is visualized in figure 3.2.

Table 3.1 R –squares of the fitted models for growing days (DAP) and growing degree days (GDD)

Variables	DAP	GDD
Shoot weight	0.425	0.740
Root weight	0.419	0.344
Tuber weight	0.890	0.801
Underwater weight	0.512	0.550
Number of tubers	0.733	0.739
Number of stems	0.680	0.660
Number of compound leaves	0.645	0.608
Stem length	0.858	0.801
Nitrate in the leaves	0.815	0.822
Chlorophyll index	-	-
Flavonoid	0.504	0.534
Nitrogen Balances Index	-	-

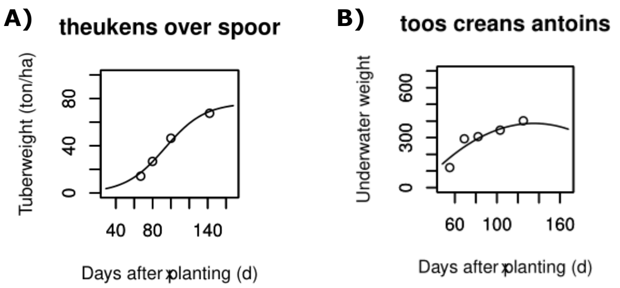


Fig. 3.1 Examples of fitted models on data for tuber weight (A) and underwater weight (B).

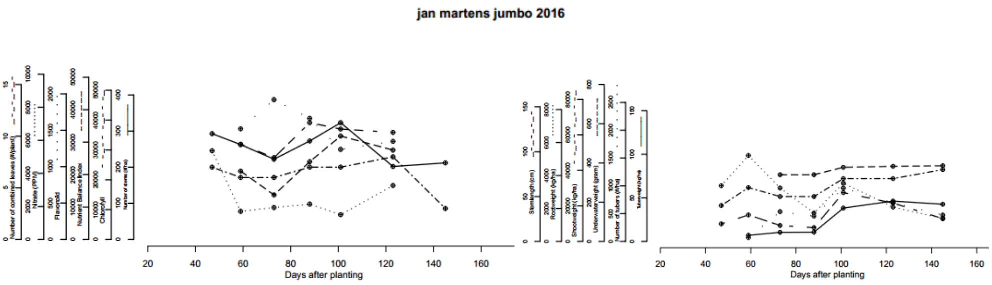


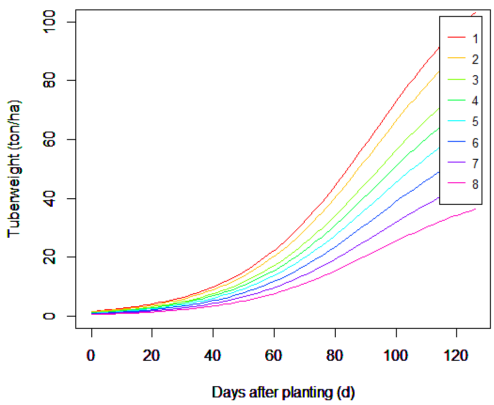
Fig. 3.2 Observation for field “Jan martens jumbo in 2016”, for all the plant characteristics.

3.2 Tuber weight

The main difference between the clusters is the level of tuber weight. Cluster one (which always represents the highest value that can be obtained) reaches over 100 tons/ha after 120 DAP, while cluster eight less than 40 tons/ ha after 120 DAP. The growth curves show the potential of the fields. The potential is the highest yield that can be achieved if the growing days and circumstances were the same. The first cluster shows that the measured yield and yield from the samples vary. The yield of the harvester was 43 ton per hectare even if the tuber weight on the sample size would be 73 ton per hectare after 100 days. The yield measured by the harvester in the fields with a lower growth curve was 45 -65 ton/ha, so slightly higher. Harvester yields were also lower for clusters 6 – 8, but the differences were smaller than based on the field measurements. The field in the cluster with higher predicted tuber weight, did not result in the highest yield according to the yield obtained from the harvester. The yield of the harvester is higher from cluster 3 to 8 than the predicted yield and lower for the first cluster, this is probably due to the high yield variability.

Table 3.2 Cluster information for tuber weight (n= 497).

Cluster	Number of fields (DAP)	Tuber weight at 100 days (ton/ha) Function	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Tuber weight at 2000 GDD (ton/ha)	Yield harvester ton/ha (GDD)
1	3	73 (3.57)	43 (9.8)	3	109 (11.2)	52 (21.8)
2	6	66 (2.79)	61 (17.6)	53	77 (6.8)	65 (15.6)
3	26	56 (1.98)	65 (16.3)	126	65 (4.5)	64 (16.2)
4	52	51 (1.68)	65 (17.0)	129	54 (5.0)	58 (16.1)
5	97	45 (1.83)	65 (14.8)	65	41 (6.3)	48 (15.0)
6	106	39 (2.37)	55 (16.2)			
7	60	32 (2.36)	50 (14.4)			
8	13	25 (2.53)	45 (15.1)			



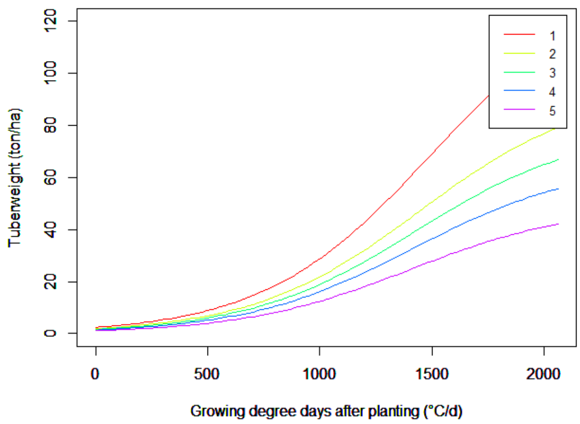


Fig. 3.3 Development of clusters over time for tuber weight.

Heavy clay soil did achieve the highest yield growth curve combined with a K50 fertilizer application in the first cluster. A higher planting distance resulted in an overall higher yield growth curve. The fields with the lowest tuber growth had a longer growing season and were planted later in the season. Due to a longer growing season also the temperature and radiation accumulation was high (table 3.4). The highest yield growth functions were obtained in 2013 and 2016. But on average there is no pattern that the yield functions differs too much in the different years (table 3.5).

Table 3.3 P-values of the ANOVA and logistic regression analyses for tuber weight clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	*	ns	L.s	Boron in the soil	ns	*
	Planting distance	**	ns		Calcium in the soil	ns	ns
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	ns	ns		Clay fraction	*	ns
	Variety	***	ns		C/n ratio	ns	ns
					Conductivity	ns	ns
D.w.	Radiation amount	**	ns		Drought sensitivity	ns	ns
	Radiation duration	*	ns		GHG	ns	ns
	Temperature sum from planting	*	ns		GLG	ns	ns
	Temperature till planting	*	ns		Iron in the soil	ns	ns
					Magnesium in the soil	ns	ns
	Evapotransporation	**	ns		Mangan in the soil	ns	ns
L.m	Irrigation	ns	ns		Nitrogen in the soil	ns	ns
	K50	***	***		Nutrient content in the soil	ns	ns
	K60	ns	ns		Phosphorus in the soil	ns	ns
	KAS	ns	ns		Potassium in the soil	ns	*
	Manure amount	ns	ns		Silicon in the soil	ns	ns
	Manure type	ns	ns		Zinc in the soil	ns	ns
	Magnesium from manure	ns	*				
	Nitrogen available	ns	ns	L.w	Rainfall amount	ns	ns
	Nitrogen from manure	ns	ns		Rainfall duration	ns	ns
	Phosphorus from manure	ns	*		Relative humidity	ns	ns
	Potassium from manure	ns	**				
	Sulphate from manure	ns	**	R.m	Granule	ns	ns
	Sulphasote	ns	ns		Group of spraying	***	***
	Urea	ns	*				
	Total nitrogen applied	ns	ns				
	Total phosphorus applied	ns	*				
	Total potassium applied	ns	ns				

Table 3.4 Average values for variables that showed significant differences between tuber weight clusters (DAP).

	Clay fraction	Radiation duration	Evapo-transpiration	Growing days haulm killing	K50	Planting distance	Radiation amount	Temperature until planting	Temperature until haulm killing
1	8.3	955	417	144	60.0	27.3	$24.1 * 10^{4}$	$24.2 * 10^{2}$	$24.2 * 10^{2}$
2	5.0	932	402	143	0.0	28.5	$23.3 * 10^{4}$	$23.5 * 10^{2}$	$23.5 * 10^{2}$
3	5.1	997	430	151	6.9	32.7	$25.0 * 10^{4}$	$24.8 * 10^{2}$	$24.5 * 10^{2}$
4	5.1	1001	431	151	2.3	32.1	$25.3 * 10^{4}$	$24.5 * 10^{2}$	$24.4 * 10^{2}$
5	4.9	1010	435	152	2.5	34.2	$25.5 * 10^{4}$	$24.6 * 10^{2}$	$24.6 * 10^{2}$
6	5.0	996	430	151	5.7	33.9	$25.2 * 10^{4}$	$24.6 * 10^{2}$	$24.5 * 10^{2}$
7	5.6	1028	442	157	9.0	34.5	$25.9 * 10^{4}$	$25.4 * 10^{2}$	$25.4 * 10^{2}$
8	4.6	1057	450	159	0.0	36.2	$26.4 * 10^{4}$	$25.8 * 10^{2}$	$25.6 * 10^{2}$

Table 3.5 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different types of varieties.

Cluster	Year				Variety					
	2013	2014	2015	2016	Dakota	Fontane	Ivory russet	Lady anna	Ludmilla	Miranda
1	1	-	-	2	-	2	-	-	-	1
2	2	2	1	1	-	5	-	-	-	1
3	9	6	5	6	-	23	-	-	-	3
4	20	14	10	8	-	43	-	1	-	8
5	29	29	25	14	-	84	-	-	-	13
6	29	31	17	29	-	79	8	-	8	11
7	17	13	10	20	2	45	3	-	3	7
8	4	1	3	5	-	12	1	-	-	-

3.3 Shoot weight

The number of clusters for the growing days is ten and for the degree days seven. The clustering indicated that the variation between fields is large, ranging from 13 ton/ha till 49 ton/ ha. The main difference between the clusters is the maximum observed shoot weight. The moment that the maximum shoot weight is obtained is generally later for clusters with smaller shoot weight. A high shoot weight resulted also in a high obtained yield (table 3.7). So, there is a large variation in shoot weight and a high shoot weight resulted in a high yield.

Table 3.6 Cluster information of fitted model for shoot weight (n= 497).

Cluster	Number of fields (DAP)	Shoot weight at 100 days (ton/ha)	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Shoot weight at 2000 GDD (ton/ha)	Yield harvester ton/ha (GDD)
1	8	49 (3.45)	79 (21.7)	13	40 (5.3)	73 (19.2)
2	20	45 (3,33)	69 (13.3)	31	34 (3.7)	67 (15.3)
3	34	39 (2,80)	64 (14.3)	73	31 (5.2)	67 (14.1)
4	60	35 (3,61)	64 (14.3)	98	26 (4.9)	61 (13.9)
5	68	31 (3,24)	60 (13.1)	77	22 (4.7)	58 (15.1)
6	71	28 (3,11)	62 (16.2)	57	18 (3.8)	50 (15.8)
7	42	24 (2,87)	51 (13.2)	22	11 (2.4)	33 (15.7)
8	34	20 (1,88)	48 (14.9)			
9	10	16 (1,50)	39 (10.8)			
10	13	13 (1,45)	33 (15.7)			

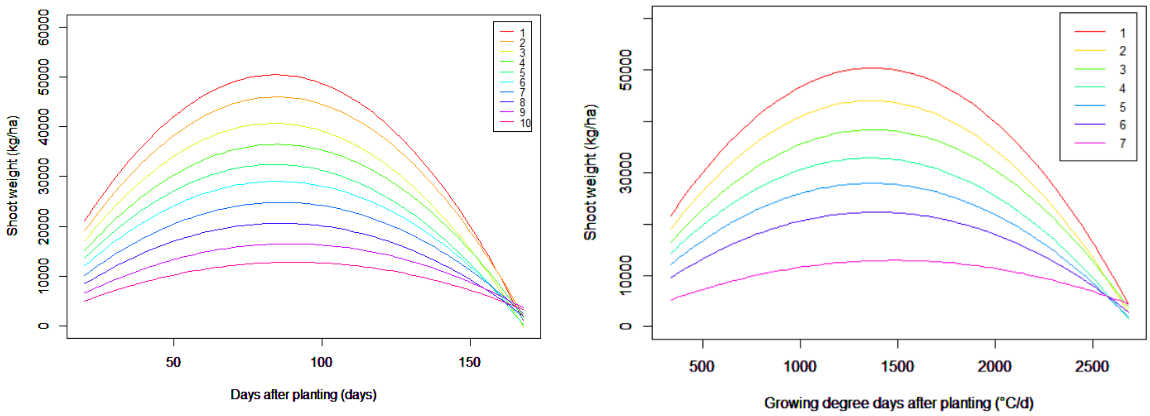


Fig. 3.4 Development of clusters over time for shoot weight.

Surprisingly, a high total applied nitrogen resulted in a lower shoot weight. A certain level of urea, however seems to be needed to obtain high yields, as the lowest yield was obtained with zero urea application. The nitrogen in manure did not differ much between clusters. Highest shoot weight was obtained with highest soil nitrogen levels, but levels varied among clusters. So a good soil is more important than fertilizer according the results. The results indicated that the amount of fertilizer was the main factor affecting shoot weight.

There were clear differences in shoot weight over the years. Shoot weight reduced over the years, with the first clusters mainly occurring in 2013. The type of manure did not have much influence on shoot weight; high shoot weight was obtained with different types of manure.

Table 3.7 P-values of the ANOVA and logistic regression analyses for shoot weight clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	ns	ns	L.s	Boron in the soil	ns	ns
	Planting distance	ns	ns		Calcium in the soil	ns	ns
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	ns	ns		Clay fraction	ns	ns
	Variety	ns	ns		C/n ratio	ns	ns
					Conductivity	*	*
D.w	Radiation amount	ns	ns		Drought sensitivity	ns	ns
	Radiation duration	ns	*		GHG	ns	ns
	Temperature sum from planting	ns	ns		GLG	ns	ns
	Temperature till planting	ns	ns		Iron in the soil	ns	ns
					Magnesium in the soil	ns	ns
	Evatransporation	ns	ns		Mangan in the soil	ns	ns
L.m	Irrigation	ns	ns		Nitrogen in the soil	**	**
	K50	***	***		Nutrient content in the soil	ns	ns
	K60	**	**		Phosphorus in the soil	**	*
	KAS	***	***		Potassium in the soil	ns	*
	Manure amount	ns	ns		Silicon in the soil	**	**
	Magnesium from manure	ns	ns		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	ns	L.w	Rainfall amount	ns	ns
	Organic manure type	***	ns		Rainfall duration	ns	ns
	Phosphorus from manure	ns	ns		Relative humidity	ns	*
	Potassium from manure	ns	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	ns
	Sulphasote	**	**		Group of spraying	***	***
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	ns				
	Total potassium applied	ns	ns				

Table 3.8 Average values for variables that showed significant differences between shoot weight clusters (DAP).

Cluster	Soil conductivity	K50	K60	KAS	Litre sulfasote	Litre urea	N manure	N soil	P2O5 soil	Si soil	Total N
1	2.7	0	81	205	75	110	102	305	12	7	289
2	NA	0	57	100	64	137	120	-	-	-	252
3	6.2	5	71	164	73	122	116	66	108	9	282
4	5.5	6	88	128	61	108	112	186	63	11	259
5	4.7	4	101	191	64	101	116	85	28	8	279
6	5.2	11	106	193	60	100	117	105	18	9	274
7	5.8	6	132	250	85	63	123	71	5	9	312
8	3.8	0	120	299	83	38	111	115	7	10	296
9	2.6	0	161	425	139	0	102	55	8	8	358
10	5.4	0	42	307	118	0	134	84	6	14	376

Table 3.9 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different manure types.

Cluster	Year				Manure						
	2013	2014	2015	2016	Compost	Goat manure	Calf manure	Chicken manure	Dairy cattle slurry	Cattle manure	Sows manure
1	5	2	1	-	-	1	-	-	1	5	1
2	12	8	-	-	-	-	5	-	3	10	2
3	22	8	2	2	-	3	7	1	4	14	5
4	24	20	11	5	-	1	15	-	7	27	10
5	29	17	10	12	-	2	15	-	14	31	6
6	14	25	20	12	1	3	15	2	6	31	13
7	4	10	17	11	-	-	12	2	4	19	5
8	-	4	10	20	1	-	8	-	3	17	4
9	-	-	-	10	-	-	1	-	-	9	-
10	-	-	-	13	-	-	4	1	-	4	4

3.4 Root weight

The number of clusters for the growing days is eight and for the degree days seven. The development of the curves over time was visualized in figure 3.5 a and b. Root weight has no clear influence on the tuber yield. There is no clear pattern in the outcome of the obtained yield of the fields.

Table 3.10 Cluster information of fitted model for root weight (n= 497).

Cluster	Number of fields (DAP)	Root weight at 100 days (ton/ha)	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Root weight at 2000 GDD (ton/ha)	Yield harvester ton/ha (GDD)
1	4	3.8 (0.06)	49 (13.9)	6	3.0 (0.09)	51 (12.1)
2	8	3.5 (0.21)	47 (18.0)	10	2.7 (0.06)	43 (16.2)
3	20	3.1 (0.13)	43 (13.3)	17	2.5 (0.13)	45 (14.3)
4	47	2.8 (0.22)	52 (20.3)	46	2.4 (0.26)	52 (17.8)
5	75	2.6 (0.17)	62 (17.8)	64	2.4 (0.23)	64 (20.8)
6	99	2.4 (0.13)	64 (14.9)	81	2.0 (0.16)	59 (13.6)
7	72	2.2 (0.12)	60 (12.4)	46	1.8 (0.13)	56 (13.0)
8	35	1.9 (0.11)	55 (14.6)			

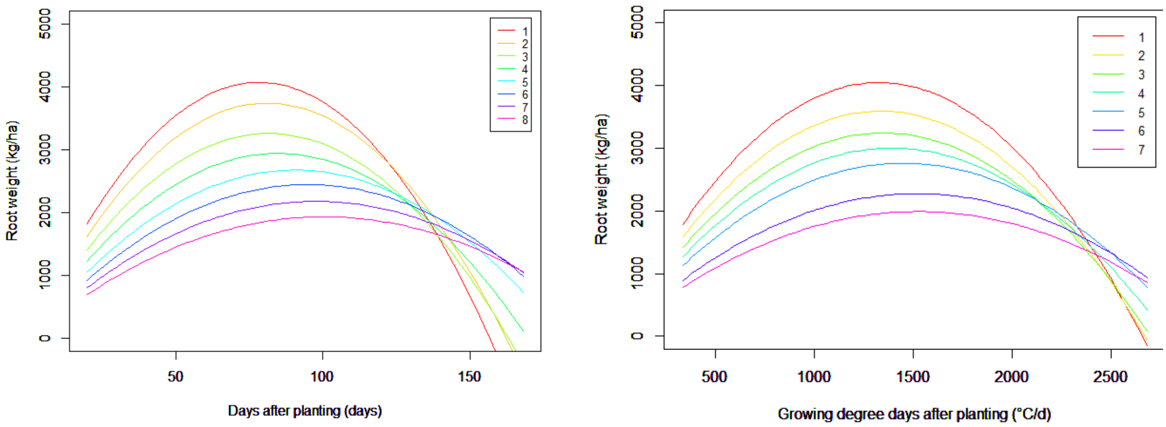


Fig. 3.5 Development of clusters over time for root weight.

A high root weight was obtained on a field with a low conductivity and high clay fraction, although clay fraction did not differ much between cluster 2 -8. Related to the management practices the high root weight had a high amount of K60, KAS application and a low planting distance. So, the amount and type of Nitrogen application and seed distance influence the root weight. The highest root growth function had also the highest amount of accumulated temperature, rainfall, evapotranspiration. Besides those findings also the highest root growth curves were planted later in the season (table 3.11). Root weight functions were different between years. In 2016 the highest root weight functions were obtained. The results indicated that bigger seed potatoes result in a higher amount of root weight (table 3.12 & 3.13).

Table 3.11 P-values of the ANOVA and logistic regression analyses for root weight clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	**	***	L.s	Boron in the soil	ns	ns
	Planting distance	***	***		Calcium in the soil	ns	ns
	Seed tuber Origin	***	***		Cation exchange complex	**	*
	Size of seed tubers	**	**		Clay fraction	**	**
	Variety	ns	**		C/n ratio	ns	ns
					Conductivity	**	***
D.w	Radiation amount	***	***		Drought sensitivity	ns	ns
	Radiation duration	**	**		GHG	ns	ns
	Temperature sum from planting	***	***		GLG	ns	ns
	Temperature till planting	***	***		Iron in the soil	ns	ns
					Magnesium in the soil	**	*
L.m	Evatransporation	***	***		Mangan in the soil	ns	ns
	Irrigation	ns	ns		Nitrogen in the soil	ns	ns
	K50	**	**		Nutrient content in the soil	ns	ns
	K60	***	**		Phosphorus in the soil	***	**
	KAS	***	***		Potassium in the soil	ns	ns
	Manure amount	ns	ns		Silicon in the soil	ns	ns
	Magnesium from manure	ns	ns		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	ns	L.w	Rainfall amount	***	***
	Organic manure type	ns	ns		Rainfall duration	**	**
	Phosphorus from manure	ns	ns		Relative humidity	ns	ns
	Potassium from manure	ns	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	ns
	Sulphasote	**	**		Group of spraying	***	***
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	ns				
	Total potassium applied	ns	ns				

Table 3.12 Average values for variables that showed significant differences between root weight clusters (DAP).

Clusters	Conductivity	CEC	Clay fraction	Radiation duration	EV	Growing days haulm killing	K50	K60
1	2.9	NA	8.3	$10.4 * 10^2$	449	158	0	133
2	2.3	NA	5.5	$11.0 * 10^2$	469	165	0	146
3	3.2	53	4.5	$10.4 * 10^2$	448	156	0	158
4	3.9	31	4.8	$10.0 * 10^2$	434	151	0	136
5	5.7	39	4.9	$10.2 * 10^2$	437	152	0	116
6	6.2	45	5.1	$10.2 * 10^2$	437	154	2	81
7	6.1	40	5.2	$9.8 * 10^2$	425	150	15	80
8	NA	41	5.9	$9.6 * 10^2$	412	145	22	52

Table 3.13 Average values for variables that showed significant differences between root weight clusters (DAP).

Clusters	KAS	Litre sulfasote	Litre urea	Mg soil	Nematodes	P2O5 soil	Seed distance
1	322	80	0	342	0	10	38
2	360	110	0	325	0.5	22	37
3	349	113	0	322	0.3	6	38
4	284	93	40	330	0.3	9	35
5	230	81	68	262	0.3	6	35
6	176	60	110	278	0.2	49	33
7	135	46	136	290	0.1	40	33
8	98	82	128	329	0.1	384	32

Table 3.14 Average values for variables that showed significant differences between root weight clusters (DAP).

Clusters	Radiation amount	Rainfall amount	Rainfall duration	Temp sum till planting	Temp planting till haulm killing	Total N
1	26.0 * 10^4	401	209	27.0 * 10^2	26.7 *10^2	308
2	27.4 * 10^4	426	225	27.2 * 10^2	26.9 *10^2	351
3	26.0 * 10^4	403	214	26.2 * 10^2	26.0 *10^2	333
4	25.3 * 10^4	382	212	25.0 * 10^2	25.1 *10^2	311
5	25.6 * 10^4	365	216	24.9 * 10^2	24.8 *10^2	291
6	25.7 * 10^4	360	218	24.8 * 10^2	24.8 *10^2	281
7	24.9 * 10^4	342	208	24.2 * 10^2	24.2 *10^2	255
8	24.1 * 10^4	287	201	23.4 * 10^2	23.4 *10^2	258

Table 3.15 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different seed sizes.

Cluster	Year				Seed size		
	2013	2014	2015	2016	Big	Middle	small
1	-	-	-	4	2	1	1
2	-	-	-	8	4	4	0
3	-	-	1	19	9	8	3
4	2	7	8	30	11	29	7
5	11	20	26	18	15	45	15
6	32	36	27	4	4	63	32
7	38	24	9	1	6	36	30
8	28	7	-	-	4	15	16

3.5 Underwater weight

The number of clusters for underwater weight based on the growing days is seven and based on the degree days also seven. Underwater weight is a quality aspect of potatoes. A high underwater weight indicates a high biomass accumulation per quantity of potatoes. The highest yield was obtained with a low underwater weight, in cluster 5, and a high underwater weight of 396 gram resulted in a low yield.

Table 3.16 Cluster information of fitted model for underwater weight (n= 497).

Cluster	Number of fields (DAP)	Underwater weight at 100 days (gram)	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Tuber weight at 2000 GDD (ton/ha)	Yield harvester ton/ha (GDD)
1	23	396 (7.22)	57 (10.3)	4	401 (19.2)	55 (9.0)
2	50	378 (6,75)	63 (15.4)	57	393 (9.9)	61 (13.7)
3	126	351 (8,70)	50 (15.5)	149	371 (16.7)	55 (16.1)
4	68	335 (7,83)	56 (18.5)	67	368 (16.7)	51 (19.0)
5	12	297 (9,23)	76 (16.3)	16	328 (4.2)	75 (16.8)
6	52	274 (5,26)	68 (12.5)	46	318 (2.2)	69 (13.0)
7	32	256 (7,29)	68 (10.2)	37	309 (3.4)	68 (10.2)

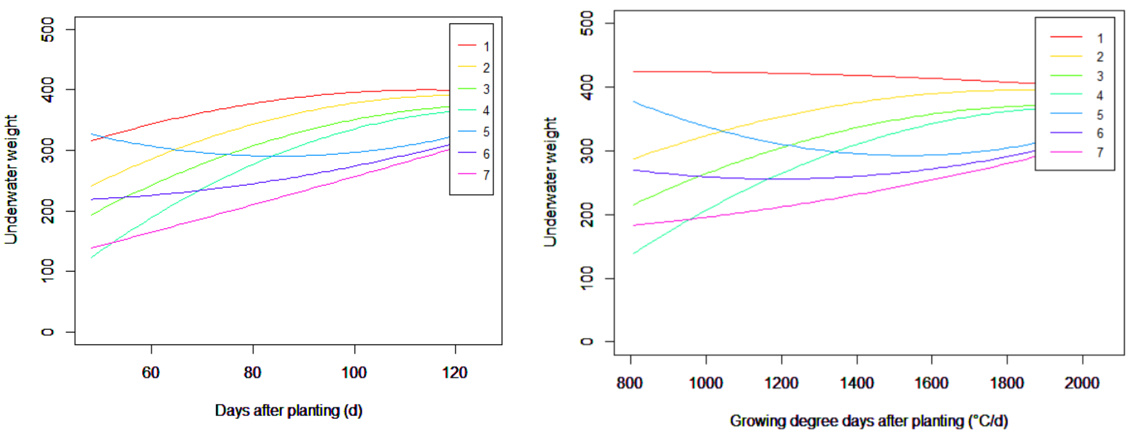


Fig. 3.6 Development of clusters over time for underwater weight.

Table 3.17 P-values of the ANOVA and logistic regression analyses for underwater weight clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	ns	ns	L.s	Boron in the soil	ns	ns
	Planting distance	ns	ns		Calcium in the soil	*	ns
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	*	**		Clay fraction	*	**
	Variety	ns	ns		C/n ratio	ns	ns
					Conductivity	***	***
D.w	Radiation amount	***	***		Drought sensitivity	ns	**
	Radiation duration	***	***		GHG	ns	ns
	Temperature sum from planting	ns	ns		GLG	ns	ns
	Temperature till planting	ns	ns		Iron in the soil	ns	ns
					Magnesium in the soil	**	**
L.m	Evatransporation	***	***		Mangan in the soil	***	***
	Irrigation	ns	ns		Nitrogen in the soil	***	*
	K50	ns	**		Nutrient content in the soil	ns	ns
	K60	**	**		Phosphorus in the soil	*	ns
	KAS	***	***		Potassium in the soil	**	**
	Manure amount	ns	ns		Silicon in the soil	ns	ns
	Magnesium from manure	ns	ns		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	ns	L.w	Rainfall amount	***	***
	Organic manure type	ns	***		Rainfall duration	***	***
	Phosphorus from manure	ns	ns		Relative humidity	***	***
	Potassium from manure	ns	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	ns
	Sulphasote	***	***		Group of spraying	***	***
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	ns				
	Total potassium applied	**	**				

A high underwater weight is obtained on the fields with a high conductivity, low amount of potassium in the soil, low rainfall, low K60 and KAS application, low amount of urea and a high total nitrogen and potassium application (table 3.18 & 3.19). Differences between years were also observed. The relative humidity is mainly depending on temperature and rainfall. In 2014 there was a lot of rainfall during the season, this resulted in a low underwater weight. High temperature and therefore a low RV in 2015 resulted in on average high underwater weights. In 2014 the lowest underwater weight is obtained, due to rainfall and high relative humidity.

Table 3.18 Average values for variables that showed significant differences between underwater weight clusters (DAP). – Indicated that there was no data.

cluster	Conductivity	CaO soil	Clay fraction	Radiation duration	EV	K60	KAS	Litre sulfasote	Litre urea	Mg soil	Mn soil
1	6.5	-	4.7	1066	452	162	307	84	35	211	4601
2	6.4	116.5	4.5	1063	451	136	255	77	16	279	3372
3	3.5	102.2	5.2	990	427	91	227	97	61	345	3797
4	3.4	216.9	5.2	1003	432	89	233	105	58	309	4387
5	-	-	4.3	1007	437	60	90	10	183	-	-
6	-	-	5.8	982	429	89	83	10	206	-	-
7	-	-	5.2	978	426	71	97	15	205	-	-

Table 3.19 Average values of significant differences between the underwater weight clusters (DAP)

cluster	Nematode	N soil	P2O5 soil	K2O soil	Radiation amount	Rainfall amount	Rainfall duration	RV	Temp sum till planting	Total N	Total K
1	0.3	94	4	118	$26.5 * 10^4$	275	218	72	$24.3 * 10^2$	335	371
2	0.4	137	6	193	$26.4 * 10^4$	307	229	73	$25.0 * 10^2$	295	318
3	0.1	75	42	189	$24.9 * 10^4$	330	212	75	$24.6 * 10^2$	306	304
4	0.2	88	32	270	$25.2 * 10^4$	334	214	75	$24.9 * 10^2$	305	295
5	0.3	-	-	-	$25.8 * 10^4$	469	208	76	$25.3 * 10^2$	229	294
6	0.3	-	-	-	$25.2 * 10^4$	462	205	76	$24.7 * 10^2$	219	295
7	0.3	-	-	-	$25.1 * 10^4$	454	202	76	$24.6 * 10^2$	237	286

Table 3.20 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different seed sizes.

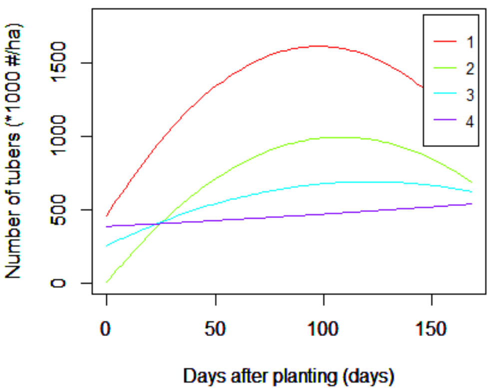
Cluster	Year				Size potatoes		
	2013	2014	2015	2016	Big	Middle	Small
1	1	-	22	-	5	17	1
2	2	-	41	7	6	33	11
3	70	-	5	51	25	65	36
4	39	-	2	27	17	32	19
5	-	12	-	-	1	7	4
6	-	52	-	-	1	29	22
7	-	32	-	-	1	18	13

3.6 Number of tubers

The number of tubers clusters based on the growing days was four and based on degree days nine clusters. Between the number of tubers and obtained yields is no indication of a positive or negative influence. Number of tubers is a plant characteristic that in the beginning increase slightly and is stable after a certain amount of time. A few clusters showed an increase over time, with a decrease after a maximum. These clusters included relatively few fields, however (24 out of 364 based on DAP; 89 out of 376 for GDD) some clusters indicated a slight increase in saleable tubers (figure 3.7).

Table 3.21 Cluster information of fitted model for number of tubers (n= 376).

Cluster	Number of fields (DAP)	Number of tubers at 100 days (# (1000/ha)	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Number of tuber at 2000 GDD (# (1000/ha)	Yield harvester ton/ha (GDD)
1	2	1616 (78)	58 (7.7)	2	1603 (109)	58 (7.7)
2	32	993 (116)	43 (16.1)	7	1176 (86)	42 (14.9)
3	145	679 (71)	58 (16.9)	14	995 (43)	41 (14.5)
4	185	474 (64)	62 (15.2)	24	855 (48)	46 (17.0)
5				42	725 (48)	66 (10.6)
6				32	719 (55)	42 (13.9)
7				98	608 (38)	65 (16.2)
8				112	502 (32)	62 (14.5)
9				45	409 (33)	60 (14.9)



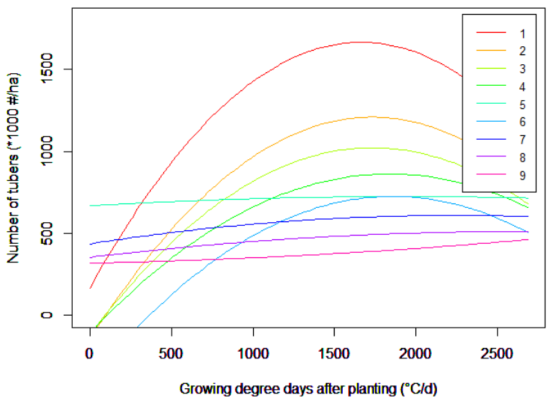


Fig. 3.7 Development of clusters over time for number of tubers.

Table 3.22 P-values of the ANOVA and logistic regression analyses for number of tubers clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 376). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	ns	*	L.s	Boron in the soil	**	**
	Planting distance	**	***		Calcium in the soil	ns	*
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	***	***		Clay fraction	ns	ns
	Variety	ns	ns		C/n ratio	ns	ns
					Conductivity	**	***
D.w	Radiation amount	**	***		Drought sensitivity	ns	ns
	Radiation duration	***	***		GHG	ns	*
	Temperature sum from planting	***	***		GLG	ns	ns
	Temperature till planting	***	***		Iron in the soil	ns	ns
					Magnesium in the soil	ns	**
L.m	Evatransporation	***	***		Mangan in the soil	ns	ns
	Irrigation	ns	ns		Nitrogen in the soil	ns	**
	K50	ns	ns		Nutrient content in the soil	ns	ns
	K60	***	***		Phosphorus in the soil	***	*
	KAS	***	***		Potassium in the soil	ns	ns
	Manure amount	ns	ns		Silicon in the soil	ns	ns
	Magnesium from manure	ns	ns		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	ns	L.w	Rainfall amount	*	***
	Organic manure type	ns	***		Rainfall duration	***	***
	Phosphorus from manure	ns	ns		Relative humidity	***	***
	Potassium from manure	**	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	ns
	Sulphasote	***	***		Group of spraying	***	***
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	ns				
	Total potassium applied	ns	**				

In the results a low conductivity, high boron in the soil, high radiation duration (long growing season) indicated a high number of tubers. The high boron amount is only found in two fields, therefore it should be mentioned. Related to the management practices a high K60/ KAS/ sulfasote and low urea application resulted in a high number of tubers. Seed distance had no clear influences on the number of tubers. A low potassium in the manure resulted also in a high number of tubers. The amount of nitrogen and type of nitrogen is a key parameter related to the number of tubers. A low total nitrogen application resulted in a low number of tubers. In the size of seed potatoes, there is no clear pattern that smaller or bigger seed potatoes result in a large number of tubers. The number of tubers was higher in 2016 compared to other years (table 3.23, table 3.24 & 3.25).

Table 3.23 Average values for variables that showed significant differences between number of tubers clusters (DAP).

Cluster	Conductivity	Boron soil	Radiation duration	EV	K60	KAS	Litres sulfasote	Litres urea	P2O5 soil	Seed distance
1	3.8	3537	1063	456	134	277	110	0	17	31.0
2	3.4	802	1021	442	141	350	117	9	11	35.4
3	5.0	706	1028	441	123	253	88	52	11	34.2
4	6.1	1016	985	426	71	132	52	134	72	33.0

Table 3.24 Average values of significant differences between the number of tubers clusters (DAP).

Cluster	K in manure	Radiation amount	Rainfall amount	Rainfall duration	RV	Temp sum till planting	Temp from planting until haulm killing	Total N
1	157	$26.3 * 10^4$	404	211	76	$27.7 * 10^2$	$27.9 * 10^2$	321
2	247	$25.6 * 10^4$	388	212	75	$26.0 * 10^2$	$26.1 * 10^2$	339
3	229	$25.8 * 10^4$	347	220	74	$25.0 * 10^2$	$24.9 * 10^2$	299
4	257	$25.0 * 10^4$	361	209	75	$24.3 * 10^2$	$24.3 * 10^2$	264

Table 3.25 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different seed sizes.

Cluster	Year				Size seed potatoes		
	2013	2014	2015	2016	Big	Middle	Small
1	0	0	0	2	0	1	1
2	1	0	3	28	13	12	7
3	31	16	49	49	27	90	28
4	80	80	19	6	16	99	70

3.7 Number of stems

The number of clusters based on the growing days is ten and based on the degree days eight clusters. Between time and stems there is a linear decreasing relationship observed. Over time some stems senescence due to for example Erwinia. There is an indication that a high number of stems result in a low obtained yield. There is a slight increase in yield from cluster 1 to cluster 10.

Table 3.26 Cluster information of fitted model for number of stems (n= 497).

Cluster	Number of fields (DAP)	Number of stems at 100 days (# (1000/ha)	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Number of stems at 2000 GDD (# (1000/ha)	Yield harvester ton/ha (GDD)
1	9	270	49 (19.2)	11	244 (12.7)	53 (23.7)
2	27	233	50 (17.5)	30	214 (8.8)	49 (17.4)
3	46	205	53 (15.8)	63	191 (6.8)	55 (16.8)
4	62	183	56 (17.2)	81	167 (7.3)	55 (16.1)
5	55	163	55 (15.4)	77	144 (7.6)	60 (17.6)
6	61	143	62 (18.4)	52	123 (5.1)	64 (11.9)
7	44	125	63 (11.6)	43	104 (4.8)	68 (15.3)
8	39	104	68 (15.5)	16	88 (5.4)	68 (11.2)
9	16	87	68 (10.8)			
10	2	70	69 (11.5)			

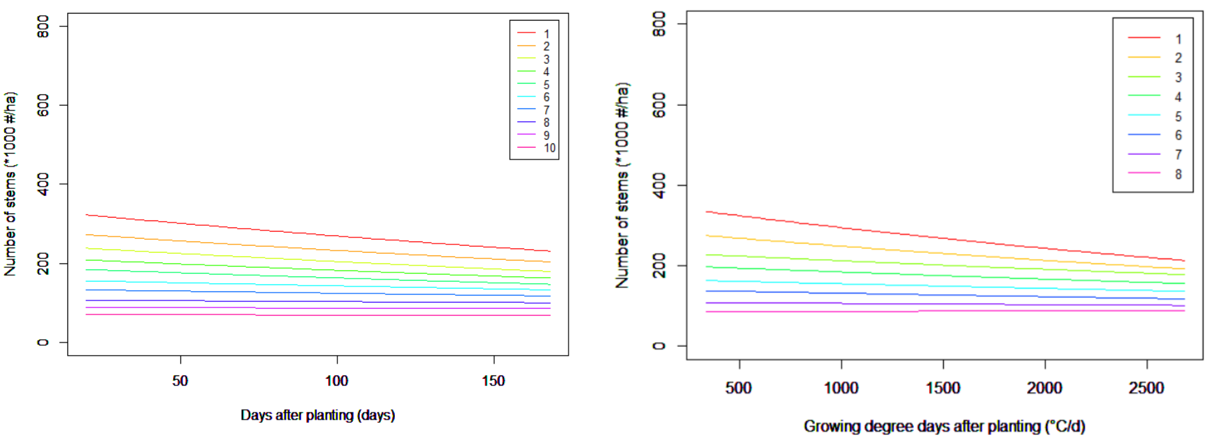


Fig. 3.8 Development of clusters over time for number of stems.

Table 3.27 P-values of the ANOVA and logistic regression analyses for number of stems clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	ns	ns	L.s	Boron in the soil	ns	ns
	Planting distance	**	***		Calcium in the soil	ns	ns
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	***	***		Clay fraction	ns	ns
	Variety	ns	ns		C/n ratio	ns	ns
					Conductivity	**	*
D.w	Radiation amount	**	**		Drought sensitivity	ns	ns
	Radiation duration	**	**		GHG	ns	ns
	Temperature sum from planting	ns	ns		GLG	ns	ns
	Temperature till planting	*	**		Iron in the soil	ns	ns
					Magnesium in the soil	**	**
L.m	Evatransporation	**	**		Mangan in the soil	ns	*
	Irrigation	ns	ns		Nitrogen in the soil	ns	ns
	K50	ns	ns		Nutrient content in the soil	ns	ns
	K60	**	**		Phosphorus in the soil	***	***
	KAS	***	***		Potassium in the soil	ns	ns
	Manure amount	ns	ns		Silicon in the soil	ns	ns
	Magnesium from manure	ns	ns		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	ns	L.w	Rainfall amount	***	***
	Organic manure type	ns	ns		Rainfall duration	ns	**
	Phosphorus from manure	ns	ns		Relative humidity	***	***
	Potassium from manure	ns	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	ns
	Sulphasote	***	***		Group of spraying	***	***
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	ns				
	Total potassium applied	**	**				

The ANOVA analysis indicated that especially the type and amount of nitrogen is important. A high K60 and a KAS application resulted in a high number of stems. A high urea application resulted in a low number of stems. A high total nitrogen and extreme high potassium (380 kg/ha) resulted in a high number of stems. A high number of stems resulted in a longer growing season (radiation duration, radiation amount and ET). A high rainfall amount resulted in less stems. Big seed potatoes generally tend to have a high number of stems. Due to planting distance, this effect will be partly levelled off (smaller seed potatoes -> smaller planting distances). The last two years the number of stems was higher. In 2014 the number of stems was extremely low (table 3.30).

Table 3.28 Average values for variables that showed significant differences between number of stems clusters (DAP).

Clusters	Conductivity	Radiation duration	ET	K60	KAS	Litre sulfasote	Litre urea	Mg soil	P2O5 soil
1	3.4	1098	466	155	333	73	22	360	10
2	4.2	1008	435	128	286	110	15	298	5
3	4.4	1036	444	134	300	92	26	286	7
4	5.7	1037	444	107	269	111	35	257	8
5	5.6	996	429	99	209	70	76	301	30
6	4.9	982	423	74	149	71	116	341	68
7	1.1	990	429	88	137	46	159	426	107
8	9.2	996	431	67	90	28	161	329	384
9	-	994	434	78	75	0	208	-	-
10	-	963	424	167	69	0	200	-	-

Table 3.29 Average values for variables that showed significant differences between number of stems clusters (DAP).

Clusters	Seed distance	Radiation amount	Rainfall amount	RV	Temp plant Haulm killing	Total N	Total K
1	32	$27.3 * 10^{4}$	315	72	$25.3 * 10^{2}$	333	380
2	37	$25.3 * 10^{4}$	338	74	$24.7 * 10^{2}$	320	327
3	36	$25.9 * 10^{4}$	343	74	$25.1 * 10^{2}$	323	324
4	34	$26.0 * 10^{4}$	333	74	$24.9 * 10^{2}$	307	306
5	34	$25.0 * 10^{4}$	325	74	$24.5 * 10^{2}$	294	300
6	32	$24.8 * 10^{4}$	331	75	$24.1 * 10^{2}$	274	310
7	33	$25.2 * 10^{4}$	391	75	$24.5 * 10^{2}$	248	281
8	32	$25.3 * 10^{4}$	422	76	$24.9 * 10^{2}$	248	300
9	32	$25.5 * 10^{4}$	472	77	$25.3 * 10^{2}$	217	239
10	30	$24.9 * 10^{4}$	451	76	$24.4 * 10^{2}$	169	308

Table 3.30 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different seed sizes.

Cluster	Year				Size potatoes		
	2013	2014	2015	2016	Big	Middle	Small
1	-	-	3	6	5	3	1
2	3	-	10	14	12	11	4
3	5	-	18	23	13	27	6
4	17	1	22	22	6	47	9
5	24	5	12	14	10	35	10
6	37	16	5	3	8	31	22
7	17	24	0	3	2	24	18
8	8	30	1	-	-	18	21
9	-	16	-	-	-	5	11
10	-	2	-	-	-	-	2

3.8 Number of compound leaves

Compound leaves based on growing days did consist of seven clusters and based on degree growing days four clusters. A high number of compound leaves in time resulted in the highest yield based on the yield obtained by the harvester. For the cluster with the highest optimum, the yield was not as high as for the clusters with an optimum longer in time.

Table 3.31 Cluster information of fitted model for number of compound leaves (n= 497).

Cluster	Number of fields (DAP)	Number of compound leaves at 100 days (#/plant)	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Number of compound leaves at 2000 GDD (#/plant)	Yield harvester ton/ha (GDD)
1	111	8.1 (0.80)	60 (14.3)	111	3.8 (0.97)	60 (14.3)
2	53	8.9 (0.84)	66 (12.0)	161	6.2 (1.44)	68 (12.7)
3	23	8.1 (0.72)	70 (13.5)	60	7.3 (1.15)	48 (15.2)
4	70	8.4 (1.02)	67 (11.7)	39	6.7 (1.78)	38 (13.7)
5	37	8.8 (0.82)	53 (18.5)			
6	41	8.3 (0.95)	43 (13.8)			
7	25	7.9 (0.95)	37 (12.8)			

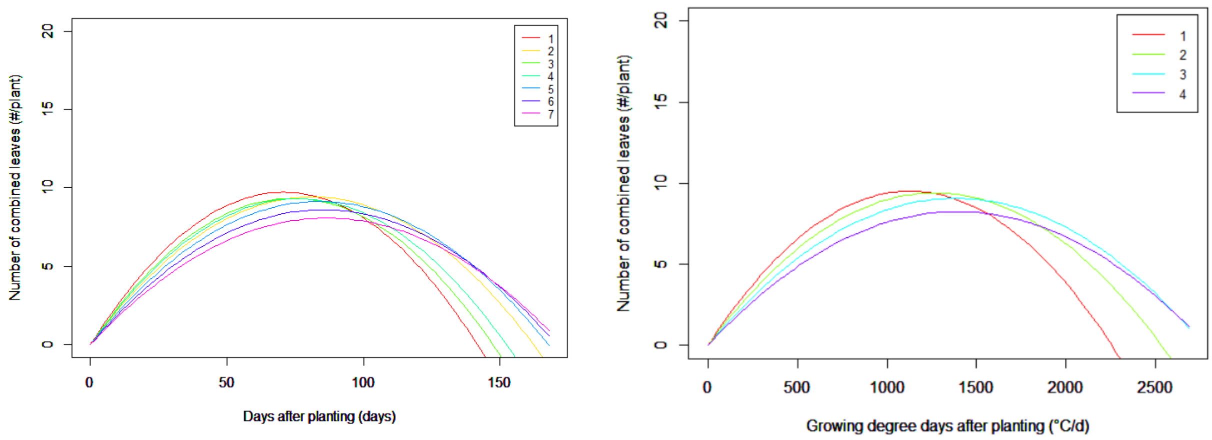


Fig. 3.9 Development of clusters over time for number of compound leaves.

Table 3.32 P-values of the ANOVA and logistic regression analyses for number of compound leaves clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		**DAP**	**DGG**	**Index**		**DAP**	**DGG**
D.m	**Growing days planting**	**	***	**L.s**	**Boron in the soil**	ns	Ns
	Planting distance	***	**		**Calcium in the soil**	*	Ns
	Seed tuber Origin	***	***		**Cation exchange complex**	**	Ns
	Size of seed tubers	***	***		**Clay fraction**	ns	**
	Variety	ns	***		**C/n ratio**	ns	Ns
					Conductivity	***	Ns
D.w	**Radiation amount**	***	***		**Drought sensitivity**	**	Ns
	Radiation duration	***	***		**GHG**	**	Ns
	Temperature sum from planting	***	***		**GLG**	ns	Ns
	Temperature till planting	***	***		**Iron in the soil**	ns	Ns
					Magnesium in the soil	**	ns
L.m	**Evatransporation**	***	***		**Mangan in the soil**	ns	ns
	Irrigation	**	***		**Nitrogen in the soil**	ns	ns
	K50	***	***		**Nutrient content in the soil**	ns	ns
	K60	***	***		**Phosphorus in the soil**	***	***
	KAS	***	***		**Potassium in the soil**	ns	ns
	Manure amount	**	***		**Silicon in the soil**	ns	ns
	Magnesium from manure	ns	Ns		**Zinc in the soil**	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	Ns	**L.w**	**Rainfall amount**	***	***
	Organic manure type	ns	Ns		**Rainfall duration**	**	***
	Phosphorus from manure	***	***		**Relative humidity**	***	***
	Potassium from manure	ns	Ns				
	Sulphate from manure	ns	Ns	**R.m**	**Granule**	ns	ns
	Sulphasote	***	**		**Group of spraying**	***	***
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	Ns				
	Total potassium applied	**	**				

Between the clusters, there is a difference in the number of growing days (table 3.32). The highest cluster had fields with the shortest growing season and were planted earlier in the season (table 3.33 & 3.34). K 60 and KAS had a negative influence on the compound leaves. So, a low application of K60 and KAS, but a manure application result in a higher amount of compound leaves. Finally, the number of compound leaves is mainly influenced by years. There is a decreasing trend in the growth curve of the number of leaves over the years (table 3.35).

Table 3.33 Average values for variables that showed significant differences between number of compound leaves clusters (DAP).

Cluster	Clay fraction	Radiation duration	ET	GLG	Growing days	K50	K60	KAS	Litre sulfasote	Litre urea	Mg manure
1	5.4	984	421	117	150	18	52	140	91	107	65
2	4.8	1053	449	118	155	0	134	197	50	87	63
3	5.7	965	421	115	151	0	60	87	7	200	52
4	5.1	998	432	117	151	0	109	169	29	136	61
5	4.5	1039	448	120	156	0	147	246	86	36	59
6	5.0	1005	440	117	152	0	129	373	122	2	59
7	4.8	1030	446	116	157	0	120	337	119	0	64

Table 3.34 Average values of significant differences between the number of compound leaves clusters (DAP).

Cluster	Magnesium soil	P2O5 soil	P2O5 soil	Radiation amount	Rain fall	Rain duration	RH	Temp sum planting	Temp sum haulm killing	Total K
1	366	261	32	$24.7 * 10^4$	288	213	74	$24.0 * 10^2$	$24.0 * 10^2$	284
2	249	5	34	$26.4 * 10^4$	354	222	74	$25.0 * 10^2$	$25.0 * 10^2$	328
3	-	-	33	$24.8 * 10^4$	454	201	76	$24.2 * 10^2$	$24.2 * 10^2$	270
4	253	4	33	$25.4 * 10^4$	393	210	75	$24.4 * 10^2$	$24.4 * 10^2$	314
5	284	11	36	$26.1 * 10^4$	396	219	75	$25.7 * 10^2$	$25.6 * 10^2$	326
6	346	11	37	$25.4 * 10^4$	406	211	75	$25.7 * 10^2$	$25.9 * 10^2$	299
7	348	9	34	$25.8 * 10^4$	411	214	76	$26.5 * 10^2$	$27.0 * 10^2$	334

Table 3.35 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different levels of wetness of the fields.

Cluster	Year				Field wetness		
	2013	2014	2015	2016	Dry	Average	Wet
1	111	-	-	-	25	55	31
2	-	18	35	-	23	18	12
3	-	23	-	-	2	13	8
4	-	46	24	-	11	32	27
5	-	6	10	21	17	13	7
6	-	-	2	39	10	18	12
7	-	-	-	25	2	15	8

3.9 Stem length

Stem length based on growing days had six clusters and based on degree days five clusters. For stem length, there seems to be an optimum related to the obtained yield. The second cluster shows the highest obtained yield. This suggests that an extremely long stem (123 cm) will not result in a high yield. The variation in the yield was on average around 15 ton/ha. The high variation implies that multiple plant characteristics are influencing the yield. A lower optimal stem length reaches this stem length in an earlier stage (80 days). The highest stem length is obtained around 110 days. It suggests that a higher stem length delays the development stage. The results indicated that a high tuber weight is obtained with a high stem length (110 cm) (table 3.36).

Table 3.36 Cluster information of fitted model for stem length (n= 497).

Cluster	Number of fields (DAP)	Stem length at 100 days (ton/ha)	Yield harvester ton/ha (DAP)	Number of fields (DDG)	Stem length at 100 days (ton/ha)	Yield harvester ton/ha (DDG)
1	18	123 (3.7)	65 (14.9)	17	135 (3.7)	67 (16.2)
2	53	108 (4,2)	67 (16.9)	72	112 (4.2)	68 (16.5)
3	93	97 (3,9)	63 (14.5)	131	96 (3.9)	62 (15.2)
4	87	86 (3,9)	57 (15.6)	118	79 (4.2)	55 (14.5)
5	80	75 (4,2)	54 (15.4)	35	60 (5.6)	40 (14.8)
6	29	59 (5,6)	41 (15.5)			

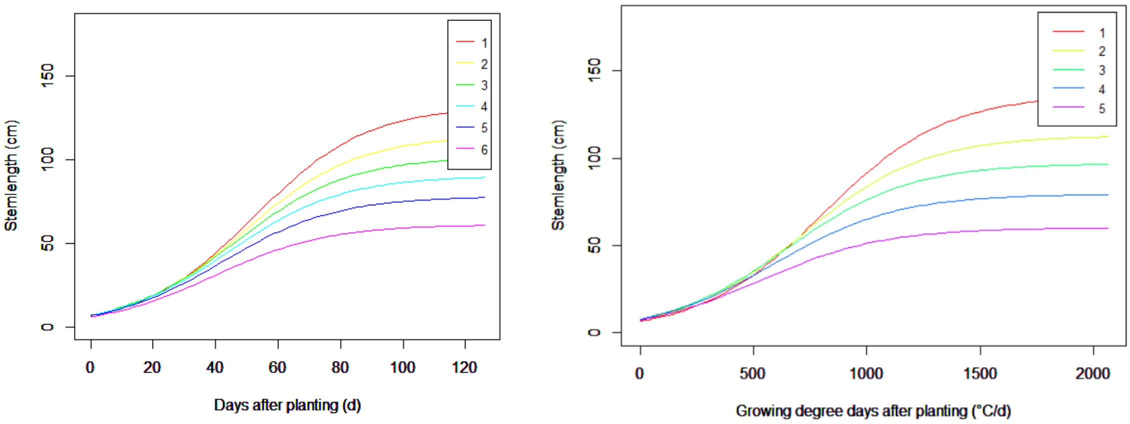


Fig. 3.10 Development of clusters over time for stem length.

Table 3.37 P-values of the ANOVA and logistic regression analyses for stem length clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	**	**	L.s	Boron in the soil	**	*
	Planting distance	ns	ns		Calcium in the soil	*	**
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	ns	ns		Clay fraction	ns	ns
	Variety	ns	**		C/n ratio	ns	ns
					Conductivity	ns	ns
D.w	Radiation amount	**	**		Drought sensitivity	ns	**
	Radiation duration	**	**		GHG	ns	ns
	Temperature sum from planting	ns	**		GLG	**	ns
	Temperature till planting	ns	**		Iron in the soil	ns	ns
					Magnesium in the soil	ns	ns
L.m	Evatransporation	**	**		Mangan in the soil	ns	ns
	Irrigation	ns	ns		Nitrogen in the soil	*	**
	K50	ns	ns		Nutrient content in the soil	ns	ns
	K60	**	ns		Phosphorus in the soil	ns	ns
	KAS	**	***		Potassium in the soil	**	**
	Manure amount	ns	ns		Silicon in the soil	ns	ns
	Magnesium from manure	ns	ns		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	ns	L.w	Rainfall amount	ns	*
	Organic manure type	ns	ns		Rainfall duration	**	**
	Phosphorus from manure	ns	ns		Relative humidity	ns	ns
	Potassium from manure	ns	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	ns
	Sulphasote	**	**		Group of spraying	***	***
	Urea	***	***				
	Total nitrogen applied	**	**				
	Total phosphorus applied	ns	ns				
	Total potassium applied	ns	ns				

Related to the management and soil variables there are some indications that some practices are suboptimal. A high amount of boron in the soil has a positive influence on the stem length. A low groundwater table, low K50 and a low K60 application seems to result in a high stem length. High amounts of soil potassium and nitrogen seems also to result in a higher stem length (table 3.38 & 3.39). Finally, between years the stem length seems to have no clear pattern, so this suggests that the stem length is independent of years. The water, potassium and nitrogen are the main variables that influence the stem length

Table 3.38 Average values for variables that showed significant differences between stem length clusters (DAP).

Clusters	B soil	Conductivity	Radiation duration	ET	GLG	Growing days	K60	KAS
1	2269	5.9	1026	440	123	155	131	185
2	611	4.5	1021	439	119	155	104	196
3	678	5.4	1009	434	117	153	90	165
4	651	4.4	995	429	118	151	86	177
5	998	4.9	1015	438	115	152	114	252
6	773	5.0	937	414	115	143	86	275

Table 3.39 Average values for variables that showed significant differences between stem length clusters (DAP).

Clusters	Litre sulfasote	Litre urea	N soil	K2O soil	Radiation amount	Rainfall duration	Total N
1	88	71	231	292	$25.7 * 10^4$	215	283
2	67	80	119	230	$25.7 * 10^4$	221	290
3	55	113	115	233	$25.4 * 10^4$	215	274
4	64	109	94	205	$25.1 * 10^4$	209	272
5	96	72	73	144	$25.6 * 10^4$	213	297
6	82	33	104	175	$23.9 * 10^4$	205	316

Table 3.40 Number of fields belonging to a certain shoot weight cluster (DAP) in different years.

Cluster	Year			
	2013	**2014**	**2015**	**2016**
1	5	5	4	4
2	19	11	11	12
3	29	35	17	12
4	32	27	13	15
5	21	15	20	24
6	5	1	6	17

3.10 Nitrate content

The nitrate content in the leaves based on growing days did consist of seven clusters and based on degree growing days three clusters. The graphs show that there are quadratic curves with peaks and valleys, this indicates that the amount of nitrate is increasing and decreasing during the season (figure 3.11). The lines indicate that the amount of nitrogen in the plant is increasing in case of peaks in the first stage. Valleys indicate that the amount of nitrogen in the plant is decreasing. Generally, a decreasing line can be observed. The trend is that if the nitrate amount decreases below 4000 ppm at 90 days after planting or 1250 growing degree days resulted in a lower yield (figure 3.11).

Table 3.41 Cluster information of fitted model for nitrate content (n= 497).

Cluster	Number of fields (DAP)	Nitrate content at 100 days (ppm)	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Nitrate content at 2000 GDD (ppm)	Yield harvester ton/ha (GDD)
1	35	8603 (501)	61 (14.0)	94	5678 (1652)	62 (14.3)
2	41	6290 (839)	58 (13.2)	108	2598 (1510)	58 (14.8)
3	20	7482 (451)	66 (14.0)	63	3103 (857)	42 (14.4)
4	18	5548 (627)	53 (14.5)			
5	84	3466 (757)	59 (15.1)			
6	21	3309 (471)	42 (16.0)			
7	38	1711 (469(	40 (13.0)			

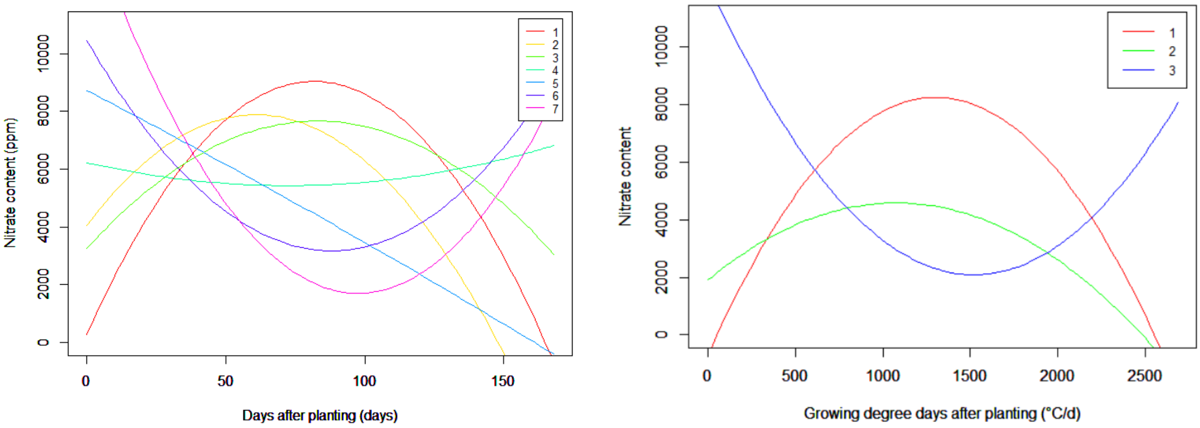


Fig. 3.11 Development of clusters over time for nitrate content leaves.

Table 3.42 P-values of the ANOVA and logistic regression analyses for nitrate content leaves clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	**	ns	L.s	Boron in the soil	ns	**
	Planting distance	**	***		Calcium in the soil	ns	ns
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	**	***		Clay fraction	ns	*
	Variety	ns	ns		C/n ratio	ns	ns
					Conductivity	***	***
D.w	Radiation amount	***	**		Drought sensitivity	*	*
	Radiation duration	***	**		GHG	ns	ns
	Temperature sum from planting	**	**		GLG	ns	ns
	Temperature till planting	**	***		Iron in the soil	ns	ns
					Magnesium in the soil	**	***
L.m	Evatranspiration	***	**		Mangan in the soil	ns	ns
	Irrigation	ns	**		Nitrogen in the soil	***	***
	K50	ns	ns		Nutrient content in the soil	ns	ns
	K60	**	**		Phosphorus in the soil	**	**
	KAS	***	***		Potassium in the soil	ns	ns
	Manure amount	*	*		Silicon in the soil	ns	**
	Magnesium from manure	ns	**		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	*	ns	L.w	Rainfall amount	***	***
	Organic manure type	ns	ns		Rainfall duration	***	***
	Phosphorus from manure	ns	ns		Relative humidity	***	***
	Potassium from manure	ns	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	*
	Sulphasote	**	**		Group of spraying	***	ns
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	ns				
	Total potassium applied	*	ns				

Management and soil variables are variables that have a positive and negative impact on the nitrate content. Soil conductivity has a positive influence, compared with KAS and sulfasote that have a negative impact. The amount of Nitrogen in the soil has a positive influence on the nitrate content, but the amount of Manganese in the soil has a negative effect on the nitrate content. The amount of rainfall has also a negative impact, more rain resulted in a lower nitrate content. There is no clear difference between the size of seed potatoes and the wetness of the field. Between the years there are some differences. In 2016 the nitrate content of the plants was low, compared with 2013 and 2015. The amount of rainfall was extremely high, especially the intensity during the season. So, the rainfall intensity influences the leaching of nitrate and therefore the amount of nitrogen that the plant can take up.

Table 3.43 Average values for variables that showed significant differences between the nitrate content in leaves clusters (DAP).

Clusters	Conductivity	Radiation duration	ET	Growing days	K60	KAS	Manure quantity	Litre sulfasote	Litre urea	Mg soil	N manure
1	6.1	1058	447	157	105	195	42	64	50	250	118
2	5.4	981	420	147	92	201	39	92	79	282	110
3	6.7	1076	454	156	181	246	47	90	10	234	117
4	7.5	1050	449	151	134	341	47	85	11	253	129
5	3.3	1004	430	152	77	179	44	92	92	330	114
6	3.7	955	421	143	109	361	46	141	0	355	109
7	2.8	1014	442	154	133	344	45	106	0	353	123

Table 3.44 Average values of significant differences between the nitrate content in leaves clusters (DAP).

Clusters	N soil	P2O5 soil	Planting distance	Radiation amount	Rain-fall	Rain duration	RH	Temp sum till planting	Temp sum till haulm killing	Total K
1	190	7	33	$26.3 * 10^{4}$	304	233	73	$25.1 * 10^{2}$	$25.1 * 10^{2}$	310
2	136	65	32	$24.6 * 10^{4}$	284	209	74	$23.8 * 10^{2}$	$23.8 * 10^{2}$	300
3	146	5	35	$26.6 * 10^{4}$	298	235	73	$25.1 * 10^{2}$	$25.3 * 10^{2}$	339
4	66	8	36	$26.3 * 10^{4}$	315	217	73	$24.7 * 10^{2}$	$24.7 * 10^{2}$	332
5	56	68	33	$25.2 * 10^{4}$	308	214	74	$24.5 * 10^{2}$	$24.4 * 10^{2}$	297
6	103	6	35	$24.3 * 10^{4}$	370	206	75	$24.6 * 10^{2}$	$24.2 * 10^{2}$	275
7	61	13	37	$25.6 * 10^{4}$	408	212	75	$25.8 * 10^{2}$	$25.7 * 10^{2}$	343

Table 3.45 Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different seed sizes and different levels of field wetness.

Cluster	Year			Size potatoes			Wetness field		
	2013	2015	2016	Big	Middle	Small	Dry	Average	Wet
1	12	23	-	2	24	9	11	21	3
2	32	8	1	4	19	18	13	21	7
3	1	18	1	2	15	3	6	9	5
4	-	13	5	5	11	2	6	8	4
5	66	4	14	17	44	23	22	35	27
6	-	3	18	7	10	4	3	7	11
7	-	-	38	15	19	4	8	23	6

3.11 Flavonoid

Flavonoid clusters number based on growing days was three and based on degree days seven clusters. The curves of the flavonoid also have peaks and valleys. A too high flavonoid level suggested a lower yield (table 3.46). A level above 1500 ppm at 75 days and 1250 growing degree days resulted in a lower yield. The curves that were decreasing are the fields that had the lowest yield and the valley curves had all a relatively high yield. So, a high yield is achieved with field were the curves showed a valley curve.

Table 3.46 Cluster information of fitted model for flavonoid (n= 497).

Cluster	Number of fields (DAP)	Flavonoid at 100 days	Yield harvester ton/ha (DAP)	Number of fields (GDD)	Flavonoid at 100 GDD	Yield harvester ton/ha (GDD)
1	68	1363 (84.3)	41 (13.5)	21	1054 (96)	39 (13.9)
2	86	1294 (48.6)	61 (13.3)	41	1329 (100)	42 (13.7)
3	91	1170 (36.5)	61 (14.3)	71	1503 (73)	62 (13.6)
4				52	1450 (68)	60 (17.4)
5				45	1269 (64)	61 (11.4)
6				10	1726 (116)	59 (10.6)
7				12	1045 (76)	59 (13.2)

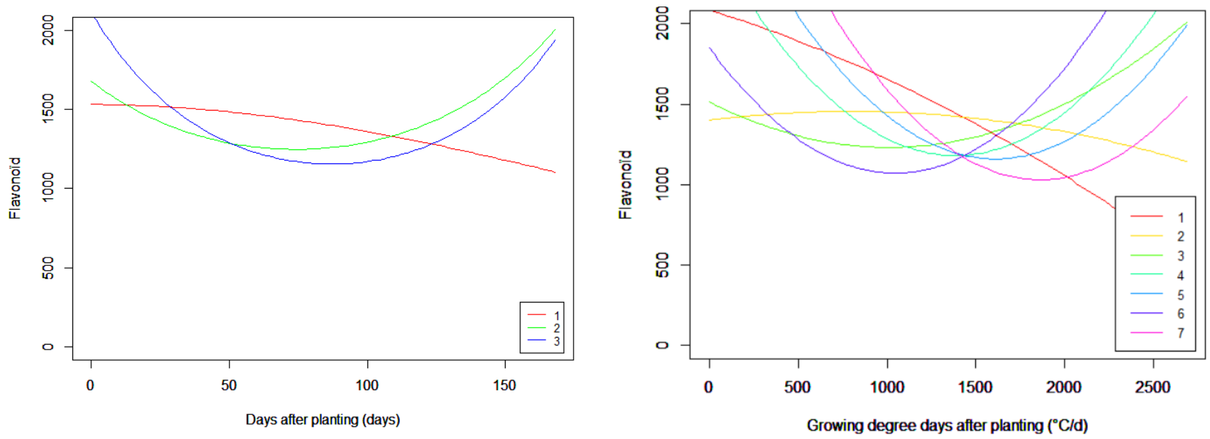


Fig. 3.12 Development of clusters over time for flavonoid.

Table 3.47 P-values of the ANOVA and logistic regression analyses for flavonoid clusters. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001, respectively (n= 497). Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Index		DAP	DGG	Index		DAP	DGG
D.m	Growing days planting	**	**	L.s	Boron in the soil	ns	ns
	Planting distance	***	***		Calcium in the soil	-	ns
	Seed tuber Origin	***	***		Cation exchange complex	ns	ns
	Size of seed tubers	***	***		Clay fraction	ns	*
	Variety	ns	ns		C/n ratio	ns	ns
					Conductivity	***	***
D.w	Radiation amount	ns	***		Drought sensitivity	ns	ns
	Radiation duration	ns	***		GHG	ns	ns
	Temperature sum from planting	***	***		GLG	ns	ns
	Temperature till planting	***	***		Iron in the soil	ns	**
					Magnesium in the soil	***	***
L.m	Evatransporation	**	***		Mangan in the soil	ns	ns
	Irrigation	**	**		Nitrogen in the soil	**	**
	K50	**	**		Nutrient content in the soil	ns	ns
	K60	***	***		Phosphorus in the soil	***	***
	KAS	***	***		Potassium in the soil	ns	ns
	Manure amount	**	**		Silicon in the soil	*	**
	Magnesium from manure	ns	ns		Zinc in the soil	ns	ns
	Nitrogen available	ns	ns				
	Nitrogen from manure	ns	ns	L.w	Rainfall amount	***	***
	Organic manure type	ns	ns		Rainfall duration	ns	***
	Phosphorus from manure	ns	ns		Relative humidity	***	***
	Potassium from manure	ns	ns				
	Sulphate from manure	ns	ns	R.m	Granule	ns	ns
	Sulphasote	**	***		Group of spraying	ns	ns
	Urea	***	***				
	Total nitrogen applied	***	***				
	Total phosphorus applied	ns	ns				
	Total potassium applied	**	**				

A high K60, KAS and sulfasote application result in a high flavonoid level. A low soil conductivity, urea, nitrogen in the soil and planting distance result in a low flavonoid level. The amount of rainfall is positively correlated with the growth curve of flavonoid. The amount of sulfasote and K60 application had a positive influence on the flavonoid curve. Potatoes planted later in the season also resulted in a higher peak curve of flavonoid. Flavonoid level in 2016 was very high on average, compared with 2013 and 2015 (table 3.48, 3.49 & 3.50). The results indicated that small tubers will also result in a lower flavonoid level and big in a high flavonoid level. So, a high potassium application, a high KAS, sulfasote application, big seed potatoes and planted and killed later in the season indicate a higher peak growth curve related to the flavonoid level.

Table 3.48 Average values for variables that showed significant differences between the flavonoid clusters (DAP).

Clusters	Conductivity	ET	Growing days	K50	K60	KAS	Amount organic manure	Litre sulfasote	Litre urea	Mg soil
1	2.6	443	154	0	142	351	45	120	0	351
2	6.9	437	148	6	131	251	45	76	40	244
3	6.3	427	153	15	58	144	41	86	106	314

Table 3.49 Average values of significant differences between the flavonoid clusters DAP.

Clusters	N soil	P2O5 soil	Planting distance	Rain-fall	RV	Temp sum planting	Temp sum haulm killing	Total K
1	78	11	37	411	75	$25.9 * 10^{2}$	$26.0 * 10^{2}$	318
2	127	9	34	277	73	$24.0 * 10^{2}$	$24.0 * 10^{2}$	329
3	125	184	32	297	74	$24.4 * 10^{2}$	$24.4 * 10^{2}$	284

Table 3.50 Counts of tuber weight clusters DAP Number of fields belonging to a certain shoot weight cluster (DAP) in different years and with different seed sizes.

Cluster	Year			Seed size		
	2013	2015	2016	Big	Middle	Small
1	-	-	68	29	32	7
2	21	65	-	12	55	19
3	88	3	-	8	49	34

3.12 Relation between plant characteristics

The relation between plant characteristics is important for the development of the plant. To obtain a high tuber weight a high photosynthetic capacity is important (high shoot weight). Shoot weight alone will have consequences on the stem length and number of leaves and number of stems (figure 3.13). The results of the interaction and differences between years of the analyses were inserted in Appendix 10.1 and Appendix 10.2, a visual representation is made in figure 3.13. A high stem length decreases the underwater weight, which is a quality parameter. By evaluating the figure 3.13 a high yield is a balance between different plant characteristics. An increasing in a certain characteristic result in a few cases in a lower other plant characteristic.

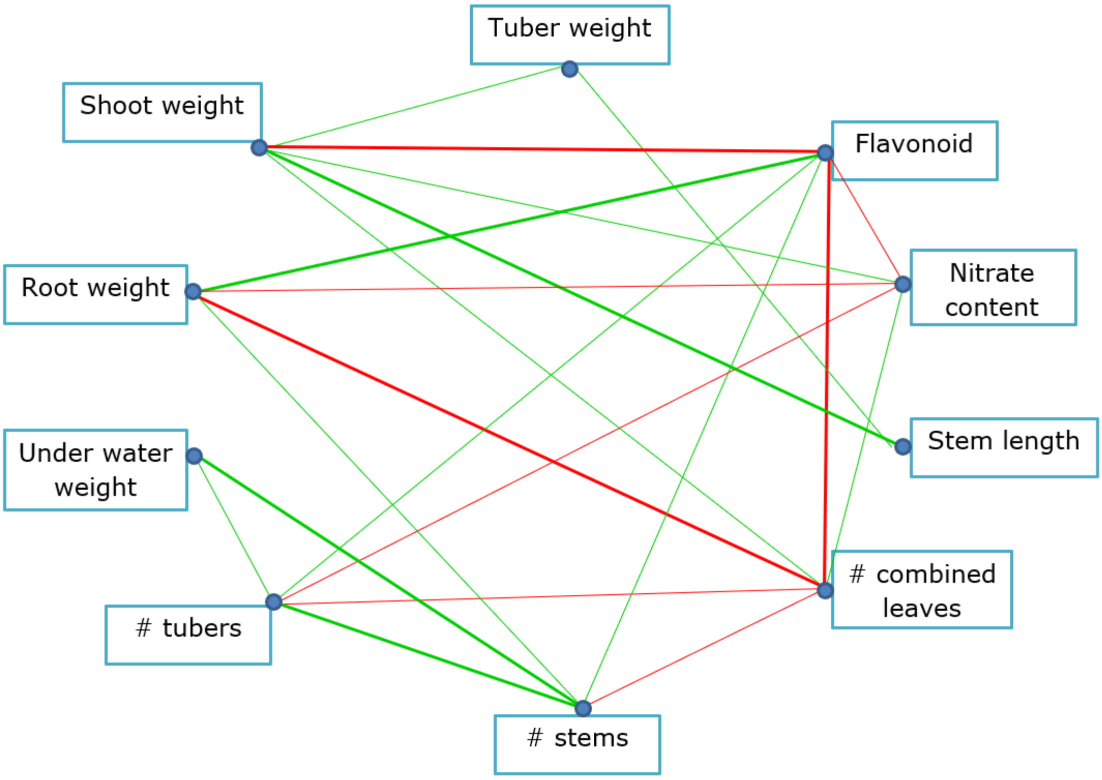


Fig. 3.13 Relation between plant characteristics: green = positive interaction, red = negative interaction, thickness represent correlation index (small line = 0.3-0.6, thick line = 0.6 – 1.0).

Between the years there are some differences observed in plant characteristics (appendix 10.2). Tuber weight and stem length were the only variables were no pattern was visible. For root weight and shoot weight it is observed that in the years were a high root weight obtained was the lowest shoot weight was obtained and vice versa. Similarly a high shoot weight is obtained with a high number of compound leaves and a high nitrate potential. The results correspond with the findings from the previous analyse (figure 3.13).

Table 3.51 Differences between years from highest to lowest based on an average cluster by years, 1 indicated highest clusters and 4 lowest cluster numbers on average.

Plant characteristics	Random	2013	2014	2015	2016
Tuber yield	X				
Shoot weight		1	2	3	4
Root weight		4	3	2	1
Underwater weight		2	3	1	2
Number of tubers		3	3	2	1
Number of stems		2	3	1	1
Number of compound leaves		1	2	2	3
Stem length	X				
Nitrate content		1		1	2
Flavonoid		3		2	1

3.13 Optimal yield

For tuber weight, the optimal curve is estimated with HPGENSELECT. The curve of the most optimal curve is estimated and visualized in figure 3.14. The most optimal combination of management practices of the curve (equation 14) indicated that different management variables influence the potential curve (table 3.52). For the different varieties, wetness and organic manure types, 0 indicated that it is not used in the equation and 1 indicated that it is the case. The model of the most optimal curve is based on the formula from the high performance procedure, based on the scale parameter (U). The outcome of this procedure is the equation 15 with the different variables and coefficients (table 3.52).

Table 3.52 Parameter estimations of the best curve and most optimal curve.

Parameter	Best cluster	Optimal cluster
C	0.0463	0.0463
B2	93.572	93.572
S2	-0.1670	-0.1670
M		3,436233
B	*6.285*	
U	2.7514	B + M

$$Y = (B / (1.0 + \exp(-(c) * (x - b2 - s2 * U)))) * 20 \qquad (14)$$

*B = 3.663 + Seed distance(cm) * -0.092 +* (15)

*Total potassium (kg) * 0.002 +*

*variety * wetness of field (table 3.52) +*

*total potassium (kg) * dry (field wetness) * 0.0044 +*

*total potassium (kg) * medium (field wetness) * -0.0028 +*

*total potassium (kg) * wet (field wetness) * 0 +*

*KAS * litre sulfasote * 0.000013*

Table 3.53 Coefficient for a combination between wetness of the field versus variety. "-" indicated that there was not combination found in the data that correspond to the formula.

Wetness Field	Variety	Coefficient
Dry	Fontana	0.744
	Dakota	-0.801
	Ivory Russet	-
Medium	Fontana	2.459
	Dakota	-
	Ivory Russet	1.745
Wet	Fontana	2.827
	Dakota	-
	Ivory Russet	0

An optimal combination of parameter B is estimated. The following combination of parameters has been chosen to achieve an optimal realistic curve. By evaluating the optimal and best cluster the differences were around 10 ton/ha. So, this difference implies a yield increase of 8 % (figure 3.14).

Table 3.54 Parameter estimations optimal curve.

Variables	Category
Seed distance	26 cm
Total potassium	320 kg/ha
Variety	Fontana
Field wetness	Wet
KAS	350 kg/ha
Sulfasote	120 litre/ha

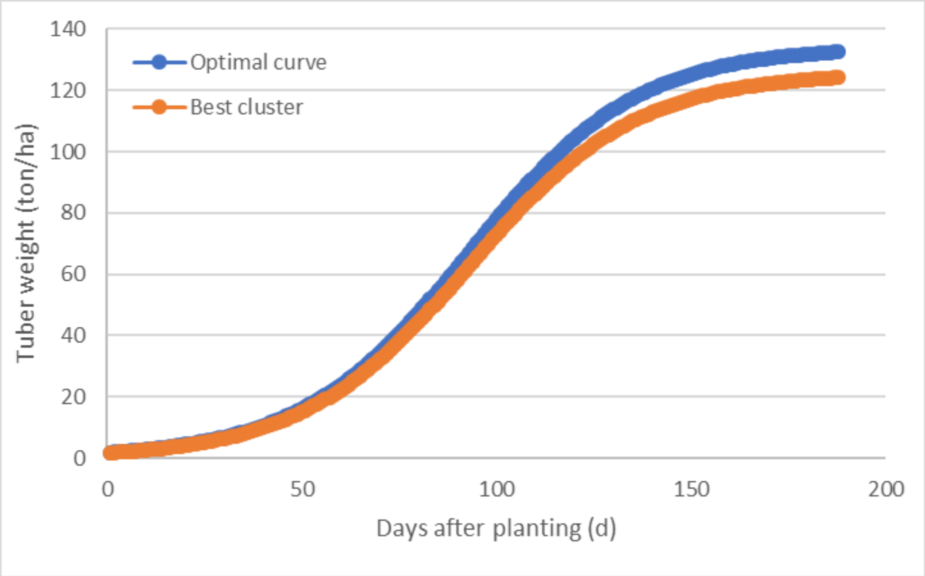


Fig. 3.14 Most optimal curve and best cluster of tuber weight on sandy soil in the south of the Netherlands.

4 Discussion

This research was performed to get a better understanding of the yield that is obtained on sandy soils in the Netherlands related to soil, management and weather variables. Before this study, an exploratory study was performed by Mulders (2017), for the data of 2016 that was provided by Van den Borne (section 4.1). For the analysis, a k-mean clustering is applied and a KL optimal cluster method is used to determine the optimal number of cluster (section 4.2). Nearly all the same variables were investigated except the chlorophyll and nutrient balance index (NBI). The NBI is a ratio between flavonoid and chlorophyll content, so therefore this variable is not used in this study. Padilla *et al.* (2014) showed in muskmelon that chlorophyll content is depending on the water content of the soil and no curve can be fitted that is possible with the data. A higher polynomial function should be used to investigate this characteristic. The main subject of this research was to investigate what the influence is of soil characteristics, crop management and weather conditions on plant characteristics and what is their effect on the final potato yield. It was expected that the data could be used to obtain the most important factors that can explain the yield variability in potatoes on sandy soils in the South of the Netherlands, based on the management and plant characteristics (leaf weight, root weight, underwater weight, number of leaves, number of tubers, number of stems, nitrate content and flavonoid content). The relationships between each plant characteristic and factor (management, soil, etcetera) were analysed separately (section 4.3). The relationship between plant characteristics were analysed (sections 4.4). The final results from the HP-genselect can be used to obtain the most optimal curve in relation to tuber weight (section 4.5). Further research is needed for the separated management practices and their influence. In this analysis some management and soil practices showed to be significant, especially the amount and combination of nitrogen types, planting distance and mainly the weather variables.

4.1 Measurements and collected data

The results are obtained on a sandy soil in Brabant. This information is important to implement the outcome in other areas, with similar soils and weather characteristics. Some variables were not significant, but it can be very important for obtaining a high yield, for example for the amount of phosphate. Even though around 50 variables related to management, soil and weather were included in the analyses, still some data were missing. For example texture was not included while it is important (Redulla *et al.*, 2002).

The measurements that were collected in a field represents three plants, which were randomly selected on a spot with the average soil conductivity (EC_a). The average EC_a was not representing the average conditions of the field, so therefore the yield on that spot was not the average of the field. The soil conductivity is depending on several factors: water content, bulk density, temperature, and texture (i.e., sand, silt, and clay), in addition to metal, surface roughness, soil compaction, and surface geometry (e.g., presence of beds and furrows) (Eigenberg *et al.*, 2006).

Some improvements could be made related to different aspects of the sampling and related to making some additional notes. It was stated by Bakker (2014) that "measurements with a relatively heterogeneous data outcome, a higher number of replicated or plants is recommended", so a bigger sampling would increase the accuracy of the data. Secondly, some inaccuracy is reported, due to planting. The planter will not plant the potatoes exactly on the planting distance which is set by the driver. The planting distance varies around 10 centimetres (inaccuracy of +/- 33 %). By measuring the planting distance the accuracy of the data will be improved (Van de Velde and Bartelen, 2015). The planting distance was used to recalculated variables per square metre. The recalculating based on the planting distance from the planter showed to have an inaccuracy. Another solution due to the planting distance could be made to use ratios between plant characteristics. The ratio (shoot weight/ tuber weight) showed to be a positive linear relation over time which is more reliable than the actual plant characteristic over time according to Mulders and Rasenberg (2017) and Venus and Causton (1979). A second ratio could be leaf weight divided by stem weight according to Bodlaender (1960); other ratios can also be used, as proposed by Lommen (1994).

Another recommendation is to write down the growth stage of the plants which were measured. It is important to know at which growth stage a plant is to know the potential growth and related nutrient, water, radiation and other requirements. Data related to phenology is until now not registered (Hassan *et al.*, 2002; Lynch *et al.*, 1995). According to Zhang *et al.* (1996) the time of nitrate measurement is very important. The differences between the time of measurement can differ 2000 PPM (~20%) if the measurement is done at 8 am or 11 am. This is because nitrate is correlated to temperature. This correction is not done on the data. To correct for this, more accurate measurement should be done.

The obtained data for haulm, root and tuber weight is fresh weight. Fresh weight will give a lot of errors due to fluctuating water contents in the plant. It would be better if the dry matter would be determined, so the amount of biomass can be compared. Beside the plant characteristics also the management and soil related data were collected. In this dataset there were some missing data noticed. For some fields also only two and even one observations were sampled. The fields with only one sample were removed from the dataset. Field with only two observation are less accurate in comparison with a field with six observation in time, but it is arbitrary (Hershberger and Moskowitz, 2013; Singer, 1998).

The calculation of temperature introduces small errors (Ritchie and NeSmith, 1991). There are different methods for calculating the time variable. Cross and Zuber (1972) did use 22 methods for calculation growing degree days. The first method was the temperature sum, this method is also used in this study and discussed by Mazurczyk *et al.* (2003). So, there are ways to measure more accurate and some other characteristics can be checked to review the impact on the yield and to analyse the impact of management, soil and weather variables.

4.2 Analysis

To find the shape of the curves for the different plant characteristic, different mathematical functions were used. To select the right mathematical function is very important (Dourado-Neto *et al.*, 1998). Unfortunately, not all the functions were tested due to limitations related to the data, such as chlorophyll. Nutrient Balance Index was also not used in this study, because it is a ratio between chlorophyll and flavonoid (Padilla et al., 2014). For the cluster analysis a K-mean clustering is used with Proc Fastclus in SAS. To find the optimal cluster number the NBclust package in R was used. NBclust consists of 30 indexes for representing the optimal clusters. The criteria to select an optimal clustering method was based on two criteria. Criteria that were used in this study was that a cluster could not have more than 25 clusters or less than one cluster if the maximum was set to 50. This method is arbitrary according to Charrad *et al.* (2014) and Kim *et al.* (2004). The significant results were not tested with a Turkey's post hoc analysis. To analyse the pattern between the means of the different clusters, often a pairwise comparison is performed. In this study this is based on the visual pattern scanning for the most obvious trends, which is in line with the study of Mulders (2017). To estimate the optimal curve, proc hp-genselect was used. Variables included in the optimal curve to explain tuber weight growth do not correspond to the outcome of the study, due to the different procedures that were used to obtain the one-to-one relationship studied with one-way ANOVA and logistic regression versus high performance procedure (proc HP-genselect).

4.3 Influence of weather, soil and management on plant characteristics

The findings of this study were sometimes contradictory with the finding in the literature. A high yield is obtained with a high number of tubers, high haulm, root weight, high stem length (due to haulm weight) and high nitrate levels in the leaves (Allen and Scott, 1980; Almekinders, 1991; Bodlaender, 1960; Bussan *et al.*, 2007; Collins, 1977; Engels *et al.*, 1993; Haase, 2003; Lommen, 1995; Nissen, 1955; Rex, 1990; Richards, 1959; Struik and Wiersema, 1999; Van Delden *et al.*, 2001; White and Sanderson, 1983; Whitte *et al.*, 1974). The fit of the models for haulm weight, root weight and a number of compound leaves are not high, it ranges from 0.4 to 0.74. This is because the variables were fitted based on some biological processes that were assumed to be quadratic without intercept (at the day of planting none of the tubers has haulm nor root nor leaves). The other models were "free" to vary with the intercept, this allows the model to be more flexible and therefore this result in a higher fit (r-square). Below, results will be discussed in more detail.

4.3.1 Comparing results from 2016 with results over 4 years

A lot of variables that were significant in Mulders (2017) based on 2016 data were not significant in the overall analyses (this report) using data from 2013 to 2016. From the 63 significant differences based on Mulders (2017), only 19 out of the 63 (30%) results were similar in 2016 and in the 2013- 2016 analyses. For example, in the overall analyses nitrogen application (KAS, urea and sulphasote) were significant in nearly all plant characteristics. The lack of relationship is probably due to the high rainfall in 2016, so that the nitrogen is leached, and therefore it had no or less effect on the yield. In 2016 the amount of potassium was only for the number of stems important, while in the overall analyses it was important for a lot of plant characteristics. So, the variables that were significantly different in one year are not always significant in the other years and vice versa. Different years imply different management practices. This implies that some variables have a certain "insurance range", so above the optimal amount of practices. Only by investigating those practices more closely a true understanding can be obtained.

4.3.2 Tuber weight

The climate factors including the number of growing days were important for the tuber weight according the results. A longer growing season implies a higher biomass production and therefore the radiation duration and amount, evapotranspiration and different temperature sums are important. The outcome of the analyses showed that potatoes planted later in the season had a higher tuber weight. Allen (1977) did show that potatoes planted not too early and not too late (~ half April) had the highest yield; this corresponds to the results. The potatoes that were planted too early were not the field with the highest yield potential. For the planting distance, a negative correlation was found, corresponding to literature (Bremner and Taha, 1966; Haverkort *et al.*, 2015; MacKerron and Jefferies, 1986; Van der Zaag *et al.*, 1990). The application of potassium (K50) had a positive effect on the yield in the results and literature (Sharma and Arora, 1987). Clay fraction represents the soil type of the fields. A higher clay fraction did have a higher amount of water holding capacity. So, a high clay fraction implies a higher yield potential. In a clay soil, a higher yield was achieved, probably due to less water stress which results in a higher yield according to Silva *et al.* (2017).

4.3.3 Shoot weight

In this study a second degree polynomial is estimated for shoot weight; according to Van der Zaag and Demagante (1987), "the function for fresh shoot weight is a third-degree polynomial function". By implementing this function a higher fit can be obtained. For shoot weight, the amount and kind of fertilizer was an important variable. The results showed that a higher application of sulfasote resulted in a lower shoot weight. The results also showed that a too high nitrogen application resulted in a low haulm weight. Those findings are contradictory to literature. In general, a higher application rate with nitrogen did result in a higher shoot weight (Riley, 2000). An explanation for this is that the fields with a high nitrogen application were less fertile. Different mineral composition differs in efficiency for potato plants. This would explain that a urea application resulted in a higher shoot weight and a sulfasote application in a lower weight. According to the results, a lower amount of nitrate and a higher amount of urea nitrogen imply a higher efficiency, this is in line with literature (Alva, 2004).

4.3.4 Root weight

Soil conductivity is an important parameter of soil fertility, a higher EC_a indicates a higher soil fertility according to Van den Borne (2017). In literature, some contradictory results showed that a high EC_e can both give a lower and a higher yield. Especially in a soil with a high EC_e, a higher value will lower the yield due to salinity hazards. The location where the data was obtained of this study had nearly no salinity hazards. A higher EC_e in this case represents the nutrient content of the soil (fertility). A higher EC_e implies therefore a more fertile soil, so a higher EC_e will lead to a lower root weight. The literature also reflects that a more fertile soil did lead to a lower root/shoot ratio, so in general a lower root weight was obtained on a higher EC_e (De Willigen and Van Noordwijk, 1987; Opena and Porter, 1999). Clay fraction negatively affected root weight. According to Battilani *et al.* (2006) the size distribution of the soil particle will influence the root growth. It is also indirectly affected due to the water holding capacity which negatively affected root growth. A higher potassium and nitrogen application also resulted in a higher root growth. According to Roberts and Mc Dole (1985), root growth increased due to potassium while Asfary *et al.* (2009) didn't find any relation between nitrogen and root growth. So, the effect of potassium is in line with the literature, while the effect of nitrogen was not confirmed by other studies. It should be noticed however, that nitrogen and potassium application is adapted based on soil conditions, so results may be confounded by the effect of soil nutrients.

4.3.5 Underwater weight

For the French fries market, a higher underwater weight is better, but a high underwater weight implies also that there will be more external and internal defects on the potato. An optimum of around 500 gram would be beneficial. The amount of salts (EC) in the soil influences the dry matter percentage of the larger tubers (46-50 mm) positive according to Bernstein *et al.* (1951b), Heuer and Nadler (1995) and Paliwal and Yadan (1980); this is in line with the findings of this study. Potassium application did influence the dry matter percentage positively in this study, according to Rastovski *et al.* (1981) a higher potassium application will enhance the underwater weight of the tubers. A longer season did have a positive influence on the size of the tubers. Dry matter increases in an S-shaped curve in relation to tuber size, which caused a lower underwater weight in this study, this is in line with literature (Rastovski et al., 1981). For nitrogen application, different results were found. A urea application resulted in a lower dry matter percentage and an overall higher total nitrogen application resulted in a higher dry matter content. According to literature

(Aghighi Shahverdi Kandi *et al.*, 2011; Painter and Augustin, 1976; Wilcox and Hoff, 1970) an increase in nitrogen resulted in a lower underwater weight, so this is in line with the urea application but is contradictory with the overall nitrogen applied results. Those findings are in line with the urea application. A plausible explanation for this is that the overall increase in total nitrogen application is a result of lower yields. The dry matter percentage is correlated with the size of potatoes, so a lower yield implies a higher underwater weight (Rastovski et al., 1981). A lower yield had nearly no effect on the number of tubers according the results, therefore a lower yield results in smaller potatoes with a higher underwater weight. So, the lowest nitrogen application, which had a high urea application resulted in the highest yield. A high yield result in bigger potatoes (+60 millimetres) and this resulted in a lower underwater weight. A lower RH implies higher temperatures, according to Rastovski et al. (1981) a dry summer imply higher dry matter percentage which is in line with the results. So, a yield with small potatoes with a diameter of around 50 mm will have a high underwater weight, compared with potatoes with a size on average of 70 mm. Therefore, the yield and number of tubers are important in monitoring underwater weight.

4.3.6 Number of tubers

A lower soil conductivity results in less water stress, this is plausible reason why in the result a lower soil conductivity resulted in a higher number of tubers (Levy and Veilleux, 2007). A high KAS and total nitrogen application resulted in a high number of tubers. According De la Morena *et al.* (1994); Jackson (1999) and Ojala *et al.* (1990)a high nitrogen application will result in a high number of tubers, so this is in line with the results. Other literature found contradictory results, nitrogen level influence tuberization negatively according (Ewing, 1990); Ewing and Struik (1992); Moorby and Milthorpe (1975); Radley (1963) and Van Schreven (1949). Beside moisture also the potassium had a positive influence, this is also reported by Van Schreven (1949). In 2016 it was a hot year, with a high radiation amount. There was also a lot of rainfall; but unfortunately, a large amount of the rainfall was in a short-term, which caused water damage. So, the majority of the fields in 2016 without water damage received a lot of water at the beginning of the season and therefore the number of tubers was very high. The fields with water damage were eliminated from the dataset according to Mulders (2017). In 2016 there was also high temperatures, which resulted in a high development rate and a high radiation result in a high net photosynthesis (Marshall, 2007) and therefore a higher tuber initiation.

4.3.7 Number of stems

The highest cluster number with the highest number of stems had on average a low yield. According to Struik and Wiersema (1999), a higher number of stems implies a higher yield. The possible explanation for the correlation between number of stems and yield is that the competition between the plant is heavy and that there is a lack of nutrients, so the balance is outweighed. Another explanation is that the fields that produce more stems are physiological older and therefore the maturity will be earlier, so the final yield will be lower compared with the fields with fewer tubers. The lowest cluster ten is excluded from the results because only two fields were included in that cluster and the results showed contradictory trends in the results. A high potassium (K60) application resulted in a beneficial effect in relation to the number of stems. In the literature, the opposite is found by Panique *et al.* (1997). An increased potassium level decreased the number of stems. So probably in the data correlations can be found between the amount of potassium applied and the soil quality/ conditions (Struik and Wiersema, 1999). The amount of KAS and sulfasote resulted also in a beneficial effect on the number of stems, but the urea application resulted in a negative effect. Between the different years, also different fertilizers were used, Cao and Tibbitts (1994) found that different nitrogen types combined resulted in a beneficial growth of potatoes. A low phosphate in the soil resulted in a higher number of stems in the results. There were no papers that argue that relation. The only relation that was found that there could be a relationship between soil conditions and phosphate in the soil. A soil with a low phosphate can have a better soil condition (Bronick and Lal, 2005). Big seed potatoes are beneficial for the number of stems. A bigger seed potato contains a higher number of eyes and therefore produce more sprouts so more stems (Struik and Wiersema, 1999). A high radiation duration and amount, combined with a low rainfall and high RH, resulted in a high number of stems, such as in 2015 and 2016 such as presented by Struik and Wiersema (1999).

4.3.8 Number of compound leaves

The results showed that a low KAS and sulfasote application resulted in a higher amount of compound leaves. In papers, no effect was found of nitrogen (Biemond and Vos, 1992; Vos and Van der Putten, 1998) only with insufficient amount of nitrogen the leaf appearance rate was negatively influenced. If the amount of nitrogen was not depleted it did not affect the leaf appearance according Haverkort and MacKerron (2012). Probably due to the correlation between nitrogen application, soil conditions, rainfall and radiation. In 2013 the highest amount of compound leaves was obtained. This finding suggests that the number of compound leaves over years were depending on the weather and soil conditions. A low amount of rain and low-temperature sum until planting, so probably low soil temperature indicated, normally a wet soil and therefore more suitable for growing potatoes (Jefferies, 1993). Further research is needed to review this outcome. If the potatoes were planted close to each other, there was a lower number of compound leaves. There was more light competition at a higher stem density, which result in more inter stem competition according Ifenkwe and Allen (1978).

4.3.9 Stem length

Stem length is randomly distributed over years, so it is not solely depending on water and or temperature. The stem length was reduced when there was a shortage of boron, this was confirmed with the findings of Johnston (1928). A low nitrogen fertilizer application with KAS suggested that it increased the stem length, but a high amount of nitrogen in the soil resulted in a high stem length. Nitrogen amount and time of application are key factors. According to Da silva Oliveria (2000). a higher nitrogen application or nitrogen in the soil resulted in a higher stem length. A higher amount of potassium in the soil, resulted in a higher stem length, this is in line with literature (Besma *et al.*, 2011). A lower soil water table indicates more water stress for the potato plant, which caused a reduction in stem length in the results. According to Deblonde and Ledent (2001) water stress implies a lower stem length. So, a lower water table will generate more stress for the potato plants. A slightly longer growing season resulted in more intercepted radiation of the potato plant, but by looking at the intensity this resulted in that the radiation per day was less in the highest clusters. According to Bodlaender (1963) a lower radiation intensity implies a higher top/tuber ratio, so a potato plant will invest more in the stem than in the tubers and therefore result in a higher stem length.

4.3.10 Nitrate

EC_a is depending on nutrient content, soil moisture content, soil texture, bulk density and soil compaction (Eigenberg et al., 2006). A high EC_a (high soil conductivity) resulted in a high nitrate content in the leaves. In Lukas *et al.* (2009), a positive correlation was founded between EC_a and clay, ph, Mg, Ca and humus and a negative relation with sand, phosphorus and potassium. This indicates also the water holding capacity is important, because a sandy soil has a lower water holding capacity. Higher clay percentages indicate therefore a higher yield potential and a better uptake of nutrients (Reidsma *et al.*, 2016). A lower amount of KAS and sulfasote indicates that the amount of organic manure was higher, because the farmer uses a calculation based on what is already applied, soil condition and required amount for the different varieties and in some cases based on soil analyses (Van den Borne, 2016). A lower amount of nitrogen in the soil resulted in normal cases less uptake of nitrogen by the plant so a lower nitrate content. By using less granule fertilizer and more organic manure, different types of Nitrogen sources are provided for the plant. According to Cao and Tibbitts (1994) showed that different nitrogen compounds result in a beneficial growth of potatoes. Stefanelli *et al.* (2011) showed that an increase of nitrate content in the leaves resulted in a lower magnesium content. This implies that an increase of nitrate in lettuce can be due to a lowering of magnesium. So, a lower magnesium content resulted in a higher nitrate content. Lukas et al. (2009) did show the opposite, that a higher magnesium content resulted in a higher nitrate content. The results showed that more plants per square meter resulted in a lower nitrate content. Jamaati-e-Somarin *et al.* (2009) showed that if fewer plants were planted per square meter (+ 7.5 tubers/m2), this did increase the nitrate in tubers. When the potatoes were planted too small (11 tubers/m2) the amount of nitrate in the tuber decreased. The planting distance of the farmer was around 33 cm, so there were four plants per square meter. Low rainfall affects the soil moisture conditions negatively and therefore a lower rainfall increase the amount of nitrate in the leaves. In 2013 and 2015 the nitrate content was very high and in 2016 very low. Haddock (1961) found that a dry soil resulted in an increase in nitrogen in the plant.

4.3.11 Flavonoid

From the results of this study an increase in nitrogen application, resulted in a lower flavonoid level. On soils with a high nitrogen and phosphate content, a lower flavonoid level was found. Liu *et al.* (2010) found that by increasing the nitrogen the amount of flavonoids decreased. A low nitrogen soil also implies a lower phosphorus soil, as these are related to a low organic matter and its decomposition (McGill and Cole, 1981; Walker and Adams, 1958). The results showed that bigger seed potatoes did obtain more yield, this implies a higher demand for nitrogen. More demand also results in more stress, which lead to a higher flavonoid level. A longer season implies that the potatoes had more potential (Van den Borne, 2017). There was a large difference between years, in 2016 the fields did have a high content of flavonoid. The high content of flavonoid is due to the large amount of nitrogen leaching by the rain at the beginning of the growing season. By nitrogen leaching some of the available nitrogen was less available for the plant, so more stress is experienced by the potato plants, which probably caused a higher flavonoid level.

4.4 Interactions among plant characteristics

Between plant characteristics there were interactions, which could be positive and negative. The positive and negative interactions (4.4.1 & 4.4.2) are divided into weak and strong interactions, based on the r-square (0.3-0.6: weak, 0.6-1: strong) (Mukaka, 2012).

4.4.1 Positive relation

The strong relation between shoot weight and stem length is a result of a higher assimilate production by the plant. A higher aboveground biomass production leads to more light competition according Goudriaan and Monteith (1990); Haverkort *et al.* (1991) and Jefferies and MacKerron (1989). A higher root weight indicated that the plant experienced water or nutrient shortage. So, more root weights were related to a higher flavonoid level curve (Sattelmacher *et al.*, 1990a; Tremblay *et al.*, 2012). More stems indicated more tubers and therefore the grading of the potatoes will be smaller and therefore the tubers are lower in terms of underwater weight. The amount of shoot weight and therefore stem length had a positive effect on the potential tuber weight. More leaf area indicated also an earlier coverage of the field and therefore intercept more light and that produce more assimilated, so more yield (Goudriaan and Monteith, 1990; Haverkort et al., 1991; Jefferies and MacKerron, 1989). More haulm weight indicated that the amount of nutrient or water is not a huge deficiency. More aboveground biomass indicated a higher nitrate level and became more haulm weight (Sattelmacher et al., 1990a; Tremblay et al., 2012). Due to less water and nutrient stress (nitrogen content increase), a higher stem length is obtained and more compound leaves were present on the stem (Hang and Miller, 1986; Miyashita *et al.*, 1996). The number of compound leaves were a combination of total initiated leaves and dead leaves. The initiated leaves are mainly depending on temperature (Fleisher *et al.*, 2006; Struik, 2007). The absorption of the oldest leaves is due to root impedance, light, temperature and leaf age (Hang and Miller, 1986; Kirk and Marshall, 1992; Spitters *et al.*, 1989; Van Delden et al., 2001). More stems also imply a higher competition for nutrients and water, this result in more root weight (Arab *et al.*, 2011). An underwater weight is a result of growing circumstances and of tuber size. More tubers will lead to a smaller grading size of the potatoes this resulted in a higher underwater weight (Struik and Wiersema, 1999). The number of stems results in a higher number of tubers, this leads to an increase in nitrogen uptake what cause more nitrogen demand, which resulted in a higher flavonoid content (Arab et al., 2011; Tremblay *et al.*, 2007). As a concluding remark, all the results of this study were in line with the literature, no contradictory results were found.

4.4.2 Negative relation

The interaction between shoot weight (above ground biomass fresh weight) and flavonoid indicate that potato grown on a lower nutrient and water content have a higher flavonoid level. The conclusion is that potatoes with a lower shoot weight did grow in a soil with fewer nutrients and water according to Miyashita et al. (1996) and Sharifi *et al.* (2005). More roots indicated that relative less aboveground biomass is produced and therefore contain fewer compound leaves, this is in line with literature (Sharifi et al., 2005). More roots indicated also that the potato plant needs more nutrients (nitrogen/ potassium, etcetera) and therefore result in a higher flavonoid level (Trehan and Claassen, 2000). Davies Jr *et al.* (2005) and Rolfe and Gresshoff (1988) found that flavonoid is triggering the interaction between rhizobia bacteria and the potato plant. Therefore, it is logical that if the nitrate level in potato increases the flavonoid decreases because the benefit is less for the potato when the nitrate content in the soil is high.

4.5 Modelling

In the past, different methods were used to analyse data sets of precision farmers, such as Data Envelopment Analysis (DEA) and multiple regression analyses by Rietema (2015), sequential path analyses by Asghari-Zakaria *et al.* (2006) and factor analyses . There is a conceptual model made and represent a system that is based on data that is used for this study (Thornley and Johnson, 1990). This model presents the most optimal curve for a potato field related to the yield. By combining a crop growth model such as LINTUL-POTATO-DSS (Haverkort et al., 2015) with this report, this can help to improve the study to underpin the variables and estimate the impact of those yield defining, limiting and reducing variables (Deguchi *et al.*, 2016; Machakaire et al., 2016). The high performance procedure resulted in contradictory results in relation to the findings in the other analyses, this is due to the different procedures.

5 Conclusions

5.1 Weather, management and soil variables

5.1.1 Growing circumstances

A later planting and haulm killing had a positive influence on the tuber weight and stem length, due to an increase in radiation duration and amount. The potatoes that were planted too early were not the fields with the highest yield potential. A longer growing season also influenced the underwater weight. If a potato is larger than 50 mm it decreases in underwater weight. A higher yield implies bigger tubers and therefore a lower underwater weight. The amount of rainfall increased the yield and number of tubers positively, but reduced underwater weight. So, a high amount of rain implies a higher yield, but a lower underwater weight. So, to obtain a high yield the timing and amount of rain is a key indicator. To test the effect of the timing and amount of irrigation further research is needed because only the number of application were tested.

5.1.2 Management practices

Fertilizer application was very important, in particular the potassium and nitrogen application. The overall applied potassium fertilizer did increase the underwater weight and stem length, but it had a negative effect on the number of stems. The K50 potassium fertilizer had a positive influence on the potential yield and root weight. K60 had a higher percentage of potassium and had a positive effect on the number of stems. Nitrogen application had a positive influence on the root growth, underwater weight, number of tubers and a negative impact on shoot weight. Only sulfasote had a negative impact on the stem length and on shoot weight, but positive on the number of stems. KAS had a positive effect on underwater weight and the number of tubers, but KAS had a negative effect on nitrate content, stem length and compound leaves. Urea resulted in a lower underwater weight, number of stems, but positive on the nitrate content and yield. A mix of different fertilizers is better, so different types of nitrogen and applications are better for the potato.

Planting distance was negatively correlated to tuber weight, so a decrease in the planting distance resulted in an increase of tuber weight. A bigger seed distance implies that bigger seed tubers were used because the farmer tries to obtain a certain number of stems per square meter, based on the predicted stems per tuber. The big seed potatoes generated more yield, due to shorter emergence time and higher stem density and therefore intercept more radiation. The demand for nitrogen is therefore increasing for the potato plant, but the yield will be higher. By planting the bigger seed tubers closer, more yield will be obtained, unless more nitrogen is applied with a higher yield. There is an optimum for planting distance and seed size, see for further information Bartelen (2016).

5.1.3 Soil

Clay fraction represents the soil type of the fields. A field with a high clay fraction has a higher amount of water holding capacity, therefore on the farm more tuber weight was achieved on a heavier soil (more clay), but negatively affected the root weight. This is most likely due to less water and nutrient stress. A sandy soil contains less water and therefore according to the results the amount of nitrogen in the plant increases. A lower soil conductivity suggested a higher number of tubers. The soil conductivity is also influenced by the water in the soil. A higher EC_a indicated a more fertile soil. A higher fertilize soil resulted in a higher underwater weight, but a more fertile soil did decrease the nitrate content in the leaves and the stem length.

Nitrogen in the soil leads to a decrease in flavonoid. For phosphate, a low amount in soil suggested that the stem density was higher. Beside the macronutrients also boron (micronutrient) caused a reduction in stem length. So, a low phosphate and boron indicate a higher stem density and higher stem length and a high nitrogen lead to a high yield potential. Further research is needed to argue those findings due to the correlation between the variables. There is an interaction between nutrients and their effect on the soil conditions.

It should be noticed however that on the farm more nutrients were applied in fields with fewer soil nutrients. This may have influenced the results, but it could be argued that soil nutrients increase yield more than applied nutrients, related to nitrogen, phosphate and boron nutrients.

5.2 Relations among plant characteristics

Different plant characteristics were related, so a change in one characteristic may cause a change in another characteristic. Depending on different interactions it can have a positive or negative influence. For obtaining a high yield those interactions should be used and monitored. To obtain a high yield, a high haulm weight and therefore a high stem length and compound leaves and nitrate content was important to intercept radiation. The number of stems is important to obtain an early radiation interception and a higher density implies more tubers. More stems imply more roots which imply more stress (flavonoid) is detected. A high stem density results in more tubers, which implies smaller tubers. A negative correlation was found between eight plant characteristics. The data showed that a higher amount of shoot weight leads more leaves, so more nutrient uptake. More shoot weight implies more compound leaves which indicated a more fertile soil because less flavonoids were measured. Beside shoot weight, a higher root weight indicated a higher nutrient demand which is related to a lower amount of nitrate in the leaves, and this resulted in less compound leaves. For a higher number of tubers, more nutrients are required, the results showed that the nitrate content in the leaves and compound leaves decreases. Because more stems indicated more tubers and therefore more intraspecific competition. According to the findings flavonoid increases if the plant experience more stress due to water and or nutrients (less nitrate in the leaves). So, to obtain a high yield with a relatively high underwater weight, a high stem density should be obtained by planting bigger seed potatoes, so the number of tubers would be relatively high.

5.3 Effect on the potato yield

In the analysis a good soil conditions in terms of nutrient en soil water content showed to influence the yield variability largely, together with the fertilizer application and the amount of radiation and rainfall. To improve soil conditions is on short term very difficult to improve. According to Rijk (2017) the soil is a substrate and if the input is sufficient the yield can increase, only if the application method of nutrients and water is optimal. The effect on the potato yield is partly explained in figure 3.48 for relation between the plant characteristics. For the management, soil and weather variables a HP-genselect procedure is performed to find the most optimal curve related to tuber weight. The parameters that were key were: seed distance, total potassium, variety, field wetness, KAS and sulfasote. The nitrogen and potassium nutrients are key to achieve a high yield. The most optimal yield curve was estimated at 133 ton/ ha, based on parameters that were inside the range that was used by Van den Borne.

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A Appendixes

A.1 SAS Code (proc mixed/ glimmix / NLmixed and HP-genselect)

The data analysis was done in SAS by performing different proc mixed, glimmix and NLmixed procedures. An overview of the different procedures which were used for the different plant characteristics is presented in table A.1. For the different plant characteristics different function were used, which were based on literature. For HP genselect only the most important model statements were inserted (script A.5).

Table A.1 Overview of type of functions and SAS procedures for the plant characteristics.

Plant characteristics	Type of function	Type of curve	Intercept (yes/ no)
Tuber yield	NLmixed	S-shaped	No
Root weight	Mixed	Quadratic	No
Shoot weight	Mixed	Quadratic	No
underwater weight	NLmixed	Quadratic	Yes
Number of tubers	Mixed	Quadratic	No
Number of stems	Glimmix	Linear	Yes
Number of compound leaves	Mixed	Quadratic	No
Stem length	NLmixed	S-shaped	No
Nitrate content	Mixed	Quadratic	Yes
Flavonoid level	Mixed	Quadratic	Yes

Script A.1 default statement proc mixed with intercept

```
ods output solutionr=coefficients;
ods output solutionf=&dataout_fixedeffects;
proc mixed data=&dat covtest;
      class Naam Jaar;
      model &RESP = Jaar Jaar*Groeidagen_normal
Jaar*Groeidagen_normal*Groeidagen_normal / NOINT solution DDFM=KR residual
outp=edwin;
      random INT Groeidagen_normal Groeidagen_normal*Groeidagen_normal /S
type=un subject=Naam;
run;
```

Script A.2 default statement proc mixed without intercept

```
ods output solutionr=coefficients;

ods output solutionf=&dataout_fixedeffects;
proc mixed data=&dat covtest maxiter=1000 maxfunc=1000;
      class Naam Jaar;
      model &RESP = Jaar*Day Jaar*Day*Day / NOINT solution DDFM=KR residual
outp=edwin;
      random Day Day*Day /S type=un subject=Naam;
run;
```

Script A.3 default statement proc glimmix with intercept

```
ods output solutionr=coefficients;
ods output parameterestimates=&dataout_fixedeffects;
ods graphics on;
proc glimmix data=&dat method=quad(qpoints=5)
plots=residualpanel(conditional marginal);
      class naam Jaar;
      model &resp = Jaar Jaar*Groeidagen_normal / NOINT solution
dist=&distr link=&lin;
      random INT Groeidagen_normal / S type=un subject=naam;
      nloptions tech=trureg MAXITER=5000;
      output out=Edwin pred=pred;
run;
ods graphics off;
```

Script A.4 default statement proc NLMIXED

```
proc nlmixed data=&dat TECH=trureg qmax=20;
PARMS B11= &B1 B12=&B1 B13=&B1 B14=&B1 B2=&B2 C=&C lns1=&lns1 S2=&S2
lnse=&lnse;
bounds c>0, B11>0, B12>0, B13>0, B14>0;
      B  =
(B11+U)*(JAAR=2013)+(B12+U)*(JAAR=2014)+(B13+U)*(JAAR=2015)+(B14+U)*(JAAR=2
016);
      MU = B/ (1.0 + EXP(-(C)*(Groeidagen_bemonstering-B2-S2*U)));
      V1 = exp(2*lns1);
      Ve = exp(2*lnse);
      MODEL &RESP ~ NORMAL(MU,VE);
      RANDOM U ~ NORMAL(0,V1) SUBJECT=NAAM;
      predict B out=edwin_2 (rename = (pred = B));
      predict MU out=Edwin;
      predict U out=Robbin (rename = (pred = u));
      ods output ParameterEstimates= parms;
run;
```

Script A.5 default statement proc HPgenselect

```
%MACRO modelselect(resp=, datain=);


proc hpgenselect data=&datain;

      class       ras groep aaltjes voorvrucht organische_mestsoort
herkomst maat_pootgoed droogte_gevoeligheid
                  beregenen Rijkdom_perceel;

      model       &resp = pootafstand groeidagen_loofdoding
                  temp_1_plant_loofdoding Temp_sum_tot_planten
                  gemiddelde_geleiding Kuub_organische_mestsoort  N_mest
                  P_mest K_mest SO3_in_mest Mg_in_mest
                  radiationduur radiationamount neerslagduur neerslagamount
                  RV ET neerslagspecific /*GLG*/ GHG kleifractie
                  totaal_N totaal_P totaal_K
 /*variety*/
                  ras*groep

etcetera.



      dist=normal link=id;
      SELECTION METHOD=stepwise( STOP = SL SLS =0.05) HIERARCHY=SINGLE;
run;
%MEND;
```

A.2 Weather data

Beside temperature also other weather variables are important (figure A.1). The amount of rain and especially the frequency and timing are important (June 2016). The amount of sun and sun duration are presented together with the relative humidity (RH).

A.2.1 Temperature

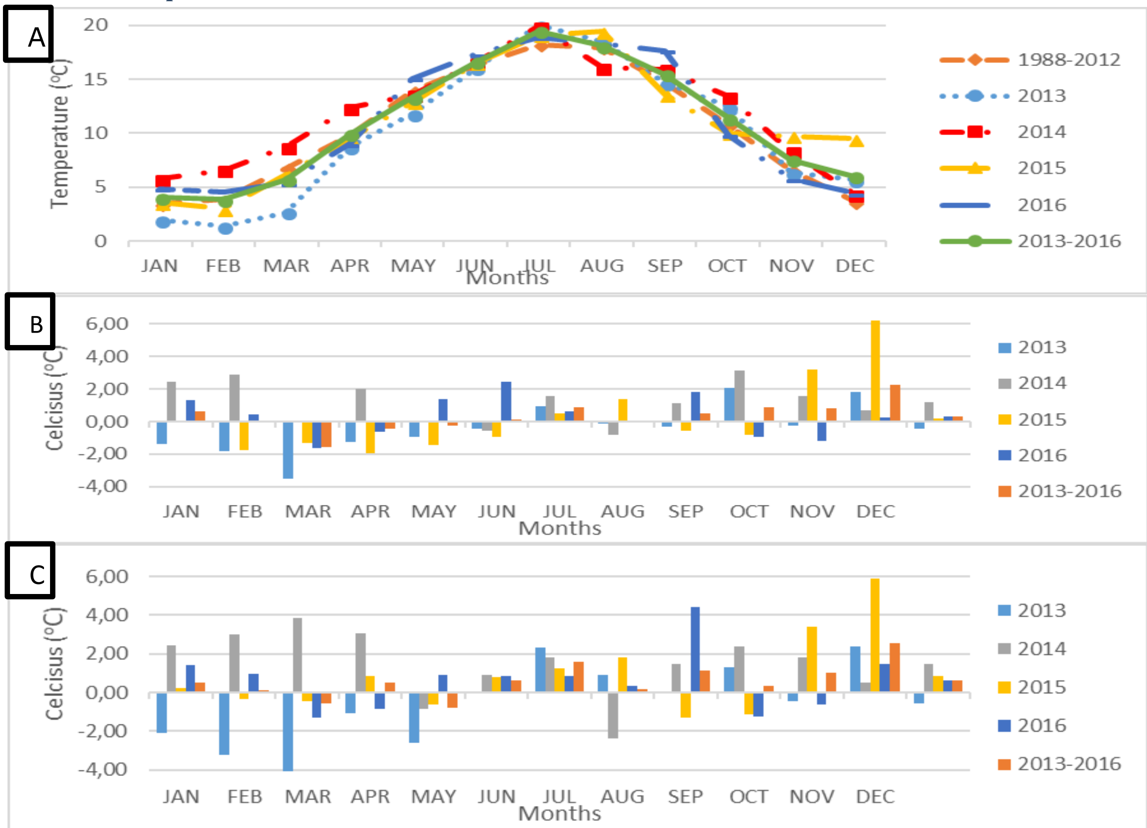

Fig. A.1 A)Average temperature (°C) of the years that were studied per month, versus the average of the last 25 years B) Absolute difference in minimal temperature (°C) in Eindhoven between the years mentioned in the table and 1988 till 2012 C) Difference in maxima temperature (°C) in Eindhoven between the years mentioned in the table and 1988 till 2012 (Anonymous, 2017b).

A.2.2 Rain

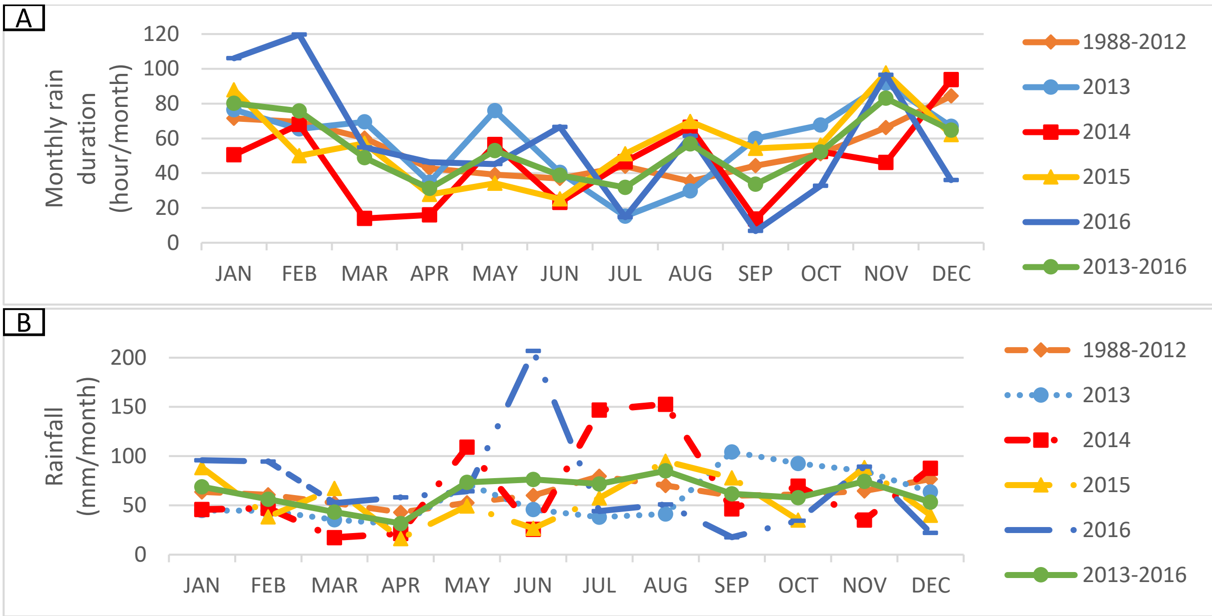

Fig. A.2 A) Duration of rainfall in hours in Eindhoven B) Rainfall amount monthly in Eindhoven (Anonymous, 2017b).

A.2.3 Sun

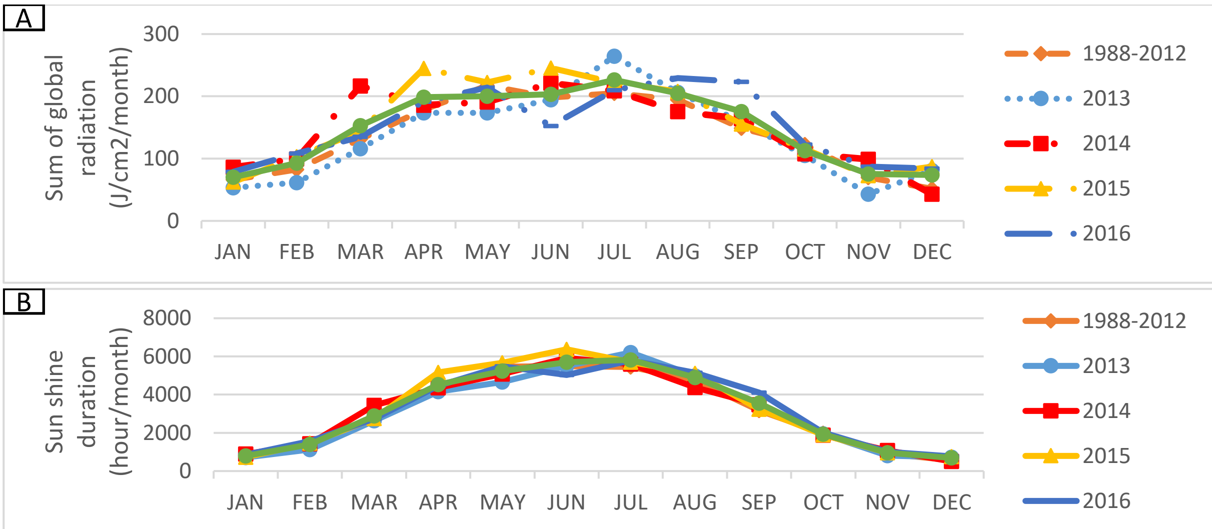

Fig. A.3 A) Global radiation per month (J/cm2) obtained in Eindhoven B) Radiation duration (hour/month) (Anonymous, 2017b).

A.2.4 Relative humidity

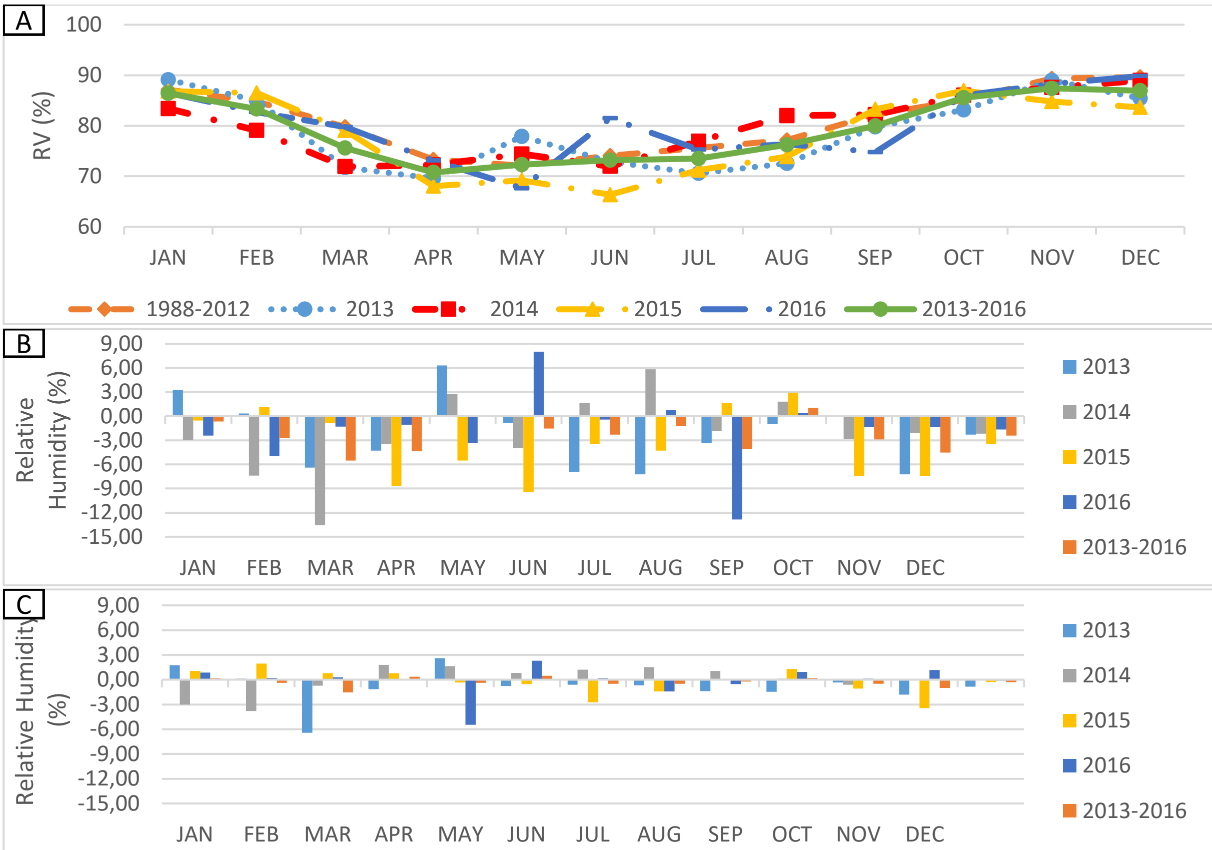

Fig. A.4 A) Average, RV B) difference in minimum relative humidity and C) difference in maxima Relative Humidity in Eindhoven compared with 25-year average (Anonymous, 2017b).

A.3 Summary dataset

The units and average values are presented, so the average values can be compared with the values from the results. For all the variables that were used the units and different categories are presented.

A.3.1 Soil, crop and management characteristics from data

In the dataset that was used, different variables were presented with the different categories, which were used in this study.

Table A.2 Soil, crop and management characteristics from the dataset.

Obtained yields	**Units**
Yield harvester	kg/ha
Yield weighing bridge	kg/ha

Soil Characteristics	**Units**	**Category**
Average conductivity	mS/m	
Nematodes	yes (1) or no (0)	
Drought resilience of the field	dry, average, wet	
C/N ratio		
CEC		
Groundwater	metre	GHG, GLG
Plant available Nitrogen	mg/ kg soil	
Plant available Potassium	mg/ kg soil	
Plant available Phosphate	mg/ kg soil	
Plant available Sulphate	mg/ kg soil	
Plant available Magnesium	mg/ kg soil	
Plant available Boron	mg/ kg soil	
Plant available Silicon	mg/ kg soil	
Plant available Zink	mg/ kg soil	
Plant available Manganese	mg/ kg soil	
Plant available Iron	mg/ kg soil	
Plant available Calcium Oxide	mg/ kg soil	

Seed tubers	**Units**	**Category**
Variety	Type of variety	Fontana, Miranda, Ivory russet, Ludmilla, Dakota, Lady Anna
Size tubers	small, average, large	Small 28/35, 28/40
		Average 35/45, 35/55, 35/50, 40/50, 45/50
		Large 50/55, 55/60, 50/60, 60/+
Origin	Name of farmer	

Crop management practices	**Units**	**Category**
Previous crop	Crop name	Maize, grass, sugar beets, conifer, green bean, triticale, potato, strawberry, grain, sugar root, vegetable, dry flower
Planting distance	cm	
Granule	yes or no	
Type of manure	name	Meat cow manure, calf manure, dairy manure, pig manure, goat manure, chicken manure, compost
Amount Organic manure	m^3/ha	
Irrigation	number (#)	Only number of irrigation applications
Planting date	dd-mm-yy	
Halm killing date	dd-mm-yy	
Harvesting date	dd-mm-yy	

Applied nutrients	Units	Category
Applied N	kg/ha	Manure, KAS, Urea, Sulphasote
Applied K	kg/ha	Manure, K50, K60
Applied P	kg/ha	Manure
Applied S	kg/ha	Manure
Applied Mg	kg/ha	Manure

A.3.2 Soil, crop and management characteristics used in this study

The variables that were used in this study differs slightly from the data that is obtained from Van den Borne. The index number is inserted based on Van Ittersum et al. (2003). The method and spatial and temporal variables were included (table A.3).

Table A.3 Information about the variables used. Index abbreviation are according Van Ittersum et al. (2003) Defining (D), Limiting (L), Reducing (R) and subcategories: management (m), soil (s) and weather (w).

Variable	Index	Unit	Measurement			Source
			Scale	Time	#	
Yield harvester	-	Ton/ha	Spot	End	1	Sensor on the harvester
Yield weight bridge	-	Ton/ha	Field	End	1	Loader are weighted on the farm
Variety	D.m	Name	Field	Start	1	Obtained from seed grower
Seed tuber origin		Name	Field	Start	1	Obtained from seed grower
Planting distance		Cm	Field	Start	1	Setting planting machine
Size of seed tubers		Index	Field	Start	1	Obtained from seed grower
Growing days planting		Days	Field	-	-	Start counting from planting
Radiation amount	D.w	J/cm2	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Radiation duration		Hour	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Temperature sum from planting		°C/ day	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Temperature till planting		°C/ day	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Evapotranspiration	L.m	Mm/day	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Irrigation		#	Field	*	\	Counted by Van den Borne
K50		Kg/ ha	Field	*	\	Counted by Van den Borne
K60		Kg/ ha	Field	*	\	Counted by Van den Borne
KAS		Kg/ ha	Field	*	\	Counted by Van den Borne
Manure amount		M^3/ ha	Field	*	\	Counted by Van den Borne
Magnesium from manure		Kg/ ha	Field	*	\	Counted by Van den Borne
Nitrogen from manure		Kg/ ha	Field	*	\	Counted by Van den Borne
Organic manure type		Index	Field	*	\	Counted by Van den Borne
Phosphorus from manure		Kg/ ha	Field	*	\	Counted by Van den Borne
Potassium from manure		Kg/ ha	Field	*	\	Counted by Van den Borne
Sulphate from manure		Kg/ ha	Field	*	\	Counted by Van den Borne
Urea		Litres/ ha	Field	*	\	Counted by Van den Borne
Total nitrogen		Kg N / ha	Field	*	\	Counted by Van den Borne
Total phosphorus		Kg P / ha	Field	*	\	Counted by Van den Borne
Total potassium		Kg K/ ha	Field	*	\	Counted by Van den Borne

Variable	Index	Unit	Measurement			Source
			scale	Time	#	
Boron soil sample	L.s	Mg/ kg soil	Field	Start	1	According Eurofins protocol
Calcium soil sample		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Cation exchange complex		%	Field	Start	1	According Eurofins protocol
Clay fraction		%	Field	Start	1	According Eurofins protocol
Drought sensitivity		Index				Louis van den Borne
C/N ratio			Field	Start	1	According Eurofins protocol
Conductivity		mS/m	Spot	Start	1	EM-38 by Van den Borne
GHG		Metre	Field	Start	1	Based on soil maps
GLG		Metre	Field	Start	1	Based on soil maps
Iron in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Magnesium in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Mangan in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Nitrogen in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Nutrient content in the soil		Index	Field	Start	1	Louis van den Borne
Phosphorus in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Potassium in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Silicon in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Zinc in the soil		Mg/ kg soil	Field	Start	1	According Eurofins protocol
Rainfall amount	L.w	Mm	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Rainfall duration		Hour	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Relative humidity		%	Region	Daily	\	Measured by weather station in Eindhoven by KNMI
Granule	R.m	Yes or no	Field	*	\	Based on Nematodes in the soil
Group of spraying		Name	Field	*	\	Counted by Van den Borne
Nematodes		Yes or no	Field	Start	1	Louis van den Borne
Previous crop		Name	Field	*	\	Counted by Van den Borne

A.3.3 Management, weather and soil variables

The summary for the management, weather and soil variables are presented in the following sections. Based on the data from 2013 to 2016 by Van den Borne.

A.3.3.1 Soil

Table A.4 Complete overview of soil variables with the counts and average values in the different years. "/" Sign indicated that the variable was missing. "-" Sign indicated that the value was zero (n=496).

		2013	2014	2015	2016	2013-2016
Previous crop (# of fields)	**Maize**	80	100	92	83	355
	Grass	27	26	24	17	93
	Sugar beets	6	8	10	7	31
	Conifer	1	-	2	4	6
	Green Bean	-	-	2	-	2
	Triticale	-	1	-	-	1
	Potato	-	-	-	1	1
	Strawberry	-	-	-	1	1
	Summer wheat	1	-	-		1
	Sugar root	-	-	-	1	1
	Vegetables	-	-	-	1	1
	Dry flower	-	-	1	-	1
Average Conductivity (mS/m)	**Min.**	/	/	/	/	/
	1st Qu.	/	/	3.3	/	/
	Median	/	/	6.09	1.7	/
	Mean	/	/	5.509	2.209	1.974
	3rd Qu.	/	/	7.655	2.965	3.36
	Max.	/	/	14.56	12.3	14.56
Drought sensitive (water availability)	**Dry**	26	31	41	33	131
	Average	56	53	62	51	222
	Wet	33	51	29	30	143
Clay fraction (%)	**Min.**	2.7	2.5	1.6	2.7	1.6
	1st Qu.	4.0	4.0	4.0	4.0	4.0
	Median	5.0	5.0	5.0	5.0	5.0
	Mean	5.4	5.4	5.0	5.2	5.3
	3rd Qu.	6.0	5.3	5.0	5.0	5.0
	Max.	10.0	10.0	10.0	15.5	15.5
	NA's	1	-	-	3	4
Loam fraction (%)	**Min.**	4.5	5.0	5.0	5.0	4.5
	1st Qu.	5.0	5.0	5.0	5.0	5.0
	Median	8.9	8.412	8.4	8.3	8.6
	Mean	10.4	10.427	9.4	10.3	10.1
	3rd Qu.	12.5	12.5	11.3	12.5	12.5
	Max.	35.0	35.0	29.0	65.0	65.0
	NA's	1	-	-	3	4

		2013	2014	2015	2016	2013-2016
Sand fraction (%)	**Min.**	59.0	57.6	66.4	19.5	19.5
	1st Qu.	77.5	78.9	83.0	80.9	80.6
	Median	87.0	86.9	87.4	87.3	87.0
	Mean	84.2	84.2	85.6	84.5	84.6
	3rd Qu.	90.0	90.0	90.0	90.0	90.0
	Max.	92.5	90.0	90.3	90.0	92.5
	NA's	1	-	-	3	4
Ground water level high(cm)	**Min.**	10.0	10.0	20.0	14.0	10.0
	1st Qu.	30.0	30.0	33.3	30.0	30.0
	Median	50.0	43.2	49.5	45.0	47.2
	Mean	51.3	50.1	49.8	49.0	50.1
	3rd Qu.	69.5	66.5	60.0	64.1	65.0
	Max.	120.0	120.0	120.0	120.0	120.0
	NA's	-	1	4	3	8
Ground water level low (cm)	**Min.**	75.0	75.0	92.1	82.5	75.0
	1st Qu.	112.5	112.5	112.5	112.5	112.5
	Median	113.1	116.7	116.8	114.7	116.7
	Mean	116.9	116.7	117.8	116.3	117.0
	3rd Qu.	125.0	125.0	125.0	125.0	125.0
	Max.	125.0	125.0	125.0	125.0	125.0
	NA's	-	1	4	3	8
Ground water level average (cm)	**Min.**	42.5	42.5	56.1	48.0	41.0
	1st Qu.	72.1	72.5	72.5	71.3	72.5
	Median	81.3	81.3	81.3	81.3	81.3
	Mean	84.1	82.8	81.3	80.5	82.2
	3rd Qu.	96.2	93.62	92.5	92.5	92.5
	Max.	122.5	122.5	122.5	122.5	122.5
	NA's					
Richness field (nutrient content)	**Poor**	14	29	24	8	75
	Average	77	92	86	86	341
	Rich	24	14	22	21	81
Nitrogen in the soil sample (gram/ kg soil)	**Min.**	8	/	20	7	7
	1st Qu.	29	/	56	13	31
	Median	50	/	112	32	68
	Mean	52	/	133	77	103
	3rd Qu.	63	/	167	111	142
	Max.	116	/	595	727	727
	NA's	107	/	66	53	361

		2013	2014	2015	2016	2013-2016
Sulphate in the soil sample (gram/ kg soil)	**Min.**	16	/	5	12	5
	1st Qu.	40	/	14	21	16
	Median	65	/	20	34	27
	Mean	78	/	28	40	37
	3rd Qu.	113	/	31	48	43
	Max.	157	/	129	195	195
	NA's	107	/	73	53	368
Potassium in the soil sample (K2O gram/ kg soil)	**Min.**	75	/	18	22	18
	1st Qu.	178	/	106	114	115
	Median	247	/	155	171	168
	Mean	238	/	183	204	196
	3rd Qu.	275	/	234	251	248
	Max.	434	/	635	560	635
	NA's	107	/	66	53	361
Magnesium in the soil sample (gram/ kg soil)	**Min.**	266	/	66	143	66
	1st Qu.	324	/	172	274	235
	Median	373	/	254	336	291
	Mean	366	/	240.9	349	300
	3rd Qu.	380	/	293	401	359
	Max.	513	/	433	600	600
Manganese in the soil sample (gram/kg soil)	**Min.**	450	/	174	150	150
	1st Qu.	585	/	537	882	644
	Median	780	/	2034	2028	1938
	Mean	1088	/	4433	4013	4047
	3rd Qu.	1044	/	4302	4970	4308
	Max.	3126	/	34218	25200	34218
	NA's	108	/	73	53	369
Boron in the soil sample (gram/ kg soil)	**Min.**	162	/	36	114	36
	1st Qu.	233	/	207	342	258
	Median	261	/	366	507	420
	Mean	261	/	833	906	833
	3rd Qu.	281	/	861	915	828
	Max.	384	/	6318	6504	6504
	NA's	107	/	73	53	368

		2013	2014	2015	2016	2013-2016
Phosphate in the soil sample	**Min.**	/	/	0.6	1.4	0.6
(P2O5 gram/ kg soil)	**1st Qu.**	/	/	1.8	2.7	2.4
	Median	/	/	3.6	5.5	5.5
	Mean	/	/	5.227	10.59	23.67
	3rd Qu.	/	/	6.9	13.7	12.4
	Max.	/	/	21	68.7	384
	NA's	/	/	73	53	368
Calcium oxide in the soil	**Min.**	/	/	/	-	-
(gram/ kg soil)	**1st Qu.**	/	/	/	-	-
	Median	/	/	/	2	-
	Mean	/	/	/	76.8	17.8
	3rd Qu.	/	/	/	68.5	-
	Max.	/	/	/	661.0	661.0
Carbon/ nitrogen (C/N ratio)	**Min.**	16.0	15.0	15.0	16.0	15.0
	1st Qu.	16.5	16.5	16.8	16.8	16.0
	Median	18.5	17.0	18.0	17.5	17.0
	Mean	18.0	17.8	18.3	17.5	18.0
	3rd Qu.	19.0	18.5	19.3	18.3	19.0
	Max.	20.0	27.0	23.0	19.0	27.0
	NA's	109	120	124	113	466
CEC complex	**Min.**	26	31	14	26	14
	1st Qu.	34	41	24	33	33
	Median	42	44	34	39	41
	Mean	44	46	37	39	42
	3rd Qu.	50	54	39	46	52
	Max.	69	57	88	53	88
	NA's	109	120	124	113	466
CEC_saturation (%)	**Min.**	95	88	92	96	88
	1st Qu.	96	90	94	97	93
	Median	96	94	95	98	96
	Mean	97	94	96	98	95
	3rd Qu.	97.5	97	97	99	97
	Max.	99	99	100	100	100
	NA's	111	122	128	113	474

A.3.3.2 Weather

Table A.5 Complete overview of soil variables with the counts and average values in the different years. "/" Sign indicated that the variable was missing. "-" Sign indicated that the value was zero (n=496).

		2013	2014	2015	2016	2013-2016
Radiation duration (hour)	**Min.**	837	787	911	789	787
	1st Qu.	925	954	1016	963	961
	Median	985	989	1054	1035	1012
	Mean	981	987	1061	1019	1012
	3rd Qu.	1031	1028	1108	1081	1060
	Max.	1136	1137	1267	1220	1267
	NA's	3	16	19	20	58
Radiation amount (J/cm)	**Min.**	$21.4 * 10^4$	$20.1 * 10^4$	$23.1 * 10^4$	$20.3 * 10^4$	$20.1 * 10^4$
	1st Qu.	$23.3 * 10^4$	$24.6 * 10^4$	$25.4 * 10^4$	$24.3 * 10^4$	$24.4 * 10^4$
	Median	$24.7 * 10^4$	$25.4 * 10^4$	$26.2 * 10^4$	$26.0 * 10^4$	$25.6 * 10^4$
	Mean	$24.6 * 10^4$	$25.3 * 10^4$	$26.4 * 10^4$	$25.7 * 10^4$	$25.5 * 10^4$
	3rd Qu.	$25.8 * 10^4$	$26.2 * 10^4$	$27.3 * 10^4$	$27.1 * 10^4$	$26.6 * 10^4$
	Max.	$27.8 * 10^4$	$28.6 * 10^4$	$30.4 * 10^4$	$30.0 * 10^4$	$30.4 * 10^4$
	NA's	3	16	19	20	58
Rain duration (hour)	**Min.**	161	158	184	182	158
	1st Qu.	192	202	215	202	204
	Median	218	206	229	214	214
	Mean	212	205	230	213	215
	3rd Qu.	230	208	239	223	228
	Max.	279	222	291	247	291
	NA's	3	16	19	20	58
Rain amount (mm)	**Min.**	2000	375	229	375	200
	1st Qu.	274	451	268	394	299
	Median	303	458	288	408	341
	Mean	287	463	291	410	362
	3rd Qu.	313	476	312	425	444
	Max.	364	507	347	453	507
	NA's	3	16	19	20	58
Relative Humidity (%)	**Min.**	73.1	74.8	70.5	74.6	70.5
	1st Qu.	73.6	76.1	71.1	74.9	73.4
	Median	74.3	76.5	72.2	75.1	74.8
	Mean	74.2	76.5	72.2	75.4	74.6
	3rd Qu.	74.6	76.8	72.9	75.7	76.1
	Max.	75.2	77.7	74.6	77.5	77.7
	NA's	3	16	19	24	62

		2013	2014	2015	2016	2013-2016
Evapotranspiration (mm)	**Min.**	369	349	401	360	349
	1st Qu.	400	418	435	424	419
	Median	422	431	449	448	437
	Mean	420	430	450	444	436
	3rd Qu.	439	445	466	464	454
	Max.	470	483	512	509	512
	NA's	3	16	19	20	58
Rain fall mm)	**Min.**	/	/	-	-	-
	1st Qu.	/	/	-	-	-
	Median	/	/	5.5	159	-
	Mean	/	/	32	108	33
	3rd Qu.	/	/	40	189	18
	Max.	/	/	187	254	254
Temperature sum from planting till haulm killing	**Min.**	$20.3 * 10^2$	$21.1 * 10^2$	$21.6 * 10^2$	$22.3 * 10^2$	$20.3 * 10^2$
	1st Qu.	$22.6 * 10^2$	$23.7 * 10^2$	$23.6 * 10^2$	$25.2 * 10^2$	$23.6 * 10^2$
	Median	$24.3 * 10^2$	$24.9 * 10^2$	$24.7 * 10^2$	$26.0 * 10^2$	$24.9 * 10^2$
	Mean	$24.0 * 10^2$	$24.9 * 10^2$	$24.6 * 10^2$	$26.0 * 10^2$	$24.8 * 10^2$
	3rd Qu.	$25.2 * 10^2$	$26.1 * 10^2$	$25.5 * 10^2$	$26.9 * 10^2$	$25.9 * 10^2$
	Max.	$27.5 * 10^2$	$28.7 * 10^2$	$28.5 * 10^2$	$29.2 * 10^2$	$29.2 * 10^2$
	NA's	3	16	19	42	80
Temperature sum from 1 Jan till planting	**Min.**	$20.3 * 10^2$	$21.1 * 10^2$	$21.6 * 10^2$	$22.3 * 10^2$	$20.3 * 10^2$
	1st Qu.	$22.6 * 10^2$	$23.7 * 10^2$	$23.6 * 10^2$	$25.2 * 10^2$	$23.7 * 10^2$
	Median	$24.3 * 10^2$	$24.9 * 10^2$	$24.7 * 10^2$	$26.0 * 10^2$	$24.9 * 10^2$
	Mean	$24.0 * 10^2$	$24.9 * 10^2$	$24.6 * 10^2$	$26.0 * 10^2$	$24.8 * 10^2$
	3rd Qu.	$25.2 * 10^2$	$26.1 * 10^2$	$25.5 * 10^2$	$26.8 * 10^2$	$26.0 * 10^2$
	Max.	$27.5 * 10^2$	$28.7 * 10^2$	$28.5 * 10^2$	$29.6 * 10^2$	$29.6 * 10^2$
	NA's	3	16	19	20	58

A.3.3.3 Seed tubers

Table A.6 Complete overview of seed related variables with the counts and average values in the different years. "/" Sign indicated that the variable was missing. "-" Sign indicated that the value was zero (n=497).

		2013	**2014**	**2015**	**2016**	**2013-2016**
Variety (# of fields)	**Fontane**	82	123	119	95	419
	Miranda	30	6	5	8	49
	Ivory russet	-	-	3	10	13
	Ludmilla	2	6	5	-	13
	Dakota	-	-	-	2	2
	Lady anna	1	-	-	-	1
Size seed potatoes	**Big**	15	5	8	38	66
	Small	45	60	33	19	157
	Average	55	70	91	61	277
Planting distance (cm)	**Min.**	24	25	26	21	21
	1st Qu.	28	30	26	32	29
	Median	32	35	34	34	34
	Mean	32	33	33	35	33
	3rd Qu.	35	36	35	44	36
	Max.	38	41	50	45	50

A.3.3.4 Management

A.3.3.4.1 General

Table A.7 Complete overview of management except for fertilizer variables with the counts and average values in the different years. "/" Sign indicated that the variable was missing. "-" Sign indicated that the value was zero (n=496).

		2013	2014	2015	2016	2013-2016
Area (ha)	**Min.**	0.43	0.46	0.37	0.20	0.20
	1st Qu.	1.55	1.66	1.64	1.36	1.52
	Median	2.95	3.13	2.87	2.51	2.94
	Mean	3.74	3.65	3.70	3.55	3.66
	3rd Qu.	4.96	4.64	5.09	4.66	4.91
	Max.	17.06	12.24	11.69	19.10	19.10
Date planted	**Min.**	4/5/2013	3/25/2014	4/7/2015	4/1/2016	
	1st Qu.	4/16/2013	4/7/2014	4/16/2015	4/13/2016	
	Median	4/22/2013	4/13/2014	4/26/2015	4/21/2016	
	Mean	4/22/2013	4/13/2014	4/24/2015	4/23/2016	
	3rd Qu.	4/28/2013	4/18/2014	4/30/2015	5/6/2016	
	Max.	5/16/2013	5/21/2014	5/18/2015	5/20/2016	
Nematode (yes=1, no = 0)	**0**	113	101	90	86	390
	1	2	34	42	29	107
Granule (yes=1, no = 0)	**0**	113	101	90	84	388
	1	2	34	42	31	109
Irrigation (#)	**Min.**	1	1	1	1	1
	1st Qu.	1.5	2	1	1	1
	Median	2	3	1	1	1
	Mean	2.4	2.8	1.5	1	1.8
	3rd Qu.	3	3	2	1	3
	Max.	4	5	3	1	5
	NA's	84	102	94	67	347

A.3.3.4.2 Fertilizer

The amount of fertilizer that is applied during the season is the mineral nitrogen and ureum nitrogen.

Table A.8 Complete overview of fertilizer application with average values in the different years. "/" Sign indicated that the variable was missing. "-" Sign indicated that the value was zero (n=496).

		2013	2014	2015	2016	2013-2016
Nitrogen during season in manure (kg/ ha)	**Min.**	78	28	43	96	28
	1st Qu.	137	134	134	137	137
	Median	156	156	175	156	156
	Mean	163	152	158	167	160
	3rd Qu.	179	165	176	191	176
	Max.	375	332	330	450	450
	NA's			2	1	3
Sulphate in manure (kg SO_4/ ha)	**Min.**	24	8	20	20	8
	1st Qu.	30	28	28	38	29
	Median	60	50	50	53	53
	Mean	81	63	60	66	67
	3rd Qu.	75	60	68	70	68
	Max.	485	420	450	389	485
	NA's			2	1	3
Potassium in manure (kg K_2O/ ha)	**Min.**	112	35	96	96	35
	1st Qu.	138	134	134	175	137
	Median	272	232	200	238	238
	Mean	243	237	221	238	234
	3rd Qu.	312	272	306	312	306
	Max.	474	578	546	420	578
	NA's	0	0	2	1	3
Magnesium in manure (kg MgO/ ha)	**Min.**	26	9	33	39	9
	1st Qu.	52	52	55	50	52
	Median	55	55	56	55.5	55
	Mean	64	57	58	61	60
	3rd Qu.	65	56	59	65	59
	Max.	195	152	159	157	195
	NA's	0	0	2	1	3
Phosphate in manure (kg P_2O_5 / ha)	**Min.**	22	20	33	33	20
	1st Qu.	45	44	50	44	45
	Median	55	50	50	55	51
	Mean	88	74	81	87	82
	3rd Qu.	105	105	139	120	120
	Max.	423	225	338	507	507
	NA's	0	0	2	1	3

		2013	2014	2015	2016	2013-2016
Total nitrogen in manure	**Min.**	52	21	43	78	21
(kg N / ha)	**1st Qu.**	102	97	86	104	101
	Median	105	110	112	114	112
	Mean	112	109	114	119	113
	3rd Qu.	125	117	125	130	125
	Max.	200	221	252	240	252
	NA's	0	0	50	1	51
KAS fertilization amount	**Min.**	0	0	25	0	0
(kg KAS / ha)	**1st Qu.**	88	48	185	255	91
	Median	100	78	270	352	185
	Mean	137	83	269	341	205
	3rd Qu.	200	105	336	415	311
	Max.	400	368	991	677	991
K50 fertilization amount	**Min.**	0	0	0	0	0
(kg K50/ha)	**1st Qu.**	0	0	0	0	0
	Median	0	0	0	0	0
	Mean	21	0	0	0	5
	3rd Qu.	0	0	0	0	0
	Max.	240	0	0	0	240
K60 fertilization amount	**Min.**	0	0	0	0	0
(kg K60 /ha)	**1st Qu.**	0	0	90	75	0
	Median	0	101	154	141	104
	Mean	51	86	149	139	107
	3rd Qu.	100	145	230.5	218	167
	Max.	200	375	396	347	396
Litres Urea applied	**Min.**	0	0	0	0	0
(l Urea/ha)	**1st Qu.**	100	200	0	0	0
	Median	100	200	0	0	100
	Mean	106	204	14	0	84
	3rd Qu.	100	230	0	0	180
	Max.	220	280	300	0	300
Litres Sulfasote	**Min.**	0	0	0	0	0
(l Sulfasote /ha)	**1st Qu.**	25	0	0	50	0
	Median	136	0	100	120	50
	Mean	92	9	88	116	74
	3rd Qu.	136	0	140	170	136
	Max.	272	272	350	172	350

		2013	2014	2015	2016	2013-2016
Total N applied (kg N /ha / year)	**Min.**	156	59	94	178	59
	1st Qu.	237	193	265	312	234
	Median	272	217	295	334	277
	Mean	275	221	298	339	281
	3rd Qu.	306	243	330	365	326
	Max.	502	500	514	550	550
Total P (kg P /ha / year)	**Min.**	22	20	33	33	20
	1st Qu.	45	44	50	44	45
	Median	55	50	50	55	51
	Mean	88	74	81	87	82
	3rd Qu.	106	105	139	120	120
	Max.	423	225	338	507	507
	NA's			2	1	3
Total K (kg K/ ha/ year)	**Min.**	137	35	96	82	35
	1st Qu.	227	219	253	258	235
	Median	272	272	290	309	289
	Mean	284	289	307	320	300
	3rd Qu.	332	333	333	393	340
	Max.	474	578	679	539	679
Date first fertilization application	**Min.**	3/5/2013	3/9/2014	2/19/2015	3/14/2016	
	1st Qu.	4/4/2013	3/24/2014	4/10/2015	4/4/2016	
	Median	4/10/2013	4/2/2014	4/19/2015	4/9/2016	
	Mean	4/11/2013	4/2/2014	4/16/2015	4/10/2016	
	3rd Qu.	4/19/2013	4/9/2014	4/23/2015	4/17/2016	
	Max.	5/7/2013	5/4/2014	5/14/2015	5/7/2016	
	NA's	2		3	32	37
Organic manure (type)	**Meet cow manure**	49	58	50	54	211
	Calf manure	23	36	42	29	130
	Dairy manure	22	21	11	6	60
	Pig manure	11	13	27	24	75
	Goat manure	7	4	0	0	11
	Chicken manure	3	2	1	1	7
	Compost	0	1	1	0	2

		2013	2014	2015	2016	2013-2016
Amount of organic manure (m3/ha)	**Min.**	16	5	20	25	5
	1st Qu.	30	35	45	40	35
	Median	40	40	45	50	45
	Mean	40	42	47	46	44
	3rd Qu.	50	55	51	56	50
	Max.	70	85	65	60	85

A.3.4 Plant characteristics

For the observations that were sampled an overview was made related to the plant and time variables (table A.9).

Table A.9 Complete overview of plant characteristics with the average values in the different years. "/" Sign indicated that the variable was missing. "-" Sign indicated that the value was zero (n=496).

		2013	2014	2015	2016	2013-2016
Degree-day sampling overall (ºC/d)	**Min.**	1061	705	502.8	336	336
	1st Qu.	1406	1190	1120	906	1155
	Median	1620	1579	1534	1386	1543
	Mean	1603	1610	1573	1443	1543
	3rd Qu.	1804	2075	2121	1974	1941
	Max.	2035	2645	2437	2684	2684
Growing days sampling overall (d)	**Min.**	66	43	35	20	20
	1st Qu.	93	81	74	63	76
	Median	103	99	99	87	99
	Mean	109	104	99	90	98
	3rd Qu.	113	128	127	119	120
	Max.	130	168	153	166	168
Weight tubers (ton/ ha)	**Min.**	3.7	1.7	1.2	0.2	0.2
	1st Qu.	33.6	25.2	23.6	18.6	25.5
	Median	45.4	42.7	40.3	36.1	40.5
	Mean	46.2	44.6	42.4	38.46	42.6
	3rd Qu.	58.0	60.4	57.3	53.4	57.5
	Max.	110.5	114.0	147.4	180.3	180.3
	NA's	2	5	17	130	154
Chlorophyll (µg/cm2)	**Min.**	22985	25590	22920	10290	10290
	1st Qu.	31172	36615	36365	27905	31905
	Median	33966	38520	40010	33560	36210
	Mean	34377	38567	40775	32296	35923
	3rd Qu.	37370	40868	44988	37186	39874
	Max.	45614	50240	55370	47890	55370
	NA's	41	275	136	256	708

		2013	2014	2015	2016	2013-2016
Flavonoïd (g/cm2)	**Min.**	818	872	870	821	818
	1st Qu.	1110	1080	1170	1192	1140
	Median	1222	1169	1270	1360	1261
	Mean	1223	1168	1290	1417	1295
	3rd Qu.	1324	1250	1380	1610	1398
	Max.	1951	1474	1850	2270	2270
	NA's	39	275	137	265	716
Nitrogen balances index (Chl/flav)	**Min.**	15140	20599	14100	6250	6250
	1st Qu.	25227	31770	28380	18135	24770
	Median	28555	34181	33143	25410	30062
	Mean	29727	34446	33101	25051	29751
	3rd Qu.	33833	37409	38190	31644	35391
	Max.	48941	48109	50940	48525	50940
	NA's	39	275	137	265	716
Number of stems (*1000 #/ha)	**Min.**	46	19	51	59	19
	1st Qu.	118	89	162	157	126
	Median	148	111	190	195	165
	Mean	154	116	196	200	171
	3rd Qu.	183	143	226	237	209
	Max.	351	228	385	458	458
	NA's	3	45		63	111
Number of tubers (*1000 #/ha)	**Min.**	180	159	85	35	35
	1st Qu.	404	397	533	533	444
	Median	495	491	632	692	567
	Mean	525	490	654	738	609
	3rd Qu.	619	578	764	902	724
	Max.	1346	1077	1230	2825	2825
	NA's	2	5	17	129	153
Number of compound leaves (#/plant)	**Min.**	2	1	1	1	1
	1st Qu.	6	5	6	6	6
	Median	7	8	8	8	8
	Mean	7.4	7.7	7.7	7.4	7.5
	3rd Qu.	9	10	10	9	10
	Max.	13	13	16	15	16
	NA's	3	49	11	79	142

		2013	2014	2015	2016	2013-2016
Stem length (cm)	**Min.**	55	45	20	10	10
	1st Qu.	80	75	65	55	70
	Median	90	90	80	70	80
	Mean	92	90	82	75	84
	3rd Qu.	100	100	100	90	100
	Max.	150	165	160	175	175
	NA's	3	45		63	111
Root weight (kg/ha)	**Min.**	370	185	125	104	104
	1st Qu.	1675	1877	1955	1681	1767
	Median	2068	2286	2393	2332	2279
	Mean	2146	2341	2437	2502	2377
	3rd Qu.	2618	2739	2895	3053	2837
	Max.	4598	6222	5149	9531	9531
	NA's	3	45		63	111
Shoot weight (kg/ha)	**Min.**	6804	1511	736	556	556
	1st Qu.	22612	21643	18659	11010	17546
	Median	29792	29173	25793	18143	25244
	Mean	31570	29988	26802	20508	26580
	3rd Qu.	39237	37678	33440	27236	34584
	Max.	78249	75689	88455	72064	88455
	NA's	3	45	2	98	148
Nitrate content (PPM)	**Min.**	597	406.7	450	427	406.7
	1st Qu.	2367	3550	5342	1637	2667
	Median	3833	5533	7400	3400	4900
	Mean	4645	5606	7050	3730	5094
	3rd Qu.	6633	7767	9567	5392	7283.5
	Max.	10000	9999	9999	9933	10000
	NA's	3	52	132	173	360

A.4 Theoretical background

For estimating the growth curves a few methods were used to determine the curves. Different plant characteristics follow different growth curves in time.

A.4.1 Tuber weight

Tuber weight is defined as the weight of the tubers in kilogram per hectare. According to Dyson and Watson (1971), tuber weight follows an S-shaped growth over time. The growth function in equation 2 was therefore implemented in the model. For grain filling also an S-shaped curve was fitted according to Yin *et al.* (2003). The growth curve of the dry weight per plant looks like a quadratic function (figure A.5).

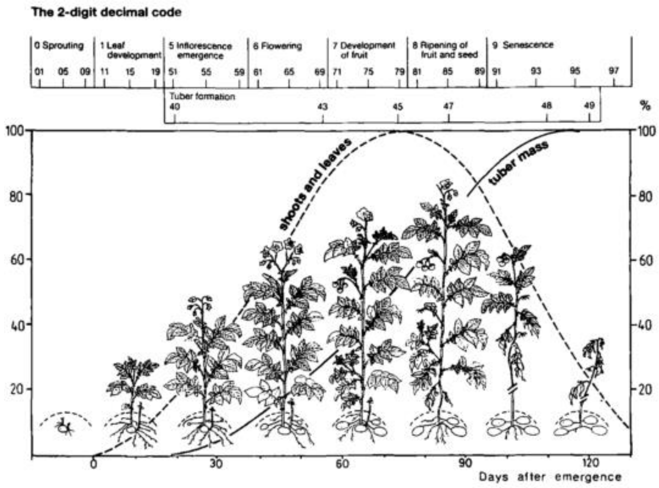

Fig. A.5 Haulm weight and tuber weight against maximum achieved weight (Kolbe and Stephan-Beckmann, 1997a)

A.4.2 Shoot weight

Shoot weight is the weight of the leaves measured on the field. According to Kolbe and Stephan-Beckmann (1997a), the function that should be fitted for shoot weight is a quadratic function fitted until the leaf senescence. Figure A.5 represents the function and gives more insight into the development of the plant.

A.4.3 Root weight

According to literature (Iwama, 1988a; Lesczynski and Tanner, 1976; Lommen, 1995), the function that fits the development of root weight over time is a third-degree polynomial (figure A.6).

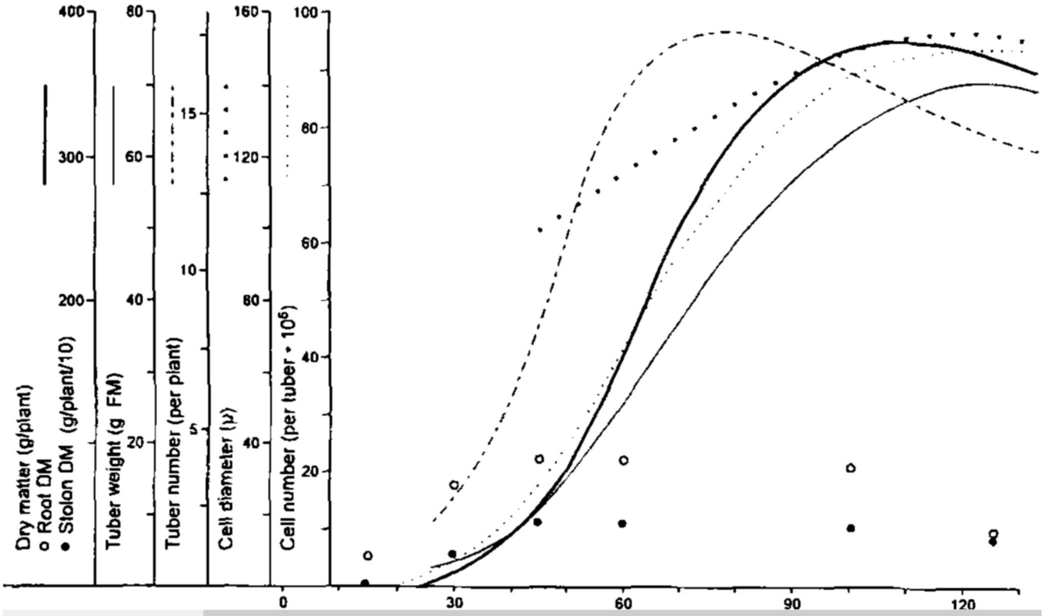

Fig. A.6 Development over time of yield and corresponding potato factors relating to the yield (Kolbe and Stephan-Beckmann, 1997b)

A.4.4 Underwater weight

The amount of starch is calculated in different ways in different countries. Simmonds (1977) studied the relationship between those different methods. The scientific calculation of the amount of dry matter in the potato is the specific gravity (figure A.7.b).

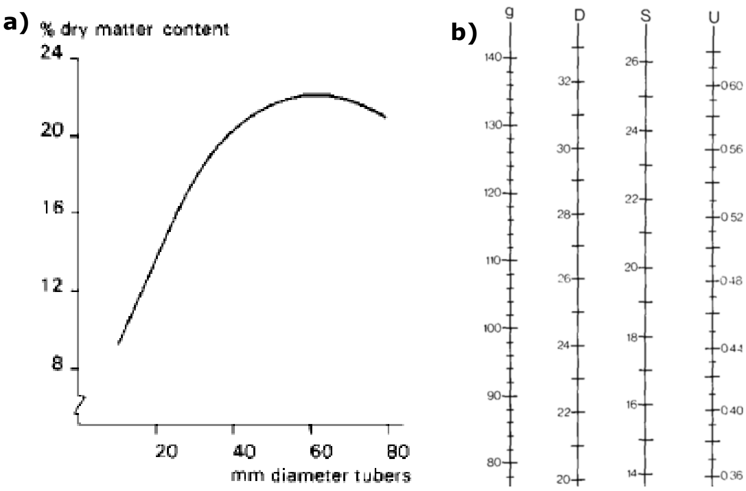

Fig. A.7 Dry matter content of potatoes in relation to the size (Beukema and Van der Zaag, 1990), B) relation between; g = 1000 * (specific gravity -1), dry matter content in % (D), Starch content in % (S) and underwater weight in gram for 5 kilogram potatoes (U) (Simmonds, 1977).

At a certain size (60 millimetres), the dry matter content decreases (figure A.7a). So, the increase in underwater weight is caused by the increase in tuber size. This is a negative effect of the yield increase, if the number of tubers is not increasing with the yield.

A.4.5 Number of tubers

For the number of tubers, a quadratic function will fit the best (figure A.6). The small decrease at the end of the season is due to tuber absorption by the potato in the total number of tubers. The function is also presented in the paper of (Farran and Mingo-Castel, 2006; O'brien *et al.*, 1998; Vreugdenhil *et al.*, 2011).

A.4.6 Number of stems

After 100% emergence no stem will be formed anymore. According to Bremner and Taha (1966) two to three weeks after emerging the number of stems is fixed. Some plants will senescence because of bacteria. So, the number of stems decrease over the season. The number of stems is also depending on the genotype, seed size and storage temperature according to Knowles and Knowles (2006).

A.4.7 Number of compound leaves

The number of compound leaves presents the number of branches with leaves formed by the potato plant (Midmore, 1984). There is a balance between the initiated leaves and the reduction in leaves due to senescence, which depends on a lot of factors (Jefferies, 1993) (figure A.8). According to Jefferies (1993), maintaining leaf growth depends on several mechanisms, such as water relations, cell wall elasticity, hydraulic conductivity and root capacity.

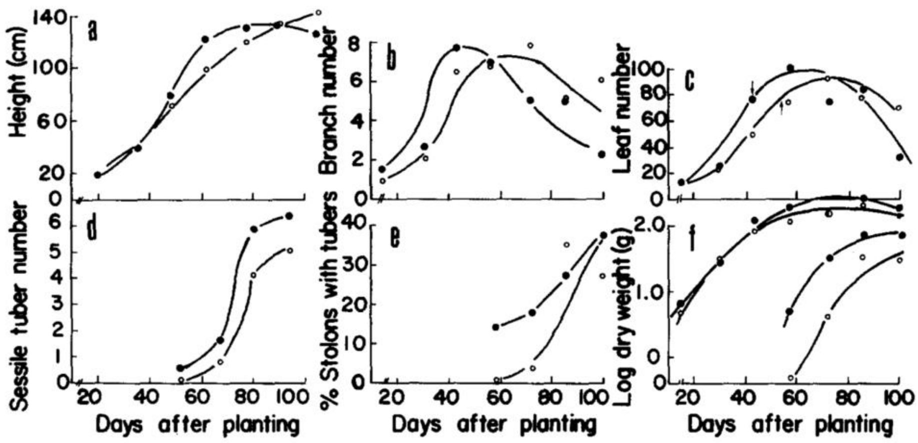

Fig. A.8 Effect of soil covering with (●) and without (○) a soil reflectant. The height (a), axillary branch number per stem (b), leaf number (c), number of sailable tubers (d), the percentage of stolons with tubers (e) and tuber and dry weight per plant (f) are presented (Midmore, 1984).

A.4.8 Stem length

The stem length represents the length of the average length of several plants. The length of the potatoes is presented by a sigmoid curve. Richards (1959) and Bodlaender (1960) showed that stem length is according to a sigmoid function in relation to days after planting (figure A.8). Different other papers showed the same function (Farran and Mingo-Castel, 2006; Pavlista, 1995; Schans and Arntzen, 1991).

A.4.9 Nitrate in the leaves

The nitrate content in the leaves is highly correlated with the chlorophyll (Mauromicale *et al.*, 2006). The nitrogen content in the leaves (ppm) showed no symmetrical quadratic function (figure A.9). For data analyses, some limitation could be observed, for a data set with only four observation a third-degree function can be used (Vos and Bom, 1993). For a dataset with only two observation, this cannot be used.

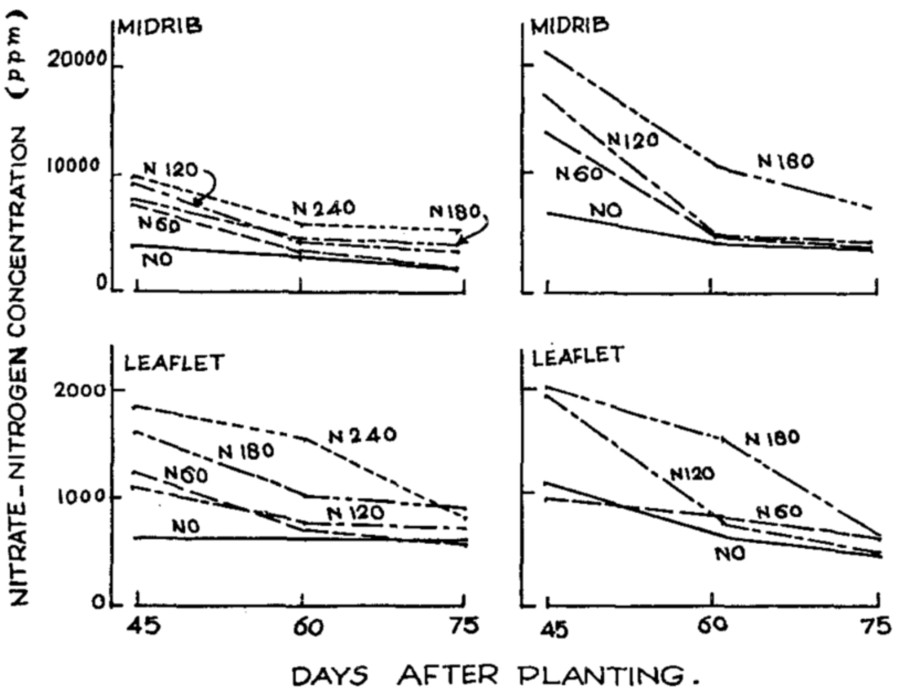

Fig. A.9 Nitrogen effect over time on leaf N content for different nitrogen treatments (Dyson and Watson, 1971; Gupta and Saxena, 1976).

A.4.10 Chlorophyll

The chlorophyll content decreases linearly over time (Vos and Bom, 1993; figure 7.9). To use a third-degree function will fit the data the best (figure A.10).

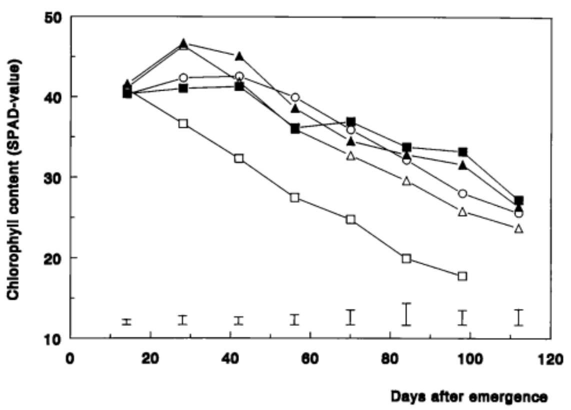

Fig. A.10 Chlorophyll content for different nitrogen contents over time (Vos and Bom, 1993).

A.4.11 Flavonoïd and NBI

Flavonoïd is a ratio and depending on the chlorophyll and nutrient balance index (figure A.11). For the flavonoid, a linear line could be used until 90 days after planting (60 days after emergence) according to Milagres *et al.* (2018).

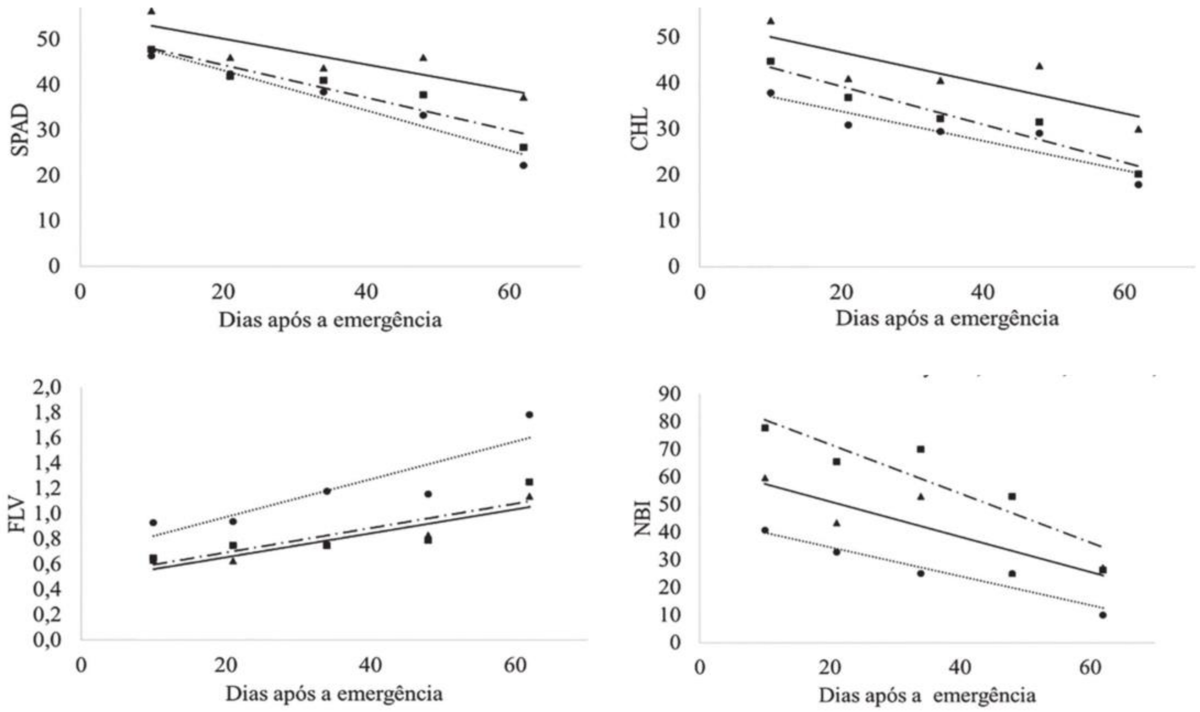

Fig. A.11 SPAD, chlorophyll, flavonoid and NBI after emergence, measured with Dualex for the variety Agate according to Milagres et al. (2018).

A.5 Optimal cluster number methods

For clustering with k mean the number of clusters needs to be specified (Jain, 2010). According to Friedman *et al.* (2001) "The main difficulty in choosing k is that clustering is fundamentally an unsupervised learning problem, meaning that there is no obvious way to use prediction ability to drive the model selection" (Fu and Perry, 2017). An overview of methods is proposed and analysed in this study (table A.10).

Table A.10 Overview of the methods for optimal cluster number

	Index name	Source	Optimal number of cluster
1	Elbow	(Thorndike, 1953)	Largest difference between slope between the number of clusters
2	ICA (BIC/ AIC)	(Akaike, 1978; Schwarz, 1978)	Maximum value of the index
3	ITA (jump)	(Sugar and James, 2003)	Fastest decline
4	Cross-validation	(Owen and Perry, 2009)	Smallest index
5	Ch	(Calinski and Harabasz, 1974)	Maximum value of the index
6	Duda	(Duda and Hart, 1973)	Smallest number of clusters such that index > critical value
7	pseudot2	(Duda and Hart, 1973)	Smallest number of clusters such that index > critical value
8	Cindex	(Hubert and Levin, 1976)	Minimum value of the index
9	Gamma	(Baker and Hubert, 1975)	Maximum value of the index
10	Beale	(Beale, 1969)	Number of clusters such that critical value >= alpha
11	Ccc	(Sarle, 1983)	Maximum value of the index
12	Ptbiserial	(Milligan, 1980, 1981)	Maximum value of the index
13	Gplus	(Milligan, 1981; Rohlf, 1974)	Minimum value of the index
14	Db	(Davies and Bouldin, 1979)	Minimum value of the index
15	Frey	(Frey and Van Groenewoud, 1972)	Cluster level before index value < 1.00
16	Hartigan	(Hartigan, 1975)	Maximum difference between hierarchy levels of the index
17	Tau	(Milligan, 1981; Rohlf, 1974)	Maximum value of the index
18	Ratkowsky	(Ratkowsky and Lance, 1978)	Maximum value of the index
19	Scott	(Scott and Symons, 1971)	Maximum difference between hierarchy levels of the index
20	Marriot	(Marriott, 1971)	Max. value of second differences between levels of the index
21	Ball	(Ball and Hall, 1965)	Maximum difference between hierarchy levels of the index
22	Trcovw	(Milligan and Cooper, 1985)	Maximum difference between hierarchy levels of the index
23	Tracew	(Milligan and Cooper, 1985)	Max. value of second differences between levels
24	Friedman	(Friedman and Rubin, 1967)	Maximum difference between hierarchy levels of the index
25	Mcclain	(McClain and Rao, 1975)	Minimum value of the index
26	Rubin	(Friedman and Rubin, 1967)	Minimum value of second differences between levels
27	Kl	(Krzanowski and Lai, 1988)	Maximum value of the index
28	Silhouette	(Rousseeuw, 1987)	Maximum value of the index
29	Gap	(Tibshirani *et al.*, 2001)	Smallest number of clusters such that critical value >= 0

	Index name	Source	Optimal number of cluster
30	Dindex	(Lebart *et al.*, 2000)	Graphical method
31	Dunn	(Dunn†, 1974)	Maximum value of the index
32	Hubert	(Hubert and Arabie, 1985)	Graphical method
33	Sdindex	(Halkidi *et al.*, 2000)	Minimum value of the index
34	Sdbw	(Halkidi and Vazirgiannis, 2001)	Minimum value of the index

A.6 Crop fields

The data that is used over different years is obtained across South of the Netherlands and in the North of Belgium. Different fields were used over the four years that were obtained by the farmer (figure A.12, A.13, A.14 & A.15).

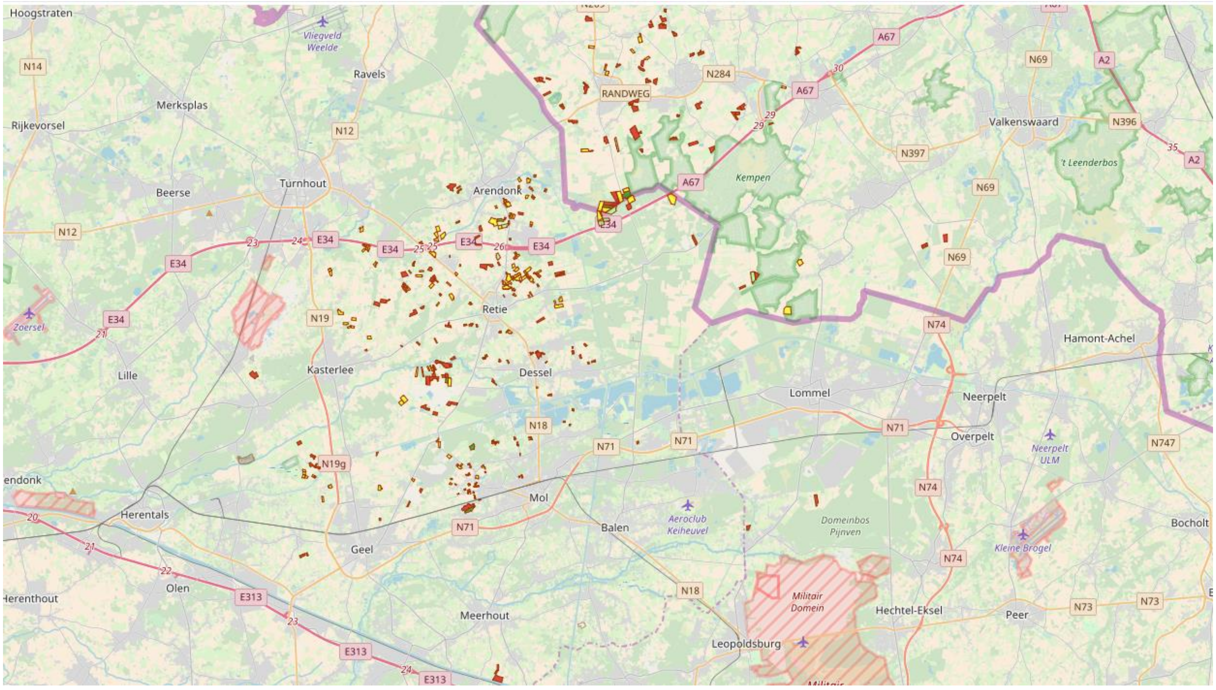

Fig. A.12 Year 2013 with 454.42 hectares of land

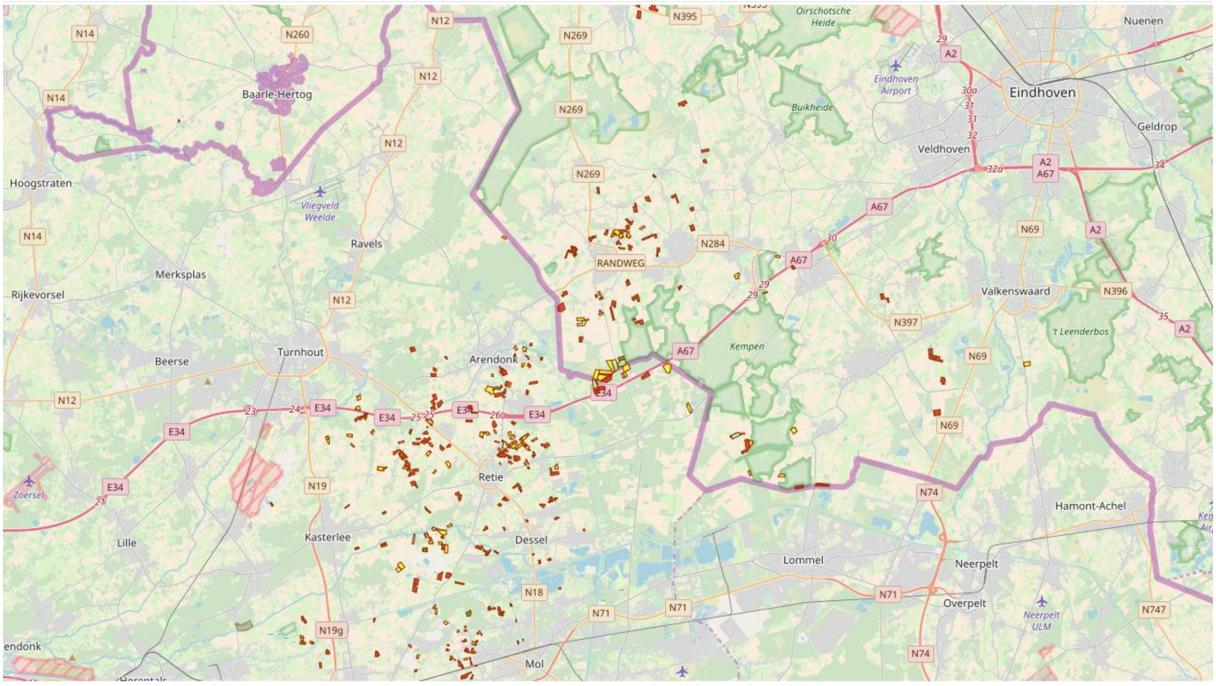

Fig. A.13 Year 2014 with 513.46 hectares of land

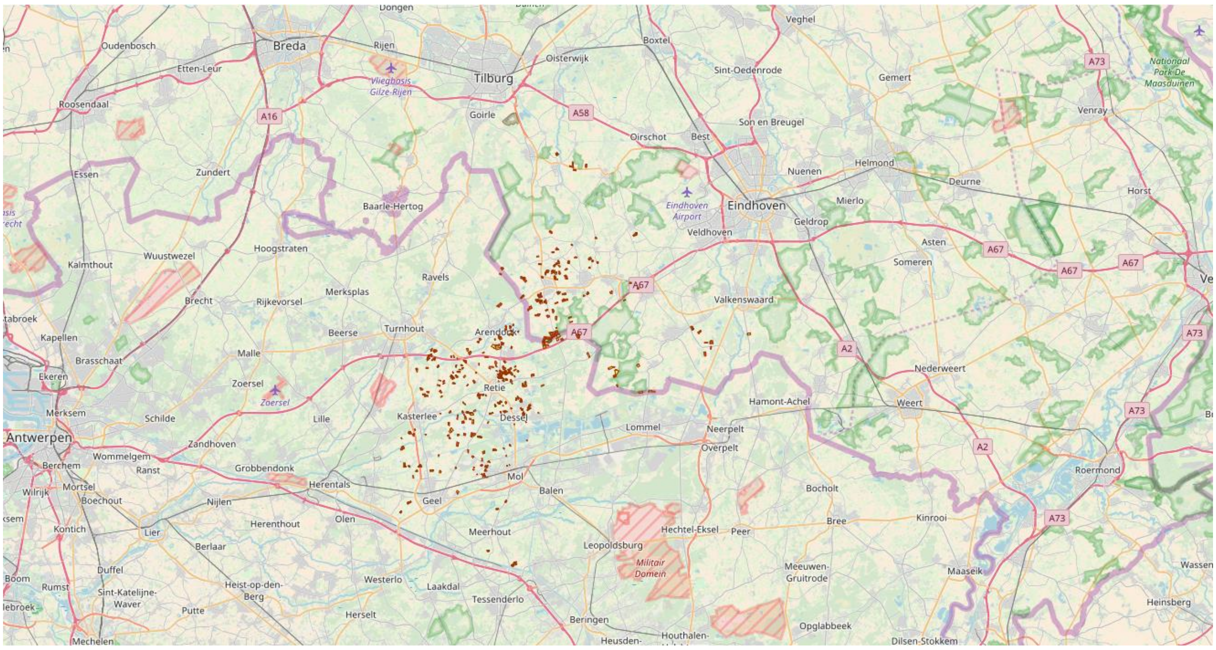

Fig. A.14 Year 2015 with 560.81 hectares of land

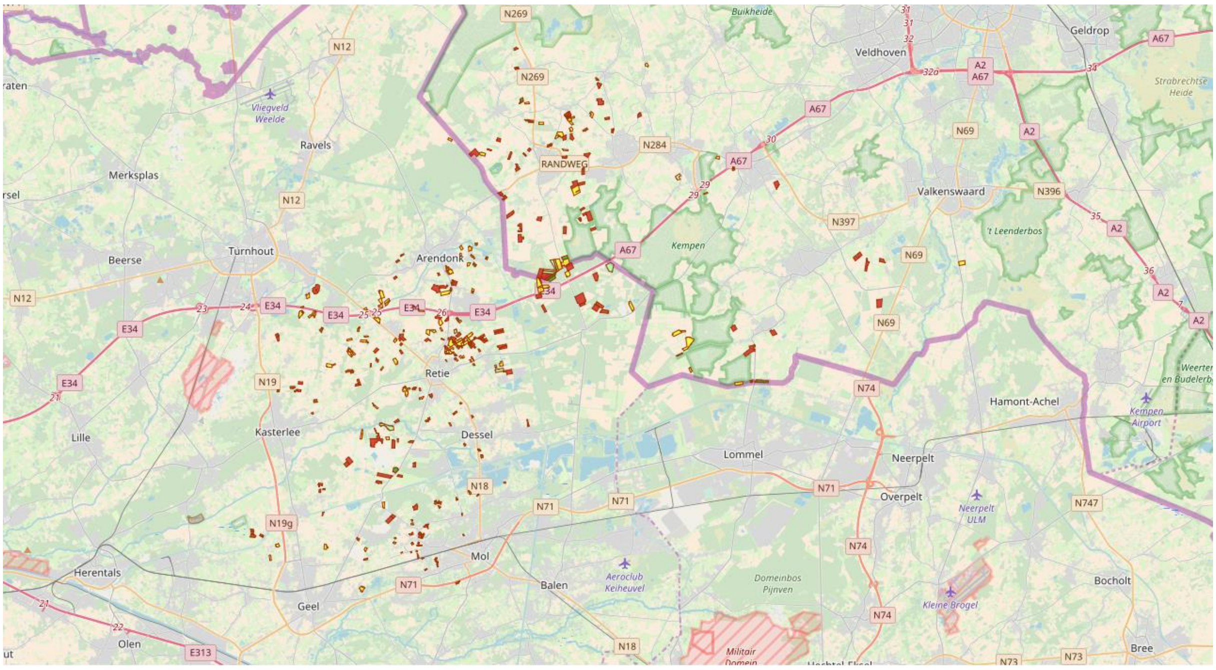

Fig. A.15 Year 2016 with 557.37 hectares of land

A.7 Significant differences

To compare the results from this study with a similar study (2013-2016) performed from the dataset of 2016 by Mulders (2017) (section A.7.1). Besides the comparison also the different time variables are compared (section A.7.2).

A.7.1 Difference between 2013-2016 and 2016

The difference between Mulders and the study is visualized (table A.11).

Table A.11 Difference between results and Mulders (2017), *= identical, #= significant from results and "/" indicated only the results from 2016 of (Mulders, 2017).

	Tuber weight	Shoot weight	Root weight	Underwater weight	Number of tubers	Number of stems	Number of leaves	Stem length	Nitrate content	Flavonoid level
Boron soil					#			#		
Calcium soil	/			#						
Conductivity		*	#	#	#	#			#	
Drought sensitivity	/		/			/		/	*	
Granule*		/			/					
Group of spraying										
Growing days	*							*	#	
Iron soil										
Irrigation		/	/						/	
K50	#	#	#							
K60		#	#	#	#	*		#	#	
KAS		#	#	#	#	#		#	#	
Organic manure amount									#	
Litres of sulphate		#	#	#	#	#		#	#	
litres urea		#	#	#	#	#		#	#	
Magnesium from manure									/	
Magnesium soil			#	#	/	#			#	
Mangan soil sample				#		/				
Nematodes*	/	/	*	#	/			/	#	
Nitrogen available									#	
Nitrogen from manure				#				/	#	
Nitrogen soil s		#			/			#	*	
Nutrient content										
Organic manure		*	/	/		/			/	
Phosphorus from		/						/		
Phosphorus soil		#	#	#	/	#			#	
Planting distance	*	/	*		*	#		/	#	
Potassium from manure					*				/	
Potassium soil		/		#				#		
Silicon in soil		#								
Size of seed tuber	/	/	*	#	*	*		/	#	
Sulphate from manure									/	
Temp. sum from planting	*	/	/	/	*			/		
Temp. sum till planting	*	/	/	/	*					
Variety	#	/								
Zinc in soil *										

A.7.2 Difference between DAP and GDD

The significant differences between days after planting and growing degree days are presented in table A.12.

Table A.12 P-values of the ANOVA and logistic regression analyses for all the plant characteristics clusters for time variable DAP and GDD. If there is referred to 'ns' this refers to no significant difference, '-' refers no observation, *, ** and *** refer to P-values of <0.05, <0.01 and <0.001 (n=270-496).

	DAP										GDD									
Variable	**Tuber weight**	**Shoot weight**	**Root weight**	**Underwater weight**	**Number of tubers**	**Number of combined leaves**	**Number of stems**	**Stem length**	**Flavonoid**	**Nitrate content**	**Tuber weight**	**Shoot weight**	**Root weight**	**Underwater weight**	**Number of tubers**	**Number of combined leaves**	**Number of stems**	**Stem length**	**Flavonoid**	**Nitrate content**
Boron soil	ns	ns	ns	ns	**	ns	ns	*	ns	ns	ns	ns	ns	ns	**	ns	ns	*	ns	**
Calcium soil	ns	ns	***	**	**	***	*	ns	***	***	ns	ns	***	***	***	***	ns	**	***	***
CEC	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Clay fraction	*	ns	**	*	ns	**	ns	ns	ns	ns	ns	ns	**	**	ns	ns	ns	ns	*	*
C_N ratio	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns
Conductivity	ns	***	***	***	***	***	***	**	***	***	ns	***	**	***	***	***	***	**	***	***
Drought sensitivity	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns	**	ns	ns	*	**	ns	*
Evapotranspiration	**	ns	***	***	***	***	**	*	**	***	ns	ns	***	***	***	***	**	**	***	**
GHG	ns	ns	ns	ns	ns	**	*	ns	ns	ns	ns	*	ns	ns	**	ns	ns	ns	ns	ns
GLG	ns	ns	ns	ns	ns	*	*	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Group of spraying	***	***	***	***	***	***	***	***	ns	***	***	***	***	***	***	***	***	***	ns	ns
Growing days until haulm killing	*	ns	**	ns	ns	**	ns	**	**	**	ns	ns	**	ns	ns	*	ns	**	**	ns
Irrigation	ns	ns	ns	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	***	ns	ns	ns	ns	**
K50	***	***	*	ns	ns	***	ns	ns	**	ns	***	***	**	**	ns	***	ns	ns	**	ns
K60	ns	**	***	**	***	***	**	**	***	**	ns	*	***	**	***	***	**	ns	***	**
KAS	ns	***	***	***	***	***	***	**	***	***	ns	***	***	***	***	***	***	***	***	***
K60	ns	**	***	**	***	***	**	**	***	**	ns	*	***	**	***	***	**	ns	***	**
KAS	ns	***	***	***	***	***	***	**	***	***	ns	***	***	***	***	***	***	***	***	***
Organic manure amount	ns	ns	ns	ns	ns	**	ns	ns	**	*	ns	ns	ns	ns	ns	*	ns	ns	**	*
Litre sulphasote	ns	**	**	***	***	***	***	**	**	**	ns	**	**	***	***	***	***	**	***	**
Litre urea	ns	***	***	***	***	***	***	***	***	***	*	***	***	***	***	***	***	***	***	***
Magnesium from	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	**
Magnesium soil	ns	ns	**	**	ns	**	**	ns	***	**	ns	ns	**	**	**	***	**	ns	***	***
Manganese soil	ns	ns	ns	***	ns	ns	ns	ns	ns	ns	ns	*	*	**	ns	ns	ns	ns	ns	ns
Nitrogen available	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen from manure	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen soil	ns	**	ns	***	ns	ns	ns	*	**	***	ns	**	ns	*	**	ns	ns	**	**	***
Nutrient content in the field	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Organic manure type	ns	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	***	***	ns	ns	ns	ns	ns
Origin seed tuber	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Phosphorus in manure	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Phosphorus soil	ns	**	***	*	***	***	***	ns	***	**	ns	*	**	ns	*	***	***	ns	***	**
Planting distance	**	ns	***	ns	**	***	**	ns	***	**	ns	ns	***	ns	***	**	***	ns	***	***
Potassium in manure	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
Potassium in soil	ns	ns	ns	**	ns	ns	ns	**	ns	ns	*	*	ns	**	ns	ns	ns	**	ns	ns
Radiation amount	**	ns	***	***	**	***	**	**	ns	***	ns	ns	***	***	***	***	**	**	***	**
Radiation duration	*	ns	**	***	**	***	**	**	ns	***	ns	*	**	***	**	**	**	**	***	**
Rainfall amount	ns	ns	***	***	*	***	***	ns	***	***	ns	ns	***	***	***	***	***	*	***	***
Rainfall duration	ns	ns	**	***	***	**	ns	**	ns	***	ns	ns	**	***	***	***	**	**	***	***
Relative humidity	ns	ns	ns	***	***	***	***	ns	***	***	ns	*	ns	***	***	***	***	ns	***	***
Silicon in soil	ns	**	ns	ns	ns	ns	ns	ns	*	ns	ns	**	ns	ns	ns	ns	ns	ns	**	**
Size of seed tuber	ns	ns	**	*	***	***	***	ns	***	**	ns	ns	**	**	***	***	***	ns	***	***
Sulphate from manure	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
Temp. sum from planting till haulm killing	*	ns	***	ns	***	***	ns	ns	***	**	ns	ns	***	ns	***	***	ns	**	***	**
Temp. sum till planting	*	ns	***	ns	***	***	*	ns	***	**	ns	ns	***	ns	***	***	**	**	***	***
Total Nitrogen applied	ns	***	***	***	***	***	***	**	***	***	ns	***	***	***	***	***	***	**	***	***
Total phosphor applied	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Total Potassium applied	ns	ns	ns	**	ns	**	**	ns	**	*	ns	ns	ns	**	**	***	**	ns	**	ns
Variety	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	***	ns	**	ns	ns
Zinc in soil	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

A.8 GDD outcome

According to literature growing degree days would be better for estimating a growth curve. The result from this analyses was therefore also analysed for the different plant characteristics (section A.8,1-A.8.8).

A.8.1 Tuber weight

For tuber weight, a high clay faction is beneficial, together with boron in the soil, k50 application. The amount of phosphate showed to have a negative effect on tuber weight (table A.13). There is no pattern between the years in tuber weight curve (table A.14).

Table A.13 Average values for variables that showed significant differences between tuber weight clusters (GDD) (n=376).

Cluster	Clay faction	Boron in soil	K50	Litres urea	Mg in manure	P2O5 in soil	K in manure	K2O in soil	SO3 in manure	Total P
1	6.7	1122	120	67	45	7	168	37	36	54
2	5.1	1418	3	92	65	23	255	204	87	86
3	5.1	737	3	98	65	30	257	243	85	89
4	5.1	807	4	93	58	24	240	191	58	72
5	5.6	570	9	60	60	13	219	165	67	97

Table A.14 Number of fields belonging to a certain tuber weight cluster (GDD) in different years (n=376).

Cluster	Year			
	2013	2014	2015	2016
1	2	0	0	1
2	16	15	12	10
3	40	36	27	19
4	35	40	26	27
5	19	8	15	28

A.8.2 Shoot weight

The amount of nitrogen in the soil and from urea resulted in a high shoot weight, but a KAS, sulfasote, RH and an overall nitrogen application had a negative influence on shoot weight. Urea had a positive influence on the shoot weight (table A.15). Shoot weight had only in 2016 a lower growth curve (table A.16).

Table A.15 Average values for variables that showed significant differences between shoot weight clusters (GDD) (n=354).

	Conductivity	Radiation duration	K50	K60	KAS	Litres sulfasote	Litres urea	N soil	P2O5 soil	Total N	K2O soil	Si soil	RH
1	2.7	1000	0	73	163	69	114	305	12	285	190	7	75
2	6.8	1014	6	75	132	61	131	111	2	261	279	9	75
3	6.4	995	5	88	138	61	116	206	62	263	268	12	75
4	5.1	1015	3	93	178	62	96	93	38	277	240	9	75
5	5.6	1023	12	116	215	72	87	90	14	280	173	8	74
6	4.8	992	0	131	253	81	57	102	7	299	172	11	75
7	5.4	919	0	42	307	118	0	84	6	376	163	14	76

Table A.16 Number of fields belonging to a certain shoot weight cluster (GDD) in different years (n=354).

Cluster	Year			
	2013	2014	2015	2016
1	7	5	1	0
2	18	9	2	2
3	25	26	12	3
4	39	23	17	17
5	18	25	30	13
6	3	9	16	21
7	0	0	0	13

A.8.3 Root weight

A high root weight was achieved on soils with a low soil conductivity, high clay faction, high radiation duration, high KAS and sulfasote application, high rainfall and with a late planting a long growing season. On a high amount of phosphate in the soil and high urea application, a low amount of root weight was achieved. In 2016 a very high amount of root weight was obtained and in 2013 and 2014 a low root weight (A.17, A.18 & A.19).

Table A.17 Average values for variables that showed significant differences between root weight clusters (GDD) (n=270).

	Calcium soil	CEC	Soil conductivity	Clay fraction	Radiation duration	Growing days until haulm killing	K50	K60	KAS	Litre sulfasote	Litre urea
1	66	NA	2.6	8.7	1084	165	0	129	289	90	0
2	140	NA	2.1	4.5	1069	161	0	157	397	122	0
3	224	53	3.4	4.6	1028	154	0	152	332	102	0
4	168	29	4.2	5.0	1025	154	0	137	273	99	34
5	105	38	5.8	4.9	1011	152	0	105	237	76	73
6	2	40	6.7	5.4	989	150	10	88	156	58	121
7	NA	NA	7.8	5.7	959	145	22	60	104	71	129

Table A.18 Average values for variables that showed significant differences between root weight clusters (GDD) (n=270).

	Mg in soil	P2O5 soil	Radiation amount	Rainfall amount	Rainfall duration	Temperature sum till planting	Temperature sum till haulm killing	Total N
1	329	9	$26.9 * 10^4$	416	220	2757	2758	303
2	306	17	$26.8 * 10^4$	417	218	2680	2644	359
3	348	7	$25.9 * 10^4$	401	214	2601	2604	329
4	316	9	$25.9 * 10^4$	385	216	2536	2542	301
5	270	6	$25.5 * 10^4$	366	215	2476	2472	299
6	276	29	$25.0 * 10^4$	344	210	2420	2419	257
7	323	131	$24.2 * 10^4$	282	202	2336	2336	264

Table A.19 Number of fields belonging to a certain root weight cluster (GDD) in different years (n=270).

Cluster	Year			
	2013	**2014**	**2015**	**2016**
1	0	0	0	6
2	0	0	0	10
3	0	0	1	16
4	1	6	10	29
5	9	18	21	16
6	37	27	16	1
7	34	9	3	0

A.8.4 Underwater weight

For underwater weight curves with a high curve, those fields did contain a relatively high apparent soil conductivity (EC_a). Beside the ECa, also the amount of KAS, sulfasote and an overall high nitrogen application and manganese were higher in those fields. In years with a lot of rain (2014) a low underwater weight was obtained (table A.20, A.21 & A.22).

Table A.20 Average values for variables that showed significant differences between underwater weight clusters (GDD) (n=376).

cluster	Clay fraction	Soil conductivity	Radiation duration	ET	K50	K60	KAS	Litre sulfasote	Litre urea	Mg soil
1	6.7	10.0	990	424	45	74	221	59	25	242
2	4.3	6.3	1073	455	0	155	270	80	29	254
3	5.3	4.9	1004	431	10	94	222	94	59	322
4	5.1	3.7	993	430	5	97	255	106	39	308
5	5.1	NA	1002	435	0	67	90	7	201	NA
6	5.7	NA	987	431	0	91	77	11	205	NA
7	5.5	NA	976	426	0	74	98	13	200	NA

Table A.21 Average values for variables that showed significant differences between underwater weight clusters (GDD) (n=376).

Cluster	Mn soil	N soil	K2O soil	Radiation amount	Rainfall amount	Rainfall duration	RV	Temp sum till planting	Total N	Total K
1	17253	324	310	246731	292	223	73	2412	340	333
2	3835	111	164	266974	295	225	72	2481	305	351
3	3259	99	189	251637	320	216	74	2464	302	301
4	5103	104	267	250300	349	212	75	2491	312	299
5	NA	NA	NA	256707	465	206	76	2511	223	280
6	NA	NA	NA	253581	465	206	76	2486	217	295
7	NA	NA	NA	250567	455	202	76	2457	234	287

Table A.22 Number of fields belonging to a certain underwater weight cluster (GDD), for different field water contents and in different years (n=376).

Cluster	Field wetness			Year			
	Dry	Medium	Wet	2013	2014	2015	2016
1	0	2	2	1	0	3	0
2	25	20	10	5	0	47	4
3	32	78	40	80	0	25	45
4	17	32	18	26	0	5	36
5	1	8	7	0	16	0	0
6	11	16	19	0	46	0	0
7	8	15	14	0	37	0	0

Table A.23 Number of fields belonging to a certain underwater weight cluster (GDD) for different manure types (n=376).

Cluster	Organic manure						
	Compost	Goat manure	Calf manure	Chicken manure	Dairy cattle slurry	Cattle manure	Pig manure
1	0	0	1	0	1	1	1
2	1	0	12	1	4	31	6
3	0	3	31	4	18	69	25
4	0	4	18	0	7	27	11
5	0	0	3	0	2	9	2
6	1	1	11	1	7	20	5
7	0	2	8	0	6	17	4

A.8.5 Number of tubers

Field with a high number of tubers did contain a relatively low apparent soil conductivity (EC_a) and urea fertilizer application, but radiation interception, rainfall, K60, KAS, sulfasote and overall applied nitrogen fertilizer application had a positive influence on the number of tubers. Fields in 2016 planted on average a high number of tuber and small seed potatoes resulted in a lower number of tubers compared with medium and large seed potatoes (table A.24, A.25, A.26 & A.27).

Table A.24 Average values for variables that showed significant differences between number of tubers clusters (GDD) (n=376).

	B soil	Soil conductivity	CaO soil	Radiation duration	GHG	Growing days until haulm killing	ET	K60
1	3537	3.8	2.0	1063	25	164	456	134
2	874	3.4	2.0	1030	45	156	446	142
3	1226	3.6	49.8	1003	51	152	437	127
4	692	2.6	148.1	1051	52	157	453	183
5	966	6.6	-	1057	52	153	448	130
6	571	3.4	171.0	1003	42	151	438	101
7	450	6.9	336.2	1014	51	154	435	106
8	1330	6.1	48.3	978	45	149	423	69
9	210	7.2	2.0	990	57	152	427	76

Table A.25 Average values for variables that showed significant differences between number of tubers clusters (GDD) (n=376).

	KAS	Litre sulfasote	Litre urea	Mg soil	N soil	P2O5 soil	Planting distance
1	277	110	0	332	145	17	31
2	368	139	0	313	51	23	33
3	375	114	7	325	148	13	35
4	342	122	8	351	56	7	38
5	253	83	51	229	130	4	34
6	317	111	0	342	53	9	35
7	180	62	102	269	117	32	33
8	134	57	130	311	166	63	33
9	110	40	139	228	65	4	32

Table A.26 Average values for variables that showed significant differences between number of tubers clusters (GDD) (n=376).

	Radiation amount	Rainfall amount	Rainfall duration	RH	Temp sum till planting	Temp plant haulm killing	Total N
1	26.3 $*10^4$	404	211	75.6	2770	2787	321
2	25.8$*10^4$	408	212	75.6	2640	2622	343
3	25.2$*10^4$	390	207	75.3	2579	2612	334
4	26.4 $*10^4$	399	221	74.9	2612	2587	348
5	26.3 $*10^4$	290	224	72.6	2465	2465	296
6	25.4 $*10^4$	409	213	75.5	2559	2557	339
7	25.5 $*10^4$	350	220	74.5	2477	2477	270
8	24.8 $*10^4$	363	205	74.9	2407	2413	264
9	25.0 $*10^4$	363	210	75.1	2458	2456	255

Table A.27 Number of fields belonging to a certain number of tubers cluster (GDD) for different seed potatoes sizes and for the different years (n=376).

Cluster	Size seed potato			Year			
	Large	Medium	Small	2013	2014	2015	2016
1	0	1	1	0	0	0	2
2	2	3	2	0	0	0	7
3	5	5	4	0	0	1	13
4	12	11	1	1	0	2	21
5	3	32	7	12	1	29	0
6	11	17	4	0	0	0	32
7	13	58	27	36	27	30	5
8	10	63	39	43	51	14	4
9	0	19	26	20	20	4	1

Table A.28 Number of fields belonging to a certain number of tubers cluster (GDD) for different types of manures (n=376).

Cluster	Organic manure						
	Compost	Goat manure	Calf manure	Chicken manure	Dairy cattle slurry	Cattle manure	Sows manure
1	0	0	1	0	0	0	1
2	0	0	2	0	0	4	1
3	0	0	4	0	1	7	2
4	0	0	5	0	1	14	4
5	0	0	9	0	5	20	8
6	0	0	9	1	2	13	7
7	1	4	26	1	13	39	13
8	1	4	16	2	16	59	14
9	0	2	12	2	7	18	4

A.8.6 Number of stems

Field with a high number of stems did contain a low amount of urea, large seed distance, rainfall and RH, but KAS, radiation amount, overall nitrogen and potassium application had a positive influence on the number of tubers. Fields in 2014 planted had on average a low number of stems (table A.29, A.30 & A.31).

Table A.29 Average values for variables that showed significant differences between number of stems clusters (GDD) (n=373).

Clusters	Soil Conductivity	ET	K60	KAS	Litre sulfasote	Litre urea	Mg soil	Mn soil	P2O5 soil
1	4.1	450	169	288	75	39	360	3683	10
2	4.1	438	123	299	112	13	292	5511	5
3	5.4	447	140	281	89	21	271	2999	8
4	5.5	437	91	248	98	50	279	5888	14
5	6.0	425	89	165	72	105	321	2317	51
6	1.1	427	86	135	48	155	426	928	107
7	9.2	431	66	89	24	169	329	450	384
8	NA	433	100	74	0	205	NA	NA	NA

Table A.30 Average values for variables that showed significant differences between number of stems clusters (GDD) (n=373).

Clusters	Seed distance	Radiation amount	Radiation duration	Rainfall amount	Rainfall duration	RH	Temperature sum till planting	Total N	Total K
1	32	263435	1048	331	211	73	2465	310	367
2	37	254682	1016	338	215	74	2499	320	320
3	35	260593	1044	335	219	74	2523	323	337
4	34	255183	1017	332	218	74	2484	300	294
5	33	248609	987	319	212	74	2422	279	310
6	33	250960	985	392	210	75	2447	246	285
7	32	253571	995	429	207	76	2488	243	289
8	31	254752	994	470	207	77	2527	211	249

Table A.31 Number of fields belonging to a certain number of stems cluster (GDD) for different seed potatoes sizes and for the different years (n=373).

Cluster	Size seed potatoes			Year			
	Big	Medium	Small	2013	2014	2015	2016
1	5	2	4	0	1	4	6
2	14	4	12	3	0	11	16
3	13	9	41	5	0	32	26
4	11	11	59	32	1	20	28
5	10	27	40	44	15	12	6
6	3	22	27	20	29	0	3
7	0	22	21	7	35	1	0
8	0	12	4	0	16	0	0

A.8.7 Number of compound leaves

In fields with a high number of compound leaves a low amount of K60, KAS, organic manure and sulfasote were applied. On fields with a low temperature sum until planting and haulm killing the amount of compound leaves was high (table A.32, A.33 & A.34).

Table A.32 Average values for variables that showed significant differences between number of compound leaves clusters (GDD) (n=371).

	Clay fraction	Radiation duration	ET	Growing days haulm killing	Irrigation	K50	K60	KAS	Organic manure amount	Litre sulfasote	Litre urea
1	5.4	984	421	150	0.6	18.4	51.8	140	40.7	90.5	106.8
2	5.3	1016	438	153	0.7	0.0	107.5	163	43.9	34.1	122.3
3	4.5	1040	449	156	0.5	0.0	161.3	321	43.1	106.0	16.6
4	5.2	992	434	152	0.5	0.0	110.9	347	46.2	120.5	0.0

Table A.33 Average values for variables that showed significant differences between number of compound leaves clusters (GDD) (n=371).

	Nematode	P2O5 soil	Seed distance	Radiation amount	Rain fall amount	Rainfall duration	RH	Temp sum till planting	Temp till haulm killing	Total K
1	0.0	261.0	32.0	246940	288	213	74.2	2405	2405	284
2	0.3	4.5	33.2	257088	388	214	74.6	2469	2469	309
3	0.4	10.7	37.4	261684	399	218	74.9	2591	2588	329
4	0.1	8.8	34.2	250534	403	209	75.8	2587	2609	310

Table A.34 Number of fields belonging to a certain number of compound leaves cluster (GDD) for different seed potatoes varieties and for the different years (n=371).

Cluster	Variety						Year			
	Dakota	Fontane	Ivory russet	lady anna	Ludmilla	Miranda	2013	2014	2015	2016
1	0	81	0	1	2	27	111	0	0	0
2	0	141	3	0	9	8	0	94	67	0
3	1	55	3	0	0	1	0	2	12	46
4	1	24	6	0	0	8	0	0	0	39

A.8.8 Stem length

Fields with a high stem length had a high number of haulm killing days, high boron, potassium and nitrogen in the soil, together with a high temperature sum until planting and from planting till haulm killing. No difference was found between the different water contents of the fields and within years (table A.35, A.36 & A.37).

Table A.35 Average values for variables that showed significant differences between stem length clusters (GDD) (n=373).

	Boron soil	CaO soil	Radiation duration	ET	Growing days haulm killing	KAS	Litre sulfasote	Litre urea
1	1903	2.0	1056	450	158	207	84	50
2	649	286	1018	438	155	172	71	87
3	677	161	1007	433	153	162	56	122
4	821	82	1005	433	150	233	82	74
5	797	109	939	414	143	287	93	30

Table A.36 Average values for variables that showed significant differences between stem length clusters (GDD) (n=373).

	N soil	K2O soil	Radiation amount	Rainfall duration	Temp sum till planting	Temp till haulm killing	Total N
1	247	318	263182	219	2578	2579	289
2	124	241	256361	219	2504	2499	281
3	101	211	254328	213	2469	2462	268
4	82	170	253215	212	2461	2452	291
5	100	161	239061	203	2403	2397	318

Table A.37 Number of fields belonging to a certain stem length cluster (GDD) for different field water contents and for the different years (n=373).

Cluster	Field wetness			Year			
	Dry	Medium	Wet	2013	2014	2015	2016
1	7	5	5	2	4	6	5
2	21	34	17	25	18	14	15
3	27	67	37	46	51	19	15
4	33	54	30	32	23	34	29
5	4	11	20	6	1	7	21

Table A.38 Number of fields belonging to a certain stem length cluster (GDD) for different seed potatoes varieties (n=373).

Cluster	Variety					
	Dakota	Fontane	Ivory russet	lady anna	Ludmilla	Miranda
1	0	17	0	0	0	0
2	0	69	0	0	0	3
3	0	108	1	0	6	16
4	2	91	2	1	5	17
5	0	16	10	0	0	9

A.8.9 Nitrate content leaves

For fields with a high nitrate content around 100 days had a high apparent soil conductivity (EC_a), but had a low KAS, organic manure amount, sulfasote, magnesium in the soil and small seed potatoes planting closer to each other (table A.39, A.40 & A.41).

Table A.39 Average values for variables that showed significant differences between nitrate content in the leaves clusters (GDD) (n=265).

cluster	Average conductivity	B soil	Clay fraction	Radiation duration	ET	Granule	Irrigation	K60	KAS
1	7.0	906	5.0	1035	439	0.4	0.3	116	202
2	5.3	391	5.4	998	429	0.2	0.8	83	204
3	3.0	1014	4.6	1022	444	0.4	0.7	133	357

Table A.40 Average values for variables that showed significant differences between nitrate content in the leaves clusters (GDD) (n=265).

Cluster	Organic manure amount	Litre sulfasote	Litre urea	Nematode	Mg soil	Mg in manure	N soil	P2O5 soil	Planting distance
1	41.5	80.2	47.6	0.2	247.5	58.4	171.0	18.7	32.8
2	45.0	90.2	78.5	0.1	292.3	67.3	66.6	44.9	33.5
3	45.2	115.7	3.2	0.3	352.4	61.9	70.1	10.6	36.7

Table A.41 Average values for variables that showed significant differences between nitrate content in the leaves clusters (GDD) (n=265).

	Planting distance	Radiation amount	Rainfall amount	Rainfall duration	RV	Si soil	Temp. sum till planting	Temp haulm killing	Total N
1	32.8	257052	296.7	226.2	73.4	9.4	2468	2474	290.9
2	33.5	250922	302.2	212.2	73.9	8.4	2426	2422	293.8
3	36.7	257854	397.7	213.6	75.0	11.1	2578	2560	344.4

Table A.42 Number of fields belonging to a certain nitrate content cluster (GDD) for different seed potatoes sizes and for the different years (n=265).

Cluster	Size potatoes			Wetness field			Year		
	Big	Middle	Small	Dry	Average	Wet	2013	2015	2016
1	6	56	32	25	53	16	39	54	1
2	21	60	27	32	42	34	72	19	17
3	25	31	7	14	33	15	0	4	59

A.8.10 Flavonoïd

In fields with a high flavonoid level a low apparent soil conductivity (EC_a) was measured. The amount of KAS, planting distance, rainfall and total nitrogen applied were positively correlated with the clusters (table A.43, A.44, A.45 & A.46).

Table A.43 Average values for variables that showed significant differences between flavonoid clusters (GDD) (n=252.

	Soil conductivity	Clay fraction	Radiation duration	EV	Growing days haulm killing	Fe in the soil	Irrigation	K50	K60
1	3.1	4.6	1021	445	158	550	0.67	0	110
2	2.5	5.2	1022	445	154	365	0.44	0	158.7
3	6.9	4.9	1059	449	153	479	0.46	0	162.9
4	6.0	5.4	978	419	148	678	0.42	20.8	38.5
5	6.0	5.5	1005	429	152	186	0.84	14.7	71.9
6	4.8	4.2	958	412	143	438	0.8	12	60.6
7	NA	4.2	1004	428	154	NA	0.6	0	83.3

Table A.44 Average values for variables that showed significant differences between flavonoid clusters (GDD) (n=252).

	KAS	Organic manure amount	Litre sulfasote	Litre urea	Mg in soil	Nematode	N in soil	P2O5 soil	Seed distance
1	312.0	47.0	116.2	0.0	338.3	0.1	65.0	9.1	36.2
2	390.7	44.1	119.8	0.0	361.0	0.4	85.7	11.3	37.3
3	272.8	46.2	75.2	9.9	240.6	0.4	131.5	5.2	33.9
4	160.7	40.8	86.1	106.0	343.8	0.1	145.6	132.5	32.8
5	152.8	40.0	82.1	100.9	317.8	0.0	53.8	111.5	31.7
6	126.6	41.1	116.0	98.0	165.0	0.0	53.0	5.4	33.2
7	131.3	45.8	77.8	101.7	NA	0.0	NA	NA	32.8

Table A.45 Average values for variables that showed significant differences between flavonoid clusters (GDD) (n=252).

	Radiation amount	Rainfall amount	Rainfall duration	RV	Si soil	Temp sum till planting	Temp sum till haulm killing	Total N	Total K
1	257775	412	216	75.5	11.9	2611	2675	328	282
2	258056	410	213	75.4	9.8	2595	2591	351	337
3	263082	304	229	72.7	9.3	2481	2481	309	341
4	245636	275	206	73.9	10.2	2374	2374	280	292
5	251807	296	219	74.0	8.6	2438	2437	275	272
6	241160	269	199	73.6	9.0	2311	2311	306	313
7	250832	308	224	74.5	NA	2474	2474	264	297

Table A.46 Number of fields belonging to a certain flavonoid cluster (GDD) for different seed potatoes sizes and for the different years (n=252).

Cluster	Seed size			Year		
	Big	Normal	Small	2013	2015	2016
1	0	0	21	8	9	4
2	0	0	41	19	20	2
3	0	65	6	6	50	15
4	46	6	0	7	28	17
5	41	4	0	4	25	16
6	9	1	0	2	4	4
7	12	0	0	2	5	5

A.9 Comparing sample versus yield

For comparing the yield of the sample with the yield obtained by the harvester and weighbridge over different year (2013 till 2016) the accuracy of the sample was investigated. There is a huge variety in the yield obtained from the sample site with the average yield of the harvester and weighbridge (figure A.16). This implies that the plot is not taken on a representative spot in the field over all the years. Average EC_a did give higher and lower yield differences. So, the conclusion is that the final yield cannot be related to the tuber weight obtained from the destructive measurements. So, therefore the yield of the harvester and weighbridge were not taken into account in this study.

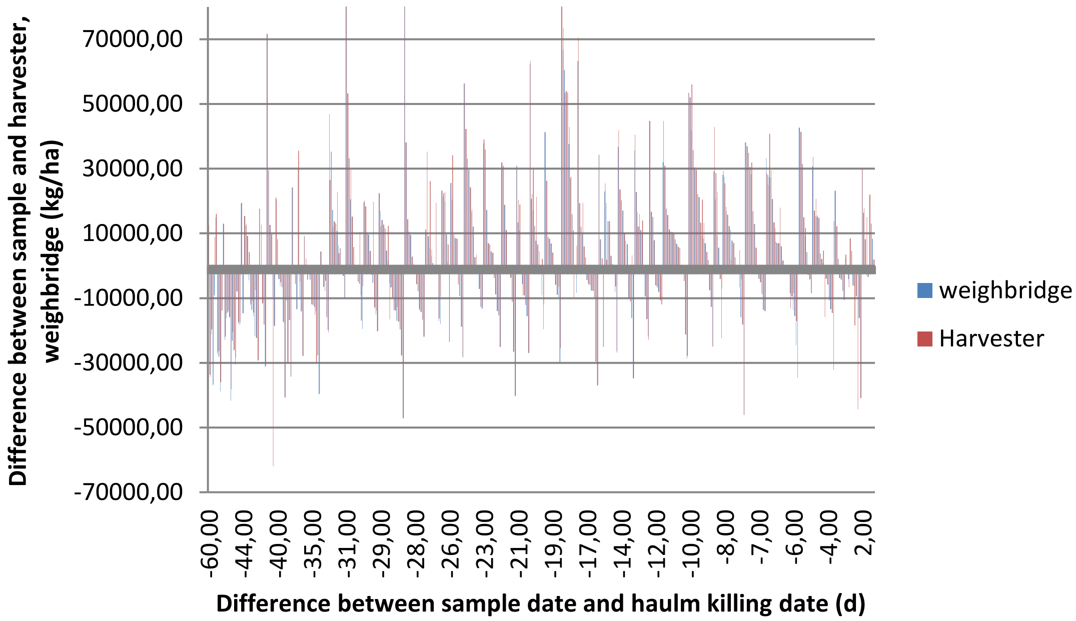

Fig. A.16 Tuber weight of sample minus yield obtained by harvester and weighbridge, in 2013 till 2016 (n = 446).

A.10 Plant interaction

The interactions between plant characteristics were investigated by performing different methods. The first analyses is a rank analyses based on the average cluster number of plant characteristics (section 10.1). The second analyses was done by performing a Spearman correlation between the cluster number and different growth parameters of the different plant characteristics.

A.10.1 Tables interaction between plant characteristics

A.10.1.1 Tuber weight

The deviation in the results show that there is still a lot of deviation, this suggests that a high tuber curve did not always have a high leaf weight or other characteristic and there is multicollinearity between the variables that cause a large deviation. The first column table A.35 is the cluster number of the tuber weight and for example the second column the shoot weight. So, the fields with the highest cluster number of tuber weight had on average a cluster number for shoot weight of 5.3 with a standard deviation of 2.1.

Table A.47 Average tuber weight cluster number and ranges for other different plant characteristics DAP.

	Shoot weight	Root weight	Underwater weight	Number of leaves	Number of tubers	Number of stems	Stem length	Nitrate content	Flavonoid level
1	5.3 (2.1)	4.3 (2.5)	3.3 (0.6)	2.7 (1.2)	4.7 (3.2)	3.3 (2.3)	4.3 (0.6)	5.3 (0.6)	1.3 (0.6)
2	4.3 (1.0)	5.0 (2.0)	4.2 (2.2)	3.0 (0.6)	3.3 (2.3)	4.8 (1.9)	3.0 (0.9)	5.2 (1.3)	2.0 (0.8)
3	4.3 (1.8)	5.0 (1.7)	3.8 (1.6)	2.8 (0.8)	3.1 (2.0)	4.6 (1.7)	3.0 (1.4)	4.5 (1.8)	2.1 (0.8)
4	4.3 (1.8)	5.7 (1.4)	3.9 (1.6)	3.3 (0.6)	2.9 (1.9)	5.2 (2.1)	3.0 (1.2)	4.2 (1.6)	2.3 (0.8)
5	5.0 (1.6)	5.6 (1.4)	3.8 (1.7)	3.4 (0.7)	3.0 (1.7)	5.2 (2.1)	3.3 (1.2)	4.0 (2.0)	2.2 (0.7)
6	5.6 (2.0)	5.6 (1.5)	3.8 (1.7)	3.5 (0.6)	3.3 (2.0)	5.3 (2.1)	3.9 (1.3)	4.1 (2.1)	2.0 (0.8)
7	6.9 (1.9)	5.8 (1.7)	3.5 (1.7)	3.6 (0.6)	3.8 (2.3)	5.4 (2.1)	4.6 (1.0)	4.1 (2.1)	2.0 (0.9)
8	7.2 (1.7)	6.2 (1.6)	3.4 (1.5)	3.5 (0.7)	3.8 (2.5)	5 (1.5)	5.0 (0.8)	3.3 (2.6)	1.8 (0.8)
Max clusters	11	9	8	7	4	10	7	7	3

So, the data suggest that the highest tuber weight related to plant characteristic is obtained with:

- High shoot weight
- High root weight
- High number of compound leaves
- High number of stems
- High stem length
- Low nitrate content

A.10.1.2 Shoot weight

The outcome of the analyses related to the plant characteristics indicated that the highest shoot weight results in a high tuber weight and is obtained with :

- Low underwater weight
- High number of tubers
- Low number of stems
- High stem length
- High nitrate content
- Low flavonoid level

Table A.48 Average shoot weight cluster number and ranges for other different plant characteristics DAP.

Cluster	Tuber weight	Root weight	Underwater weight	Number of leaves	Number of tubers	Number of stems	Stem length	Nitrate content	Flavonoid level
1	4.1 (1)	4.6 (0.7)	4.1 (1.6)	3.2 (0.7)	1.6 (1.1)	4.5 (2.2)	1.8 (0.9)	3.3 (1.9)	3 (0)
2	4.7 (1.1)	5.4 (1)	4.7 (1)	3.8 (0.4)	2 (1.3)	6.3 (1.7)	2.4 (1.2)	3.3 (1.8)	2.9 (0.3)
3	4.8 (1.4)	5.7 (1.3)	3.9 (1.5)	3.5 (0.6)	1.9 (1.4)	5.6 (1.7)	2.8 (0.9)	3.6 (1.7)	2.7 (0.6)
4	5.0 (1.3)	5.7 (1.4)	4.1 (1.7)	3.6 (0.5)	2.5 (1.5)	5.6 (1.8)	3 (1.1)	3.7 (1.7)	2.4 (0.7)
5	5.1 (1.3)	5.9 (1.7)	3.9 (1.5)	3.5 (0.7)	2.8 (1.9)	5.5 (2)	3.3 (1)	4.3 (1.9)	2.3 (0.7)
6	5.4 (1.4)	5.8 (1.7)	3.8 (1.9)	3.4 (0.7)	3.3 (1.8)	5.4 (2.2)	4 (1.1)	3.8 (2)	2 (0.7)
7	5.7 (1.3)	5.8 (1.5)	3.3 (2)	3.3 (0.7)	3.8 (1.7)	4.9 (2.1)	4.4 (0.7)	3.8 (2.1)	1.8 (0.6)
8	6.1 (1.1)	5.1 (1.7)	2.9 (1.5)	3 (0.8)	5.2 (1.5)	3.9 (2.1)	5 (0.9)	4.8 (2.2)	1.4 (0.5)
9	6.8 (0.9)	4.3 (0.7)	3.1 (0.7)	2.8 (0.8)	6.6 (0.5)	4.3 (2)	5.2 (0.6)	6.3 (0.9)	1 (0)
10	6.8 (0.6)	4.9 (1.3)	3.0 (0.6)	3 (0.6)	6.5 (0.7)	3.5 (1.3)	5.7 (0.6)	6.4 (0.5)	1 (0)
Max clusters	8	9	8	7	4	10	7	7	3

A.10.1.3 Root weight

The relation between the plant characteristics and root weight indicated that a high root weight is obtained with:

- High tuber weight
- High number of leaves
- Low number of tubers
- High number of stems
- Low nitrate content
- High flavonoid level

Table A.49 Average root weight cluster number and ranges for other different plant characteristics DAP.

Cluster	Tuber weight	Shoot weight	Underwater weight	Number of leaves	Number of tubers	Number of stems	Stem length	Nitrate content	Flavonoid level
1	4.8 (2.1)	6.2 (1.3)	3.5 (0.6)	1.5 (0.6)	6.5 (0.6)	3.2 (0.5)	3.8 (1.5)	6.2 (1.0)	1.0 (0.0)
2	4.4 (1.9)	5.4 (1.5)	3.4 (0.5)	2.5 (0.5)	5.6 (0.9)	3.6 (1.5)	3.1 (1.0)	6.2 (1.0)	1 .0 (0.0)
3	5.3 (1.6)	6.2 (2.1)	3.5 (0.6)	2.7 (0.6)	5.9 (1.1)	3.1 (1.0)	3.4 (1.5)	6 .0 (1.6)	1.1 (0.3)
4	5.3 (1.4)	5.7 (2.7)	3.5 (1.3)	2.9 (0.6)	5.0 (1.6)	3.8 (1.9)	3.6 (1.6)	5.1 (2.0)	1.4 (0.7)
5	5.4 (1.3)	5.3 (2.4)	3.6 (1.9)	3.3 (0.6)	3.5 (1.9)	4.7 (2.0)	3.5 (1.4)	4.1 (1.7)	1.9 (0.7)
6	5.2 (1.3)	5 (1.9)	3.9 (1.9)	3.6 (0.5)	2.7 (1.6)	5.7 (1.9)	3.6 (1.3)	3.1 (1.9)	2.5 (0.6)
7	5.5 (1.3)	5.4 (1.6)	4 (1.7)	3.8 (0.4)	2.2 (1.6)	6.3 (1.8)	4.1 (1.1)	4 .0 (1.7)	2.6 (0.5)
8	5.9 (1.4)	5.5 (1.4)	3.8 (1.4)	4.0 (0.2)	1.4 (1.1)	6.3 (1.3)	4.1 (0.9)	3.1 (1.6)	2.7 (0.5)
Max clusters	8	11	8	7	4	10	7	7	3

A.10.1.4 Underwater weight

Some plant characteristics are related to underwater weight. The highest underwater weight is obtained with:

- Low shoot weight
- High number of stems
- High nitrate content

Table A.50 Average underwater weight cluster number and ranges for other different plant characteristics DAP.

	Tuber weight	Shoot weight	Root weight	Number of leaves	Number of tubers	Number of stems	Stem length	Nitrate content	Flavonoid level
1	5.9 (1.3)	6.6 (1.3)	5.8 (0.9)	3.3 (0.5)	3.0 (1.3)	3.5 (1.7)	4.7 (1.1)	3.1 (1.6)	2.1 (0.3)
2	5.2 (1.2)	6.1 (1.8)	5.5 (1.1)	3.2 (0.6)	3.5 (1.6)	3.9 (1.3)	3.6 (1.4)	3.1 (2.0)	1.9 (0.4)
3	5.4 (1.5)	5.7 (2.1)	5.6 (1.8)	3.3 (0.7)	3.2 (2.5)	4.5 (1.7)	4.0 (1.3)	4.6 (1.9)	2.1 (0.9)
4	5.3 (1.5)	4.6 (2.2)	5.1 (1.9)	3.2 (0.8)	3.1 (2.5)	4.9 (1.6)	3.2 (1.4)	4.5 (1.9)	2.2 (0.9)
5	5.2 (0.9)	4.2 (1.4)	5.9 (0.7)	3.8 (0.4)	3.4 (0.9)	7.3 (1.1)	3.0 (0.9)	-	-
6	5.3 (1.1)	5.0 (1.7)	6.1 (1.1)	3.8 (0.4)	3.5 (0.9)	7.3 (1.3)	3.7 (1.0)	-	-
7	5.2 (1.4)	4.9 (1.6)	5.9 (1.0)	3.9 (0.3)	3.4 (0.9)	7.6 (1.1)	3.2 (1.2)	-	-
Max clusters	8	11	9	7	4	10	7	7	3

A.10.1.5 Number of tubers

So, the highest number of tubers indicated that:

- High tuber weight
- Low shoot weight
- High root weight
- High underwater weight
- High number of stems
- Low number of leaves
- Low stem length
- Low nitrate content
- High flavonoid level

Table A.51 Average number of tuber cluster number and ranges for other different plant characteristics.

Clusters	Tuber weight	Shoot weight	Root weight	Underwater weight	Number of stems	Number of leaves	Stem length	Nitrate content	Flavonoid level
1	3.0 (0.0)	7 (1.4)	1.0 (0.0)	3.0 (0.0)	3.5 (0.7)	6.5 (0.7)	4.0 (1.4)	6.5 (0.7)	1.0 (0.0)
2	4.7 (1.7)	6.5 (2.1)	3.5 (1.2)	3.2 (0.8)	2.8 (1.2)	5.6 (1.5)	3.8 (1.4)	6.0 (1.1)	1.2 (0.5)
3	5.2 (1.4)	5.7 (2.2)	5.0 (1.2)	3.1 (1.4)	4.2 (1.6)	3.8 (2.1)	3.7 (1.4)	4.2 (2.0)	1.9 (0.8)
4	5.6 (1.2)	4.9 (1.8)	6.5 (1.1)	4.4 (1.8)	6.4 (1.6)	2.4 (1.5)	3.7 (1.2)	3.5 (1.8)	2.5 (0.6)
Max clusters	8	11	9	8	10	7	7	7	3

A.10.1.6 Number of stems

Finally, a high number of stems is due to and is influenced by different variables. Between the plant characteristics, there are different outcomes.

A high number of stems suggest that:

- High tuber weight
- Low shoot weight
- High root weight
- High underwater weight
- High number of leaves
- High number of tubers
- Low nitrate content
- High flavonoid level

Table A.52 Average number of stem cluster number and ranges for other different plant characteristics.

Cluster	Tuber weight	Shoot weight	Root weight	Underwater weight	Number of leaves	Number of tubers	Stem length	Nitrate content	Flavonoid level
1	4.9 (1.5)	7.1 (1.4)	4.2 (1.2)	2.3 (1.0)	2.7 (0.5)	5.7 (2.1)	4.4 (1.2)	5.5 (2.0)	1.4 (0.5)
2	5.0 (1.6)	6.0 (2.4)	4.3 (1.2)	2.7 (1.0)	2.7 (0.7)	4.3 (2.2)	3.6 (1.6)	4.5 (2.1)	1.7 (0.7)
3	5.4 (1.4)	6.2 (2.2)	4.4 (1.5)	2.6 (1.0)	2.8 (0.6)	4.4 (2.1)	3.7 (1.6)	4.4 (2.1)	1.7 (0.7)
4	5.5 (1.3)	5.9 (2.1)	5.2 (1.5)	2.8 (1.0)	3.2 (0.6)	3.8 (2.1)	3.9 (1.4)	4.2 (1.9)	2.0 (0.8)
5	5.3 (1.3)	5.4 (1.9)	5.6 (1.5)	3.3 (1.2)	3.4 (0.6)	2.9 (2.0)	3.7 (1.2)	4.4 (2.0)	2.1 (0.8)
6	5.3 (1.6)	4.6 (1.8)	6.6 (1.1)	3.9 (1.5)	3.8 (0.4)	2.0 (1.4)	3.5 (1.3)	3.2 (1.8)	2.6 (0.6)
7	5.5 (1.2)	4.8 (1.8)	6.2 (1.1)	5.0 (1.5)	3.8 (0.4)	2.8 (1.8)	3.7 (1.1)	4.0 (1.5)	2.5 (0.8)
8	5.5 (1.2)	4.6 (1.7)	6.2 (1.1)	5.4 (1.6)	3.8 (0.4)	2.9 (1.3)	3.3 (1.1)	3.1 (1.8)	2.8 (0.4)
9	5.7 (0.9)	5.7 (1.7)	6.6 (0.8)	6.2 (0.5)	4.0 (0.0)	3.1 (0.9)	3.8 (1.5)	-	-
10	6.0 (0.0)	6.0 (0.0)	7.0 (0.0)	6.5 (0.7)	4.0 (0.0)	4.0 (0.0)	4.5 (0.7)	-	-
Max clusters	8	11	9	8	7	10	7	7	3

A.10.1.7 Number of compound leaves

Based on the clusters of the compound leaves there are some indications of how plant characteristics interact and influence each other. A high number of compound leaves is indicating :

- High shoot weight
- Low root weight
- Low number of tubers
- Lower number of stems
- High stem length
- High nitrate content
- Low flavonoid level

Table A.53 Average number of compound leaves cluster number and ranges for other different plant characteristics DAP.

	Tuber weight	Shoot weight	Root weight	Underwater weight	Number of tubers	Number of stems	Stem length	Nitrate content	Flavonoid level
1	5.2 (1.4)	4.1 (1.5)	6.7 (1.0)	3.3 (0.6)	3.7 (0.5)	5.5 (1.4)	3.6 (1.2)	3.7 (1.6)	2.8 (0.4)
2	5.5 (1.2)	5.4 (1.7)	5.7 (1.0)	3.3 (2.2)	3.5 (0.6)	5.0 (2.5)	3.5 (1.3)	2.4 (1.3)	2.1 (0.3)
3	5.2 (1.2)	4.6 (1.4)	5.8 (0.9)	6.2 (0.7)	3.8 (0.4)	7.3 (1.1)	3.3 (0.9)	3.1 (1.6)	2.0 (0.0)
4	5.0 (1.2)	5.2 (1.6)	5.8 (1.0)	4.7 (2.2)	3.6 (0.5)	6.3 (2.1)	3.5 (1.2)	5.0 (2.1)	1.3 (0.5)
5	5.5 (1.1)	6.0 (1.7)	4.7 (1.6)	3.4 (1.5)	3.1 (0.6)	4.5 (1.5)	3.5 (1.4)	5.8 (1.6)	1.1 (0.2)
6	5.8 (1.5)	7.4 (1.6)	3.8 (1.1)	3.2 (0.7)	2.7 (0.7)	3.5 (1.3)	4.3 (1.4)	6.2 (0.8)	1.0 (0.0)
7	5.7 (1.9)	8.3 (1.6)	4.0 (1.6)	3.2 (0.6)	2.7 (0.7)	3.0 (1.7)	4.7 (1.3)	-	-
Max clusters	8	11	9	8	4	10	7	7	3

A.10.1.8 Stem length

Stem length has also some influence and is influenced by other plant characteristics. A high potential stem length includes also a:

- High tuber weight
- High shoot weight
- High root weight
- Low underwater weight
- High number of compound leaves
- High nitrate content
- Low flavonoid level

Table A.54 Average stem length cluster number and ranges for other different plant characteristics DAP.

	Tuber weight	Shoot weight	Root weight	Underwater weight	Number of tubers	Number of stems	Number of leaves	Nitrate content	Flavonoid level
1	4.3 (1.0)	2.9 (1.6)	4.9 (1.2)	4.2 (1.7)	3.3 (0.7)	5.1 (2.5)	3.1 (2)	3.7 (2.1)	2.4 (0.8)
2	4.8 (1.1)	3.7 (1.3)	4.9 (1.4)	3.8 (1.4)	3.3 (0.6)	5.0 (2.0)	3.0 (1.8)	4.0 (2.0)	2.2 (0.9)
3	5.1 (1.2)	4.6 (1.4)	5.7 (1.4)	4.2 (1.8)	3.5 (0.6)	5.5 (1.9)	2.9 (1.7)	3.9 (2.0)	2.3 (0.8)
4	5.4 (1.4)	5.6 (1.5)	6.0 (1.6)	3.9 (1.6)	3.5 (0.7)	5.7 (2.0)	2.9 (2.0)	3.8 (2.1)	2.2 (0.8)
5	5.8 (1.4)	6.7 (1.6)	5.7 (1.6)	3.4 (1.7)	3.3 (0.7)	4.9 (2.2)	3.7 (2.2)	4.4 (1.8)	1.9 (0.7)
6	6.6 (0.8)	8.4 (1.4)	5.7 (1.3)	2.7 (1.1)	3.4 (0.6)	4.2 (1.8)	4.8 (2.2)	5.1 (2.0)	1.6 (0.8)
Max clusters	8	11	9	8	4	10	7	7	3

A.10.1.9 Nitrate content

So, the highest nitrate content in leaves is obtained with:

- High shoot weight
- Low Root weight
- Low number of tubers
- Low flavonoid level

Table A.55 Average nitrate content cluster number and ranges for other different plant characteristics DAP.

	Tuber weight	Shoot weight	Root weight	Underwater weight	Number of tubers	Number of stems	Number of leaves	Stem length	Flavonoid level
1	6.1 (1.3)	5.3 (1.9)	6.0 (1.1)	2.4 (0.9)	3.5 (0.5)	4.7 (1.6)	2.4 (1.5)	3.5 (1.1)	2.4 (0.5)
2	5.4 (1.2)	4.4 (1.7)	6.6 (1.3)	3.0 (0.9)	3.6 (0.5)	5.2 (1.7)	1.5 (1.2)	3.6 (1.4)	2.7 (0.5)
3	5.1 (1.3)	5.8 (1.3)	5.3 (0.9)	2.3 (1.0)	3.2 (0.5)	3.4 (1.3)	3.2 (1.6)	3.3 (1.5)	2.0 (0.3)
4	5.5 (1.5)	6.1 (1.3)	4.9 (1.1)	2.1 (1.0)	3.1 (0.5)	3.8 (1.1)	4.2 (1.2)	3.9 (1.4)	1.8 (0.4)
5	4.9 (1.5)	4.5 (1.8)	6.0 (1.6)	3.2 (0.7)	3.5 (0.7)	5.1 (1.6)	1.9 (1.9)	3.6 (1.2)	2.4 (0.8)
6	5.6 (1.5)	8.3 (1.5)	4.5 (1.3)	2.9 (0.9)	2.7 (0.6)	3.3 (1.1)	6.0 (1.0)	5.0 (1.0)	1.1 (0.3)
7	5.5 (1.5)	7.1 (1.9)	3.5 (1.3)	3.2 (0.6)	2.7 (0.7)	3.4 (1.4)	5.9 (0.7)	3.8 (1.6)	1.0 (0.0)
Max clusters	8	11	9	8	4	10	7	7	3

A.10.1.10 Flavonoid level

A high flavonoid level is obtained with:

- Low shoot weight
- High root weight
- High number of tubers
- High number of stems
- Low number of leaves
- Low stem length
- Low nitrate content

Table A.56 Average flavonoid cluster number and ranges for other different plant characteristics DAP.

	Tuber weight	Shoot weight	Root weight	Underwater weight	Number of tubers	Number of stems	Number of leaves	Stem length	Nitrate content
1	5.6 (1.6)	7.2 (2.0)	3.7 (1.3)	3.2 (0.6)	2.8 (0.6)	3.7 (1.5)	6.0 (0.8)	4.1 (1.4)	6.1 (1.1)
2	5.2 (1.4)	5.8 (1.4)	6.0 (1.1)	2.1 (0.9)	3.4 (0.6)	4.1 (1.6)	2.7 (1.5)	3.9 (1.3)	3.1 (1.6)
3	5.3 (1.3)	3.9 (1.5)	6.5 (1.1)	3.3 (0.6)	3.7 (0.5)	5.5 (1.4)	1 .0 (0.2)	3.3 (1.2)	3.4 (1.7)
4	8	11	9	8	4	10	7	7	7

A.10.2 Differences between years

For the individual years the average cluster number is taken. Based on those values the years were organized in magnitude of cluster number. The highest growth curve was assigned with one and the lowest with 4. If there was no pattern visible it was assigned to random such as for tuber weight and stem length.

Table A.57 Differences between plant characteristics over years (2013-2016).

	Tuber weight	Shoot weight	Root weight	Under water weight	Number of tubers	Number of stems	Number of leaves	Stem length	Nitrate content	Flavo-noid
2013	5.2 (1.40)	4.1 (1.5)	6.7 (1.01)	3.3 (0.55)	3.7 (0.48)	5.5 (1.38)	1 (0)	3.5 (1.23)	3.7 (1.63)	2.8 (0.40)
2014	5.3 (1.21)	4.9 (1.66)	6.0 (1.04)	6.2 (0.65)	3.8 (0.37)	7.4 (1.23)	3.4 (0.88)	3.4 (1.09)	NA (NA)	NA (NA)
2015	5.3 (1.28)	5.9 (1.48)	5.5 (0.91)	1.8 (0.69)	3.2 (0.51)	3.7 (1.35)	3.2 (1.28)	3.7 (1.39)	2.7 (1.47)	2.0 (0.21)
2016	5.6 (1.52)	7.2 (1.92)	3.8 (1.23)	3.2 (0.59)	2.7 (0.64)	3.5 (1.41)	6.0 (0.74)	4.1 (1.50)	6.1 (1.13)	1 (0)

A.10.3 Correlation between clusters and parameters

The relation between plant characteristic in this study is presented as the Spearman's correlation between the cluster fields of the individual fields. By performing this analysis an outcome can be obtained if a certain plant characteristic in one field has a positive or a negative relationship with another plant characteristic, which were based on the cluster number in figure A.17 and based on the individual parameters is figure A.18.

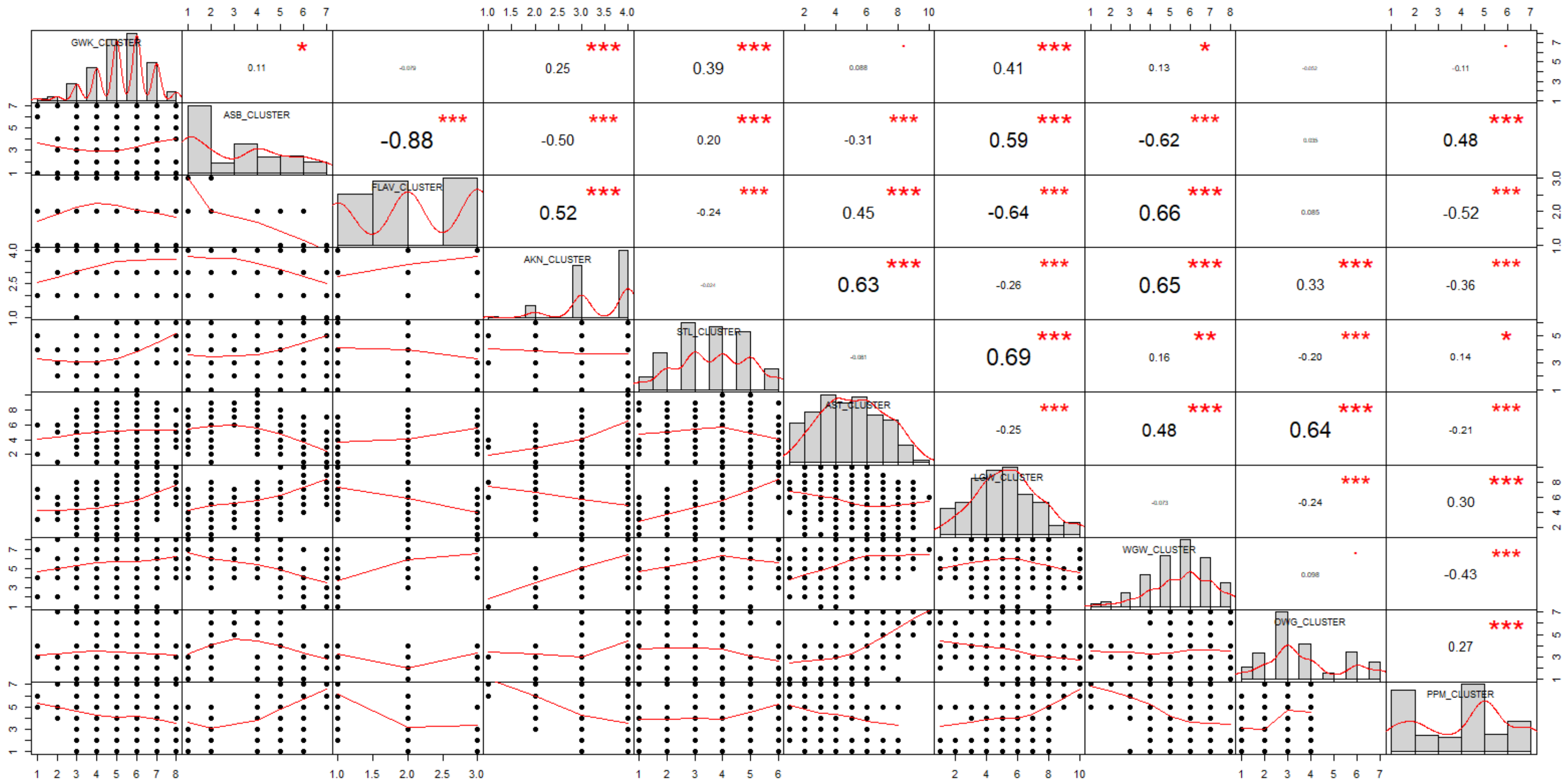

Fig. A.17 Correlation (Spearman) scheme between clusters number.

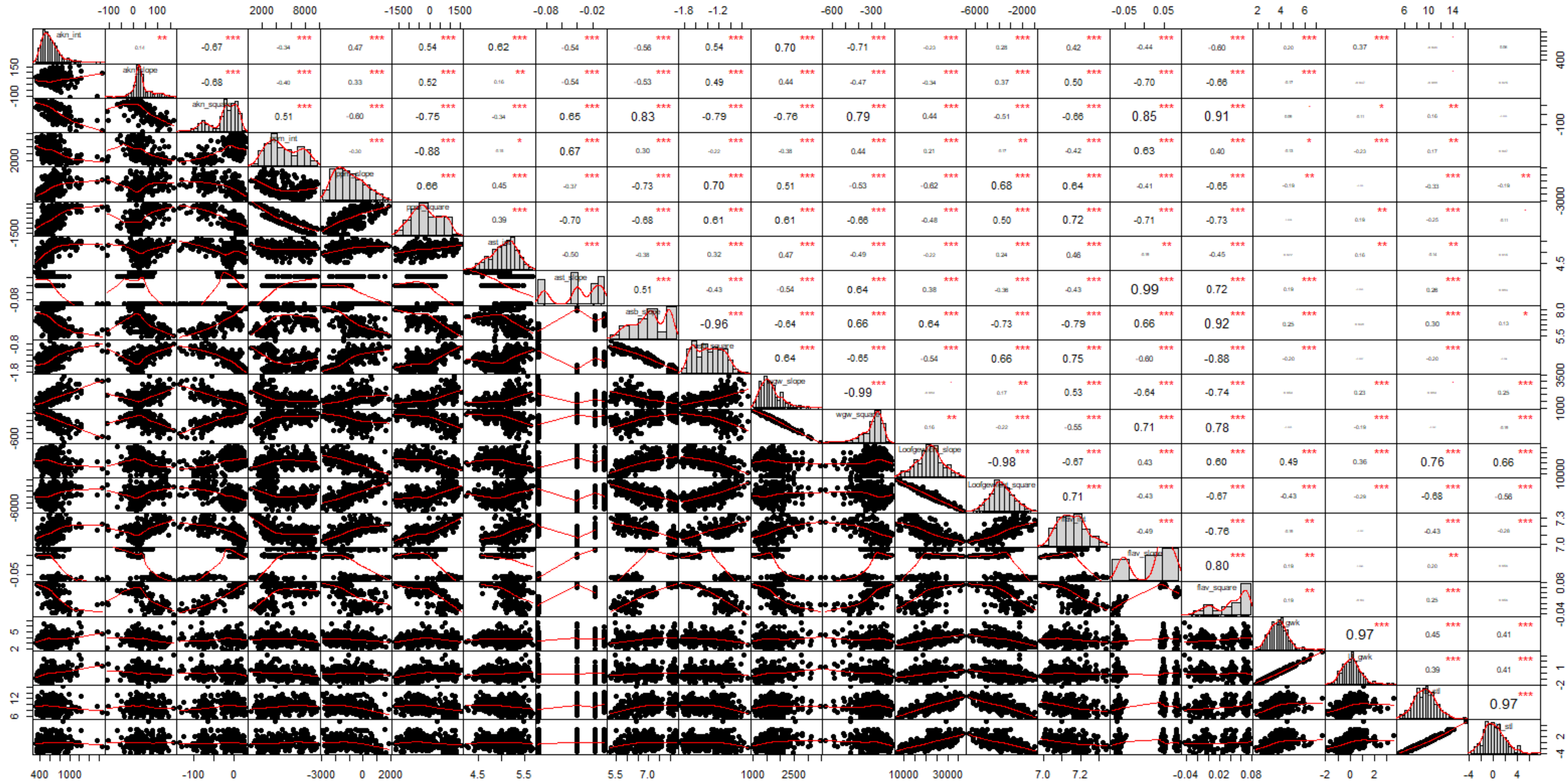

Fig. A.18 Correlation (Spearman) scheme between parameters of the growth curves.

A.11 Literature review of management/ soil and weather variables on different potato plant characteristics

To review literature for the different variables an overview is made, to visualize the difference between the different potato plant characteristics. Two sections were made, the first one about the effect (A.11.1) and the second with the references which were divided into two parts. Each section consists of five plant characteristics (A.11.2 & A.11.3).

A.11.1 Effect on soil crop and management variables

Table A.58 Effects (+ = more; - = less; +-= depends on; / = no response; o = optimum ? =no data)

	Tuber weight	Shoot growth	Root growth	Underwater weight	# tubers	# stems	Compound leaves	Stem length	Nitrate leaves	Chloro phyll	Flavo-noid	NBI
Yield	+	+	+		+	+		+	+-			
Climate												
Temperature sum January Fertilizing		+					+					
Radiation	+				+			-				
Rain				+			+					
Soil Characteristics												
Conductivity		+	+o	+	-			+	+			
Nematodes		-	-		-			-	-			
Drought resilience of the field	+	+	+	-		+		+	-			
Clay fraction	+								+			
Groundwater table	+							+	-			
Plant available Nitrogen		+	/		+			+	+		-	
Plant available Potassium			+	+	+			+	+			
Plant available Phosphate	+	+										
Plant available Sulphate									+			
Plant available Magnesium	+								-			
Plant available Boron								+				

Soil crop management	**Tuber weight**	**Shoot growth**	**Root growth**	**Underwater weight**	**# tubers**	**# stems**	**Compound leaves**	**Stem length**	**Nitrate leaves**	**Chloro-phyll**	**Flavo-noid**	**NBI**
Plant available silicon												
Plant available Zink												
Plant available Manganese						+			+			
Plant available Iron				+								
Plant available Calcium Oxide	+	+						+				
Seed tuber												
Variety		+-	+-									
Size tubers	+	+	+		+	+		+				
Sprout trail												
Origin		+-						+-				
Crop management practices												
Previous crop												
Planting distance	-	-	+		+	-		+	-			
Granule		+			+							
Type of manure		+-										
Amount Organic manure		+	+	+		+		+	+			
Content of the manure												
Irrigation	+	+	+-									
Planting date	+o	+	+	+	+			+				
Haulm killing date	+	+	+	+	+			+				
Date Fertilization	+	+		+	/							

Soil crop management	**Tuber weight**	**Shoot growth**	**Root growth**	**Underwater weight**	**# tubers**	**# stems**	**Compound leaves**	**Stem length**	**Nitrate leaves**	**Chloro-phyll**	**Flavo-noid**	**NBI**
Applied nutrients :												
Applied N		+	+		+	+	o	+	+			
Applied K		+	+		+	+-	o					
Applied P	+	+	+		+							
Applied S												
Applied Mg					+				+			

A.11.2 Sources (1/2)

For contradictory results two literature boxes were used and in front of the literature the effect is represented in that case.

Table A.59 References list of literature for the different variables on tuber weight, number of tubers, haulm growth, root growth, underwater weight and stem length

Soil, crop and management	**Tuber weight**	**Shoot growth**	**Root growth**	**Underwater weight**	**Number of tubers**	**Number of stems**
Yield	(Anonymous, 2007)	(Almekinders, 1991; Collins, 1977; Rex, 1990) (Allen and Scott, 1980; Bussan et al., 2007; White and Sanderson, 1983; Whitte et al., 1974)	(Rex, 1990; Van Delden et al., 2001)	(Haase, 2003; Nissen, 1955)	(Allen and Scott, 1980; Engels et al., 1993; Lommen, 1995)	(Beukema and Van der Zaag, 1990; Struik and Wiersema, 1999; Van der Zaag, 1992)
Climate						
Temperature sum January fertilizer						
Radiation	(Marshall, 2007)				(Marshall, 2007)	
Rain				(Rastovski et al., 1981)		
Soil Characteristics:						
Conductivity		(Cambouris et al., 2006; Chrétien *et al.*, 2000; Jegathees, 1999; Rossel *et al.*, 2010)	(De Willigen and Van Noordwijk, 1987; Honeycutt *et al.*, 1995; Novella *et al.*, 2008; Opena and Porter, 1999; Rhoades *et al.*, 1976)	(Bernstein *et al.*, 1951a; Heuer and Nadler, 1995; Paliwal and Yadan, 1980)	(Levy and Veilleux, 2007).	

Nematodes	(Been and Schomakers, 1998; Hide and Read, 1991; Trudgill *et al.*, 1975)	(Been and Schomakers, 1998) (Van den Borne, 2015)			(Robinson *et al.*, 1991; Struik and Wiersema, 1999; Tribe, 1977; Trudgill et al., 1975)	
Drought resilience of the field	(Jefferies and MacKerron, 1989; Steduto *et al.*, 2012; Van Oort *et al.*, 2012) (Schaap *et al.*, 2013)	(Gordon *et al.*, 1997; Gordon *et al.*, 1999; Levy *et al.*, 2013; Van Loon, 1981; Wang *et al.*, 2007)	(Fabeiro *et al.*, 2001; Smit and Vamerali, 1998; Wang et al., 2007)	(Rastovski et al., 1981)	(Haun, 1975; Struik and Wiersema, 1999; Van Dam *et al.*, 1996)	(Gordon et al., 1997; Gordon et al., 1999; Levy et al., 2013; Van Loon, 1981; Wang et al., 2007)
Clay fraction			(Battilani et al., 2006)			
Groundwater table	(Silva et al., 2017)					
Plant available Nitrogen		(Riley, 2000)	(Asfary et al., 2009)	(Aghighi Shahverdi Kandi et al., 2011; Painter and Augustin, 1976; Wilcox and Hoff, 1970)	(De la Morena et al., 1994; Jackson, 1999; Ojala et al., 1990)	
Plant available Potassium		(Portal, 2016; Van den Borne, 2015). (Trehan, 2005)	(Roberts and Mc Dole, 1985)	(Rastovski et al., 1981)	(Van Schreven, 1949)	
Plant available Phosphate						
Plant available Sulphate						
Plant available Magnesium	(De Baar, 1994; Thomas, 1929)					
Plant available Boron						

Plant available silicon						
Plant available Zink						
Plant available Manganese						(Bar-Yosef, 1999; CBGV, 2016; Prasad and Sinha, 1982; Robinson et al., 1991; Westermann, 2005; Yeates, 1987)
Plant available Iron				(Bartz and Brecht, 2002; Bolle-Jones, 1955; Kunkel and Holstad, 1972) (Brown *et al.*, 2010)		
Plant available Calcium Oxide	(De Baar, 1994; Thomas, 1929)	(Portal, 2016; Van den Borne, 2015). (Trehan, 2005)				
Seed tubers:						
Variety		(Allen and Scott, 1980; Kooman *et al.*, 1996; Manrique *et al.*, 1990; Oliveira *et al.*, 2016)	(Gordon et al., 1997; Manrique et al., 1990; Oliveira et al., 2016; Spitters, 1987).			
Size tubers	(Bremner and Taha, 1966; Haverkort et al., 2015; Van der Zaag et al., 1990)	(Bremner and Taha, 1966; Maris, 1986; Struik *et al.*, 1990; Wurr, 1969; Wurr and Morris, 1979)	(Bremner and Taha, 1966; Haverkort et al., 2015; Van der Zaag et al., 1990)		(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999)	(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999)
Sprout trail						

Origin		(Gordon et al., 1997; Oliveira et al., 2016; Struik and Wiersema, 1999; Wurr *et al.*, 2001)				
Crop management practices:						
Previous crop						
Planting distance	(Bremner and Taha, 1966; Haverkort et al., 2015; Van der Zaag et al., 1990)	(Bussan et al., 2007; Houghland and Akeley, 1959; Van Burg, 1967; Van der Zaag, 1992)	(Bremner and Taha, 1966; Mackie-Dawson *et al.*, 1990; Sieczka *et al.*, 1986)		(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999)	(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999)
Granule		(Been and Schomakers, 1998; Fasan and Haverkort, 1991; Hide and Read, 1991; Trudgill et al., 1975)			(Robinson et al., 1991; Struik and Wiersema, 1999; Tribe, 1977; Trudgill et al., 1975)	
Type of manure						
Amount Organic manure		(Amara and Mourad, 2013; Amara *et al.*, 2016; Anonymous, 2016; Kumar *et al.*, 2008; Van Delden, 2001)	(Iwama, 1988b; Sincik *et al.*, 2008; Yamagata and Ae, 1996)	(Abou-Hussein *et al.*, 2002) ((Kumar *et al.*, 2011) (Lynch *et al.*, 2008)		(Amara and Mourad, 2013; Amara et al., 2016; Anonymous, 2016; Kumar et al., 2008; Van Delden, 2001)
Content of the manure		(Amara and Mourad, 2013; Amara et al., 2016; Anonymous,				

		2016; Kumar et al., 2008; Van Delden, 2001)				
Irrigation	(MacKerron and Jefferies, 1986)	(Gordon et al., 1999; Kashyap and Panda, 2003; Levy et al., 2013; Onder *et al.*, 2005; Van den Borne, 2015)	(Epstein and Grant, 1973; Fabeiro et al., 2001; Khorshidi *et al.*, 2007; Smit and Vamerali, 1998)			
Planting date	(Allen, 1977; Caldiz *et al.*, 1985; Iritani *et al.*, 1983; Knowles and Knowles, 2006)	(Caldiz et al., 1985; Iritani et al., 1983; Knowles and Knowles, 2006) (Bartelen, 2016; Struik *et al.*, 1989) (Bremner and Radley, 1966; Engels et al., 1993; Muthoni *et al.*, 2014)	(Baghour *et al.*, 2001; Reynolds and Ewing, 1989; Sattelmacher *et al.*, 1990b)	(Caldiz et al., 1985; Iritani et al., 1983; Knowles and Knowles, 2006). (Veerman and Van Loon, 1995; Waterer, 2007)	(Caldiz et al., 1985; Iritani et al., 1983; Knowles and Knowles, 2006) (Struik et al., 1989) (Bartelen, 2016) (Van Dam et al., 1996)	
Haulm killing date	(Haverkort et al., 1991; Jefferies, 1992; Khurana and McLaren, 1982)	(Hansen *et al.*, 1991; Nikolaos, 2015; Rijk, 2013) (Haverkort et al., 2015; van Haren and Haverkort, 1998) (Haverkort et al., 1991; Jefferies, 1992; Khurana and McLaren, 1982)	(Haverkort et al., 1991; Jefferies, 1992; Khurana and McLaren, 1982; Rastovski et al., 1981)	(Kumar *et al.*, 2007; Veerman and Van Loon, 1995; Waterer, 2007) (Deep Priyanka Toppo, 2010; Veerman and Van Loon, 1995; Waterer, 2007)	(Kolbe and Stephan-Beckmann, 1997b)	
Fertilizing date	(Van den Borne, 2015)	(Davenport and Bentley, 2001; Gunasena and Harris, 1968; Kumar		(Deep Priyanka Toppo, 2010; Veerman and Van	(Bretzloff, 1971; Cieslik and Sikora,	

		et al., 2007) (Gunasena and Harris, 1968; Hansen et al., 1991; MacLean, 1984)		Loon, 1995; Waterer, 2007)	1998; White *et al.*, 2009)	
Storage		(Morris, 1966; Muthoni et al., 2014; Wurr, 1978, 1979)				
Applied nutrients :						
Applied N		(Riley, 2000)	(Papadopoulos, 1992; Sattelmacher et al., 1990a; Wheatley *et al.*, 1991)	(Dunn and Nylund, 1945)	(De la Morena et al., 1994; Jackson, 1999; Ojala et al., 1990)	(Cao and Tibbitts, 1994)
Applied K			(Allison *et al.*, 2001b; Iwama, 1988b; Papadopoulos, 1992)	(Dunn and Nylund, 1945)	(Hussey and Stacey, 1984; Kumar et al., 2007; Parent *et al.*, 1994; ROY, 2016	+ (Allison et al., 2001b; Iwama, 1988b; Kumar et al., 2007; Papadopoulos, 1992); - (Panique et al., 1997)
Applied P			(Allison *et al.*, 2001a; Cogliatti and Clarkson, 1983; Dechassa *et al.*, 2003; Iwama, 1988b; Papadopoulos, 1992)	(Dunn and Nylund, 1945)	(Freeman *et al.*, 1998; Jenkins and Ali, 1999, 2000; Van Schreven, 1949)	
Applied S				(Dunn and Nylund, 1945)	(Kumar et al., 2007; Rosen and Bierman, 2008;	

					Svensson, 1962)	
Applied Mg				(Dunn and Nylund, 1945)	(Bretzloff, 1971; Cieslik and Sikora, 1998; White et al., 2009)	

A.11.3 Sources (2/2)

Table A.60 References list of literature for the different variables on number of stems, compound leaves, nitrate content, NBI, flavonoid and chlorophyll

Soil, crop and management	Number of stems	Compound leaves	Stem length	Nitrate leaves	Chloro phyll	Flavo noid	NBI
Yield	(Beukema and Van der Zaag, 1990; Struik and Wiersema, 1999; Van der Zaag, 1992)		(Bodlaender, 1960; Richards, 1959) (Struik and Wiersema, 1999)	(Akhtar and Malik, 2000)			
Climate							
Temperature sum January fertilizer							
Radiation			(Bodlaender, 1963)				
Rain							
Soil Characteristics:							
Conductivity			(Honeycutt et al., 1995; Novella et al., 2008; Rhoades et al., 1976) (Eigenberg et al., 2006)	(Lukas et al., 2009)			
Nematodes			(Robinson et al., 1991; Struik and Wiersema, 1999; Tribe, 1977; Trudgill et al., 1975)	(Robinson et al., 1991; Tribe, 1977; Trudgill et al., 1975)			
Drought resilience of the field	(Gordon et al., 1997; Gordon et al., 1999; Levy et al., 2013; Van Loon, 1981; Wang et al., 2007)		(Haun, 1975; Jefferies and MacKerron, 1989; Steduto et al., 2012; Struik and Wiersema, 1999; Van Dam et al., 1996; Van Oort et al.,	(Haddock, 1961; Robinson et al., 1991; Trudgill et al., 1975; Yeates, 1987)			

			2012) (Schaap et al., 2013).				
Clay fraction				(Reidsma et al., 2016)			
Groundwater table			(Deblonde and Ledent, 2001)	(Haddock, 1961)			
Plant available Nitrogen				(MacLean, 1984; Oliveira et al., 2016; Trudgill et al., 1975; Yeates, 1987)		(Liu et al., 2010)	
Plant available Potassium			(Portal, 2016; Van den Borne, 2015) (Trehan, 2005)	(Besma et al., 2011)			
Plant available Phosphate							
Plant available Sulphate							
Plant available Magnesium				(Stefanelli et al., 2011)			
Plant available Boron			(Johnston, 1928)				
Plant available silicon							
Plant available Zink							
Plant available Manganese	(Bar-Yosef, 1999; CBGV, 2016; Prasad and Sinha, 1982; Robinson et al., 1991; Westermann, 2005; Yeates, 1987)			(Bar-Yosef, 1999; CBGV, 2016; Prasad and Sinha, 1982; Robinson et al., 1991; Westermann, 2005; Yeates, 1987)			
Plant available Iron							
Plant available Calcium Oxide			(Portal, 2016; Van den Borne, 2015) (Trehan, 2005)				
Seed tubers:							
Variety							

Size tubers	(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999)		(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999)				
Sprout trail							
Origin			(Gordon et al., 1997; Oliveira et al., 2016; Struik and Wiersema, 1999; Van Ittersum, 1992; Wurr et al., 2001)				
Crop management practices:							
Previous crop							
Planting distance	(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999)		(Beukema and Van der Zaag, 1990; Bussan et al., 2007; Struik and Wiersema, 1999; Vos, 1995)	(Jamaati-e-Somarin et al., 2009)			
Granule							
Type of manure							
Amount Organic manure	(Amara and Mourad, 2013; Amara et al., 2016; Anonymous, 2016; Kumar et al., 2008; Van Delden, 2001)			(Akhtar and Malik, 2000)			
Content of the manure							
Irrigation							
Planting date			(Bremner and Radley, 1966; Engels et al., 1993; Muthoni et al., 2014; Reynolds and Ewing, 1989)				

Halm killing date			(Timlin *et al.*, 2006) (Haverkort et al., 2015; van Haren and Haverkort, 1998)				
Fertilizing date							
Storage							
Applied nutrients :							
Applied N	(Haverkort and MacKerron, 2012)		(Biemond and Vos, 1992; Bussan et al., 2007; MacLean, 1984)	(Cao and Tibbitts, 1994)			
Applied K	(Allison et al., 2001b; Iwama, 1988b; Kumar et al., 2007; Papadopoulos, 1992)	(Biemond and Vos, 1992; Vos and Van der Putten, 1998)		(Kumar et al., 2007; Trudgill et al., 1975; Yeates, 1987)			
Applied P			(Freeman et al., 1998; Jenkins and Ali, 1999; Rosen *et al.*, 2014; Van den Borne, 2015; Westermann and Kleinkopf, 1985)				
Applied S				(Bar-Yosef, 1999; Prasad and Sinha, 1982; Robinson et al., 1991; Westermann, 2005; Yeates, 1987)			
Applied Mg				(Bar-Yosef, 1999; Robinson et al., 1991; Westermann, 2005; Yeates, 1987)			