Improvement of the competitiveness of the sugar beet crop in the Netherlands

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1 Prologue

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This dissertation focuses on the competitiveness of the sugar beet (*Beta vulgaris* L.) crop in the Netherlands. Basically the income of the farmer is the product of yield and product price (revenues) minus total costs, as a sum for all crops. For a number of crops but especially sugar beet the product price is dependent on product quality. For many years, the sugar beet crop had a relatively high share in farmers income (Berkhout and Berkum, 2005). Due to the sugar regime of the European Union (EU), minimum sugar beet prices for quota beet were guaranteed for the growers and thus causing a more or less stable income compared to other crops like onions, potatoes and carrots, whose prices are fluctuating within and between years (Berkhout and Bruchem, 2005; Vrolijk et al., 2009; Berkhout and Bruchem, 2010). As a result of the World Trade Organisation (WTO) negotiations the EU had to open their market for sugar outside the EU. Consequently the EU sugar market regime had to be adapted, with a lower guaranteed price for farmers. The guaranteed price for quota beet fell from € 43.63 t sugar beet^{-1} (EC, 2001; Zeddies, 2006) to € 26.29 t^{-1} from 2009 onwards (EC, 2006), implying a 39.7% decrease. With the costs on a similar level this causes a dramatic drop in farmers' income. At present it is not known if and how the EU sugar market regime will continue when it ends after the harvest and the processing of the 2014 cultivated sugar beet (EC, 2006).

The study LISSY (Low Input Sustainable Sugar Yield) identified possibilities to save up to 20% of the total variable costs in Dutch sugar beet production (Pauwels, 2006). However, this could not compensate for the price drop of quota sugar beet (figure 1.1). In order to keep the profitability of the sugar beet crop on the same level as before 2006, a raise in yield is needed. The potential sugar yield in the Netherlands was previously estimated at 23 t sugar ha^{-1} (De Wit, 1953). The average sugar yield realised by growers in the period 2002-2006 was 10.6 t ha^{-1} (Swaaij, 2007), only 46% of the theoretical potential. In the meanwhile, large differences between growers in the same region, encountering almost the same production circumstances like soil and climate, are reported (Agrarische Dienst, 2007). This phenomenon is not restricted to sugar beet production in the Netherlands, its found in Sweden, Germany and the United Kingdom (Blomquist et al., 2003; Fuchs et al., 2008; Limb and Atkin, 2010) and for other crops, as well (Lobell et al., 2009). However, it seems that in many cases the other crops' average yield is more close to 80% of the crops potential in that region, although large differences exist (Lobell et al., 2009). Therefore, there is an unexploited yield gap in sugar beet cultivation.

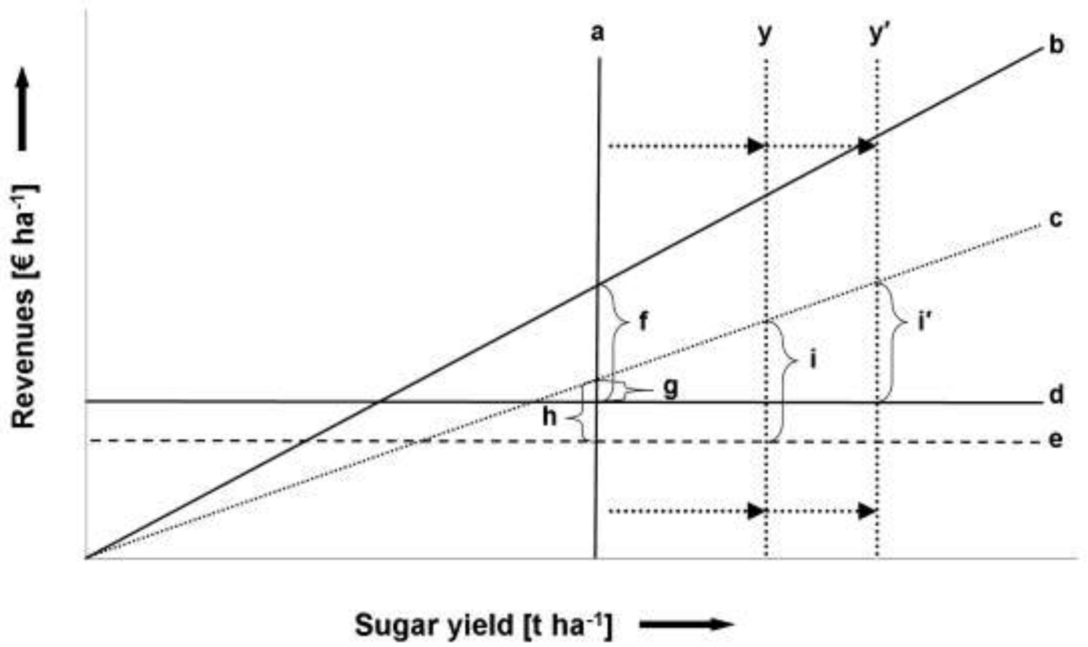

Figure 1.1. Graphical impression to the effect, for an average sugar yield (a), of the quota sugar beet guarantee price before 2006 (b) and after 2009 (c) on farmers gross margin (f, g and h) when the total variable costs are on average (d) or on a 20% reduced level (e). In response to the lower quota sugar beet guarantee price, growers have to raise yield (y/y′) to an level were the margin i/i′ equals f to keep profitability on the level before the reform of the EU sugar regime.

Considering the above mentioned, the IRS (Institute of Sugar Beet Research, The Netherlands) formulated the 3 x 15 target. In 2015 the present EU sugar market regime ends and then the target for sugar beet cultivation is a national average sugar yield of 15 t ha^{-1} (equivalent to 60% of the sugar beet potential) and 15 Euro t^{-1} sugar beet of total variable costs. This implies that, next to the savings on total variable costs, a steep raise in sugar yield is needed (figure 1.2).

The study SUSY (Speeding Up Sugar Yield) was aimed to identify possibilities to raise sugar yield by comparing 26 pairs of growers, the idea adapted from a pair study in Sweden (Berglund et al., 2002). Each pair consisted of a high yielding 'type top' and average yielding 'type average' grower in the same region, based on the 2000-2004 sugar yields. More details about the selection are given by Hanse et al. (2010a).

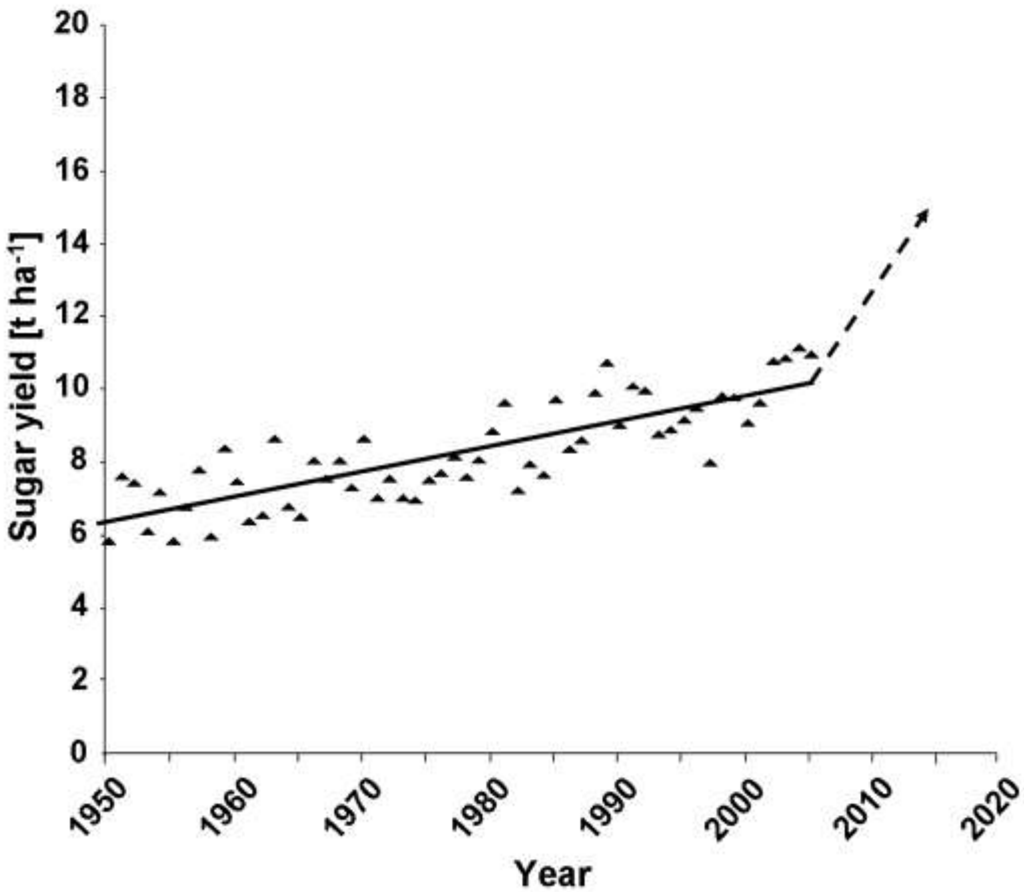

Figure 1.2. Average sugar yield (t ha^{-1}) in the Netherlands from 1950 to 2006. Sugar yield is raised on average by 1.7% a year. To reach the 15 t sugar hectare^{-1} target, sugar yield raise has to break this trend and should increase steeply (dashed arrow).

A large part of the data obtained from the SUSY-project is analysed and published in four publications, compiled in this dissertation.

The first publication analyses the data concerning the differences in costs and sugar yields between the type top and type average growers and is published in the journal Sugar

Industry (Hanse et al., 2010a). A German translation is published in the Special Edition of Sugar Industry for the purpose of the 9th Göttinger Zuckerrübentagung on September 2nd, 2010 (Hanse et al., 2010b). In this publication it is shown that the type top growers did not have higher total variable costs, although their yields were significantly higher compared to the type average growers. It was concluded that the differences in sugar yield were not caused by economical constraints. Sugar yield proved independent of total variable costs.

In the second publication the influence of pests and diseases on sugar yield is published (Hanse et al., 2011a). The occurrence of pathogens differed for the soil types clay and sand. The type top growers on clay soil had significantly lower infestation levels of *Heterodera schachtii*, *Beet necrotic yellow vein virus* (BNYVV) and other foliar diseases (*Pseudomonas, Phoma betae* and *Verticillium* spp. combined). On sandy soils, infestation levels of *Meloidogyne* spp., *Cercospora beticola* and *Erysiphe betae* were significantly lower for type top growers. The insecticides on seed pellets provided sufficient control. In the fields no insect pests causing sugar yield loss were observed. On clay soils, differences in the sugar yield could be explained by the *H. schachtii* and BNYVV infestation levels. On sandy soils, the infestation levels of *H. betae* and *Aphanomyces cochlioides*, number of fungicide sprayings and sowing date explained differences in sugar yield.

Despite crop protection measures, the calculated sugar yield losses due to pests and diseases ranged from 13.1 to 37.1% (24% average for all growers). Thus, it was concluded that the infestation levels of pests and diseases are among the explanations of the sugar yield differences between type top and type average growers.

The third publication shows the influence of soil management and intrinsic soil structure on temporal soil structure and its influence on sugar yield (Hanse et al., 2011b). Subsoil compaction, measured by the saturated hydraulic conductivity, Ks, and air-filled porosity, AP, explained 24.9% of the variance in sugar yield, although in dependency of subsoil sand content and sowing date. The Ks was explained by the content of 50-105 µm sand fraction in the subsoil and the depth of primary tillage. AP was found strongly dependent on clay content of the top soil. There was no difference between type top and type average growers for top soil AP. The type top growers' fields had a significantly higher Ks compared to the type average growers' fields. On 9% of the fields Ks was approximately 0.00 m day^{-1} and on 31% of the fields below the damage threshold of 0.10 m day^{-1}. Below this threshold, crop yield can be adversely influenced by soil structure (Lebert et al., 2004). AP below 10% was found on 25% of the type top growers' fields and 35% of the type average growers' fields. The type top growers used lower tractors tyre inflation pressure and less passes to prepare the seedbed, with the same equipment as the type average growers.

The fourth article is published in the proceedings based on a presentation at the 72^{nd} IIRB Congress in Copenhagen concerning losses while harvesting sugar beets in the SUSY-project (Hanse and Tijink, 2010). On average, 3 t sugar beet ha^{-1} are left on the fields, ranging from 0.45 to 9.1 t ha^{-1}. The losses due to overtopping and whole beet losses were significantly lower for type top growers. The losses due to root tip breakages did not differ between type top and type average growers. Total harvest losses (sum of losses by overtopping, whole beet and root tip breakage) did not differ between type top and type average growers. Options to point out the important harvest losses to both growers and harvester driver are presented.

This dissertation closes with the epilogue on the agronomical issues not yet published, as there are: fertilisation, sowing, and weed control of the sugar beet crop and the management influence of the growers.

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2 Comparison of costs and yields of 'type top' and 'type average' growers in Dutch sugar beet growing

Bram Hanse , Frans Tijink, Oliver Mußhoff and Bernward Märländer

Sugar Industry, 2010, 135, 550-560

2 Comparison of costs and yields

2.1 Summary

The Dutch sugar industry and sugar beet research initiated the project SUSY (Speeding Up Sugar Yield) as a reaction to the reform of the European Union sugar regime. The project was aimed at softening the reform's impact on growers income by improving their knowledge on raising sugar yield and identifying possible cost savings. From each sugar beet growing region in The Netherlands, 26 pairs of 'type top' (high yielding) and 'type average' (average yielding) farmers were selected, based on their yield levels in 2000-2004. During three years, all aspects of sugar beet production were investigated on 75 fields of 'type top' and 74 fields of 'type average' growers. Based on grower's crop management record, cost variables were calculated and analysed in relation to yield and quality variables. The factors year and grower caused most of the significant effects on yield, quality and cost variables. The grower can compensate for the year effect of biotic and abiotic variables on yield. The 'type top' growers had significantly higher sugar yields in each year compared to 'type average' growers, but the total variable costs did not differ. This makes the 'type top' growers more efficient in resource use. Costs for manure and fertiliser, 'other' and irrigation significantly increased the total variable costs. With higher fungicide costs, sugar yield significantly increased. There was no significant relation between the intensity of sugar beet production and sugar yield. Based on this study, it can be concluded that the most profitable strategy for the growers is maximising sugar yield and optimising costs. The observed differences in sugar yield were not caused by economical constraints.

2.2 Introduction

Sugar beet growers in Europe as well as in The Netherlands face the challenge to keep up their financial yields. Due to the reform of the European Union sugar regime, the EU minimum price for quota beet fell from € 43.63 t sugar beets^{-1} (CR (EC) 1260/2001, 2001; Zeddies, 2006) to € 26.29 t^{-1} from 2009 onwards (CR (EC) 318/2006, 2006), implying a 39.7% decrease. Growers have to raise their yield by the same percentage to compensate this price drop, if the costs remain on the level of 2006. Another strategy is to reduce costs. Possibilities to save up to 20% of the costs without yield loss in Dutch sugar beet production were identified by a previous study (Pauwels, 2006b). However, to compensate the beet price drop by cost savings, costs should decrease much more to keep the absolute difference between costs and payment the same. Therefore, cost saving still leaves a need for raising sugar yield. A combination of both raising yield and saving costs would be profitable for the growers, too.

The potential sugar yield in The Netherlands was calculated at a maximum of 23 t ha^{-1} (De Wit, 1953), more recent research found 24 t sugar ha^{-1} for Germany (Kenter et al., 2006). However, the average sugar yield achieved by Dutch growers was 10.6 t ha^{-1} in the period 2002-2006 (Van Swaaij, 2007). There is an enormous difference in sugar yield between growers, even when the fields are located in the same region (Agrarische Dienst, 2007). That is to say, there is an enormous, unexploited gap in sugar yield by a large group of growers. The aforementioned changed circumstances and the presence of a yield gap urge for knowledge how the sugar beet growers in The Netherlands can improve sugar yields and make possible savings on their costs. The causes and costs of the difference in yield were studied in the project Speeding Up Sugar Yield (SUSY) (Pauwels, 2006a) in a pairwise comparison of neighbouring growers with high yields ('type top') and average yields ('type average'), encountering the same production prerequisites: soil and climate.

The aim of this paper is to analyse the yield, quality and costs of the different ‘type top’ and ‘type average’ growers in order to identify rules for improving the economic success of Dutch sugar beet production. Therefore, the growers recorded all agronomic measures in sugar beet production, which formed the basis for calculations on the performance of ‘type top’ and ‘type average’ growers.

2.3 Materials and Methods

2.3.1 Data source

The data were obtained from the project ‘Improvement of the competitiveness of the sugar beet crop’ of the Dutch Institute of Sugar beet Research, IRS, Bergen op Zoom.

The pairwise comparison comprised 26 pairs (52 growers) in both 2006 and 2007. In 2008, data of 23 ‘type top’ and 22 ‘type average’ growers were available for costs calculation. This was due to the exclusion of 2 pairs from which the ‘type average’ sold the sugar quota and of 3 growers which did not fully complete the questionnaire in 2008.

A grower was considered ‘type top’ when the sugar yield on his farm in the period 2000-2004 was on average and in each single year among the 25% of the highest sugar yields in the region where the farm was situated. A grower was considered ‘type average’ when the sugar yields in the same period were among the 50% of average sugar yields in the region. Pairs were formed out of a ‘type top’ and a ‘type average’ grower, with at least 1.5 t ha^{-1} difference in sugar yield based on the 5 years average between those two growers. The location of the pairs in the different regions in The Netherlands is shown in figure 2.1.

Data were collected on parameters of soil physics, soil fertility, soil health, rainfall, drilling (date, depth, distance), field establishment, canopy closure, pests and diseases, nutrient uptake, yield and quality, harvest losses and exact field size (GPS). All parameters were measured following the IRS internal protocols or the standard available protocols (Pauwels, 2006a). From these variables, yield, quality and field size are presented in this publication. Additionally, the growers recorded all agronomic measures, including application dates, prices, type and amounts of consumables etc. All data obtained were fed into a specially built

Microsoft Access® database called 'Betapaar'. This database facilitates the calculation of the total variable costs based on the single cost components. Total machinery and contracting costs were calculated from the single cost components related to machinery use and contracting. Total direct growing costs were calculated from the single cost components for consumables. Root yield and sugar yield were used to calculate unit costs for root yield and sugar yield based on the total variable costs. The revenues were calculated from the yield and quality parameters and the beet price.

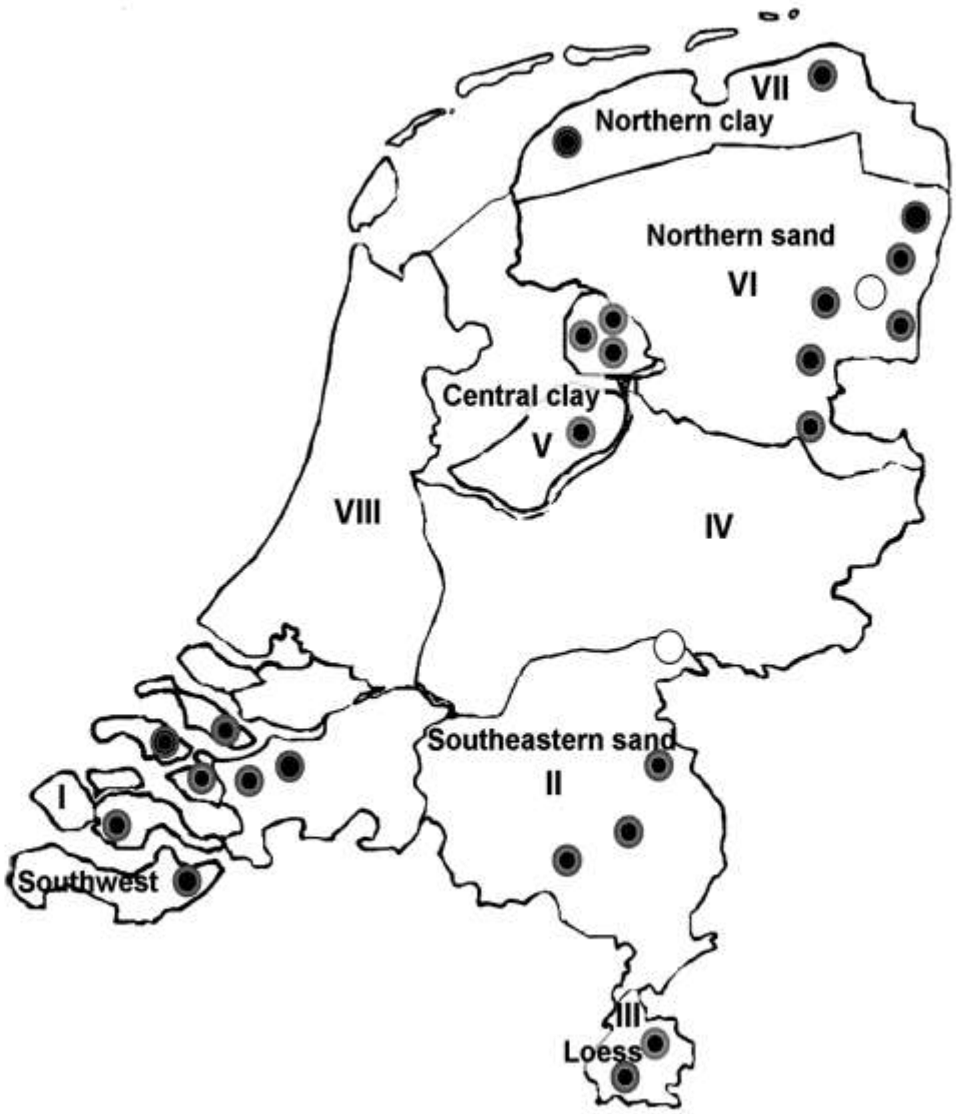

Figure 2.1. The regions and location of the SUSY-pairs in The Netherlands, each spot represents the location of a pair consisting of a 'type top' and a 'type average' grower; SUSY-project 2006-2008. *Open dots indicate two pairs of which the 'type average' grower sold the sugar reference in winter 2007/2008, therefore these pairs were not included in the study in 2008.*

2.3.2 Calculation of total variable costs

Costs for chemicals, fertilisers, manure and contracting were taken from the growers' records. Costs for farmers' own machinery used, including labour, were calculated based on standard prices per hectare and only assigned to the farm for the measures carried out (table 2.1). This harmonised the costs for growers' own equipment, which are difficult to assess in practice as a lot of diverse types and brands of equipment with an enormous variation in age were used. If measures were carried out by a contractor, the actual price paid to the contractor was obtained from the growers.

The basis was to value all inputs in growing sugar beet and assess the total variable costs enclosing labour, base materials, all machinery costs and contracting fees. The total variable costs exclude the fixed costs e.g. tenancy for the field and the overhead of the farm. The overhead encloses profit margin, costs of sugar quota, assurances for crop and grower, buildings, maintenance of fields, field and ditch edges, etc. The reason to compare only the total variable costs was that the fixed costs are very farm specific and depend on a lot of parameters which are not determined by the growing of sugar beets. Above all, the level of the fixed costs is almost independent of the grown crop. Unit costs were calculated based on the net root and sugar yield per hectare, without harvest losses, since the harvest losses remain in the field, unpaid.

The sum of the costs of the use of growers' own machinery and the contractor costs makes up the total contracting and machinery costs. This cost component enclosed all the costs related to the machinery used in sugar beet growing. This implies that also the fixed machine costs like storage, depreciation, interest, maintenance (including the labour for maintenance) and assurance costs are included in the machinery costs per hectare (table 2.1).

Table 2.1. Costs calculated for the use of own machinery by the farmers.

Cost components farmers own machinery[a]	Tractor[b] (€ hour^{-1})	Fuel consumption (litre hour^{-1})	Machine[b] (€hour^{-1})	Treatment time (hour ha^{-1})	Total (€ ha^{-1})	Taken in calculation (€ ha^{-1})
Soil treatment						
Catch crop drilling	8	10.0	15.5	0.70	32	30
Main soil tillage	18	15.0	21.0	1.18	75	75
Equalization treatment	18	15.0	19.0	1.18	73	70
Drilling of wind erosion cover crop	8	10.0	15.5	0.70	32	30
Seedbed preparation	13	10.0	22.5	1.00	57	55
Cambridge rolling	8	10.0	5.0	0.50	17	15
Application of wind erosion protection compounds						20[c]
Drilling	8	10.0	52.0	0.85	69	70
Nutrient application	13	10.0	10.0	0.30	13	15
Foliar nutrient application	13	10.0	20.0	0.30	16	20
Herbicide application	13	10.0	20.0	0.30	16	20
Herbicide application with special equipment	8	10.0	17.0	0.50	23	25
Mechanical weeding	8	10.0	32.0	0.60	37	35
Pesticide application	13	10.0	20.0	0.30	16	20
Irrigation	18	from growers' records	106.0	0.50		95[d]
Harvest						
Harverster		40.7				350[e]
Transport to clamp	13	15.0	14.0	1.18	61	60

a. All costs components include labour costs of 15 € hour^{-1} and are based on average used equipment and fuel price 0.65 € litre^{-1}.
b. The tractor and machine costs per hour are based on the yearly costs of these machines, including storage, maintenance and lubricants, depreciation, interest and assurance costs (De Wolf and Van der Klooster, 2006). For each treatment a suitably sized tractor is taken into account, e.g. a heavier tractor for ploughing than for drilling.
c. Taken without calculation from Wilting (2008).
d. To this amount the fuel costs per hectare were added.
e. Based on second hand 6 row bunker harvester, market price € 50,000 with depreciation to 0 in 4 years, including storage, assurance, interest, maintenance and lubricants. Calculation for an acreage of 100 hectares per year.

The sum of all costs for seeds, pesticides (herbicides, fungicides and insecticides), manure and fertilisers, hand weeding and the 'other' cost components makes up the total direct growing costs. These costs can be considered as the costs for the consumables in sugar beet growing. The fuel costs are included in the total contracting and machinery costs. Costs for application of fertilisers and organic manure were only assigned to the sugar beet production if they were paid by the sugar beet grower. They were neglected when the animal producer paid for these costs. In case the sugar beet growers were paid to receive the manure, this payment is taken into the cost calculation as additional payments for the sugar beets (Van den Ham et al., 2007).

'Other' costs include the costs for the seed of green manure crops, costs for covering the beet clamps, costs for wind and water erosion prevention. The costs for wind erosion prevention are the costs for the seed of barley (sown just before the sugar beets), paper pulp or manure (both sprayed after drilling).

Total variable costs are obtained by the summation of the total costs of contracting and own machinery and the total direct growing costs. All cost components are calculated in € ha^{-1}.

2.3.3 Yield and beet price

The total sugar beet quantity delivered to the sugar factory, including the quality parameters, was derived from the growers' records. Root yield, sugar yield as well as sugar beet prices, based on the quality components, were calculated with the Betapaar database, taking into account the exact field size.

Root yield (t ha^{-1}) was corrected for top and soil tare and the basis for the revenues (€ ha^{-1}), calculated by the sugar beet price (€ t^{-1}). Sugar beet quality parameters formed the basis of the sugar beet price (Huijbregts and Tijink, 2008). Sugar beet quality parameters are: sugar content (SC), potassium, sodium and α-amino nitrogen content (mmol kg^{-1}) of the sugar beets, which determine the amount of sugar which remains in the molasses (MS). The Dutch sugar industry uses a formula to calculate the sugar recovery (WIN, Winbaarheidsindex Nederland or beet quality index) based on quality parameters and the calculated quantity of sugar in molasses. The WIN is expressed as a percentage (Huijbregts, 1999):

$$WIN = 100 - 100 \cdot (MS/SC) \qquad (1)$$

The white sugar yield was not considered in the present study, since the growers only consider the sugar yield and beet quality. Sugar yield (SY) is calculated as the product of root yield (RY) and sugar content (SC). Standardised prices were taken for quota beets (35 € t^{-1}) and for surplus beets (15 € t^{-1}), both at 16% sugar and WIN = 87. Sugar content and beet quality were fined with -8.40 € t^{-1} at 14% sugar and with -4.19 € t^{-1} at WIN = 80 and paid with 6.30 € t^{-1} at 18% and with 2.68 € t^{-1} at WIN = 92 per ton root yield (Huijbregts and Tijink, 2008).

Since top tare is not fined (nor paid) by the Dutch sugar industry (Huijbregts and Tijink, 2008), the amount of top tare has no influence on sugar beet payments. Soil and other (stones, wood pieces, weeds and rotten beets) tare is fined with 12.50 € t^{-1} (Huijbregts and Tijink, 2008). In the Betapaar database the fine was calculated per ton root yield and subtracted from the sugar beet price.

In this publication, all sugar beets were considered being paid as quota beets for a transparent comparison of both grower types.

2.3.4 Statistical analysis

Data were analysed using the statistical package GenStat, 11th edition (VSN International Ltd.). Linear mixed models were used to analyse the effect of year, grower, site and their interactions in the fixed model. The given pair number, region and their interaction were used as random terms to analyse the 'type top' and 'type average' within a pair directly with each other (Thissen, 2009).

Linear regressions were calculated to estimate the effect of single variables on sugar yield and total variable costs.

2.4 Results

2.4.1 Effect of grower and interactions with site and year

Sugar yield was not related to sugar beet acreage per farm. The relation between total variable costs and sugar beet acreage (on average 11.5 ha; range 2 - 40 ha) per farm was significant, but the coefficient of correlation was very low. Therefore, the sugar beet acreage is not presented in the following.

The effect of site (S) was only significant for soil treatment and harvest costs (table 2.2). Except for root yield, the effect of year (Y) was significant for all yield and quality parameters including beet price and revenues. Concerning the total direct growing costs, the significant effect of year was influenced by the significant effect of year on costs of fungicides and manure and fertiliser. The effect of year on total contracting and machinery costs was not significant, although it was significant for costs of soil treatment, irrigation and pesticide application. The year had a significant effect on the total variable costs and unit costs of sugar yield (excluding fixed costs), but not on unit costs of root yield.

The effect of grower (G) on yield and quality was significant for root yield, sugar content, sugar yield and consequently for revenues, but neither for the beet quality index nor top or soil tare (table 2.2). The effect of grower was significant for fungicide, pesticide and nutrient application costs as well as for total contracting and machinery costs and both unit costs.

Compared to the main effects, there were only a few significant interactions: a year x site interaction for root yield, a year x grower and year x site interaction for soil tare, a grower x site interaction for seed costs, a threefold interaction of year x grower x site for hand weeding costs, a year x site interaction for 'other' costs, and interactions between grower and site respectively year and site for total contracting and machinery costs. Irrigation as well as all total costs and unit costs were significantly influenced by an interaction year x site (table 2.2).

No significant relation was found between root yield and sugar content (Figure 2.2). The relation of beet quality index and sugar content was highly significant. The influence of sugar content on beet price was highly significant while its influence on beet quality index was less strong (data not shown).

Table 2.2. Significance of the effect of year (Y), grower (G), site (S) and their interactions on yield, quality and cost variables in Dutch sugar beet production; SUSY-project, 2006 - 2008. *Grower 'type top' n = 75; grower 'type average' n = 74.*

Variable[a]	Site (S)	Year (Y)	Grower (G)	Y.S	Y.G	G.S	Y.G.S
Root yield (t ha^{-1})	n.s.	n.s.	***	*	n.s.	n.s.	n.s.
Sugar content (%)	n.s.	***	*	n.s.	n.s.	n.s.	n.s.
Sugar yield (t ha^{-1})	n.s.	*	***	n.s.	n.s.	n.s.	n.s.
WIN (beet quality index)	n.s.	***	n.s.	n.s.	n.s.	n.s.	n.s.
Soil tare (%)	n.s.	*	n.s.	*	*	n.s.	n.s.
Top tare (%)	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.
Beet price (€ t^{-1})	n.s.	***	n.s.	n.s.	n.s.	n.s.	n.s.
Revenues (€ ha^{-1})	**n.s.**	*******	*******	**n.s.**	**n.s.**	**n.s.**	**n.s.**
Seed (€ ha^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.	***	n.s.
Herbicides (€ ha^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Hand weeding (€ ha^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*
Fungicides (€ ha^{-1})	n.s.	***	***	n.s.	n.s.	n.s.	n.s.
Insecticides (€ ha^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Manure and fertiliser (€ ha^{-1})	n.s.	***	n.s.	n.s.	n.s.	n.s.	n.s.
Other (€ ha^{-1})	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.
Total direct growing costs (€ ha^{-1})	**n.s.**	******	**n.s.**	*****	**n.s.**	**n.s.**	**n.s.**
Soil treatment (€ ha^{-1})	*	**	n.s.	n.s.	n.s.	n.s.	n.s.
Drilling (€ ha^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Herbicide application (€ ha^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Mechanical weeding (€ ha^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Nutrient application (€ ha^{-1})	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.
Irrigation (€ ha^{-1})	n.s.	***	n.s.	***	n.s.	n.s.	n.s.
Pesticide application (€ ha^{-1})	n.s.	**	***	n.s.	n.s.	n.s.	n.s.
Harvest (€ ha^{-1})	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Total contracting and machinery costs (€ ha^{-1})	**n.s.**	**n.s.**	*****	*******	**n.s.**	*****	**n.s.**
Total variable costs (€ ha^{-1})[b]	**n.s.**	******	**n.s.**	*******	**n.s.**	**n.s.**	**n.s.**
Unit costs root yield (€ t^{-1})[b]	**n.s.**	**n.s.**	*******	*******	**n.s.**	**n.s.**	**n.s.**
Unit costs sugar yield (€ t^{-1})[b]	**n.s.**	*****	*******	*******	**n.s.**	**n.s.**	**n.s.**

a. n.s. = not significant; *, **, *** = significant at p ≤ 0.05, ≤ 0.01, ≤ 0.001.
b. Costs mentioned exclude the fixed costs e.g. tenancy for the field and the overhead of the farm. The overhead encloses profit margin, costs of sugar quota, assurances for crop and grower, buildings, maintenance of fields, field and ditch edges.

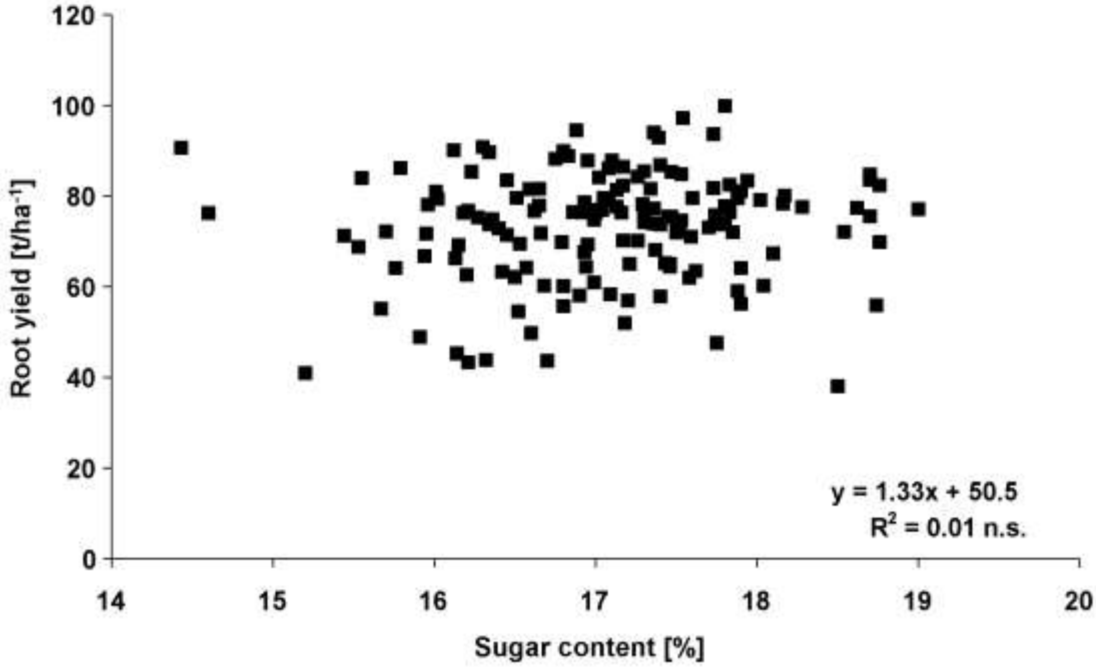

Figure 2.2. Relation of root yield to sugar content in Dutch sugar beet production; SUSY-project, 2006-2008. *n.s. = not significant.*

2.4.2 Difference between grower types

The growers ‘type top’ had significantly higher root and sugar yield, resulting in significantly higher revenues (481 € ha^{-1} difference) compared to ‘type average’, although the difference in beet price was not significant (table 2.3). The ‘type top’ growers had significantly higher costs for fungicides, nutrient application and pesticide application, the latter two causing significantly higher total contracting and machinery costs for ‘type top’ growers compared to ‘type average’ growers. Both unit costs of root and sugar yield differed significantly between growers ‘type top’ and ‘type average’. The total direct growing costs and total variable costs were not significantly different between growers ‘type top’ and ‘type average’. For all variables considerably influenced by grower, the differences between ‘type average’ and ‘type top’ growers were significant, except for the difference in sugar content.

Table 2.3. Influence of grower type on yield, quality and cost components in Dutch sugar beet production; SUSY-project, 2006 - 2008. *Grower 'type top' n = 75; grower 'type average' n = 74.*

Component	Grower			
	Significance effect[a]	'Type average'	'Type top'	lsd 5%
Root yield ($t\ ha^{-1}$)	***	66.7	78.1	2.89
Sugar content (%)	*	17.01	17.21	0.22
Sugar yield ($t\ ha^{-1}$)	***	11.4	13.4	0.51
WIN (beet quality index)	n.s.	91.1	91.1	0.29
Soil tare (%)	n.s.	8.8	8.6	0.87
Top tare (%)	n.s.	5.2	5.2	0.20
Beet price (€ t^{-1})	n.s.	39.08	39.75	0.86
Revenues (€ ha^{-1})	*******	**2618**	**3099**	**128.80**
Seed (€ ha^{-1})	n.s.	217	213	6.53
Herbicides (€ ha^{-1})	n.s.	199	190	17.72
Hand weeding (€ ha^{-1})	n.s.	48	48	15.41
Fungicides (€ ha^{-1})	***	36	52	6.65
Insecticides (€ ha^{-1})	n.s.	1	2	1.66
Manure and fertiliser (€ ha^{-1})	n.s.	42	47	51.32
Other (€ ha^{-1})	n.s.	43	53	20.84
Total direct growing costs (€ ha^{-1})	**n.s.**	**543**	**564**	**59.19**
Soil treatment (€ ha^{-1})	n.s.	150	145	9.54
Drilling (€ ha^{-1})	n.s.	68	68	3.27
Herbicide application (€ ha^{-1})	n.s.	90	97	8.28
Mechanical weeding (€ ha^{-1})	n.s.	17	19	6.33
Nutrient application (€ ha^{-1})	*	44	56	9.56
Irrigation (€ ha^{-1})	n.s.	29	46	19.36
Pesticide application (€ ha^{-1})	***	26	36	5.04
Harvest (€ ha^{-1})	n.s.	345	342	10.73
Total Contracting and Machinery costs (€ ha^{-1})	*****	**816**	**855**	**32.88**
Total variable costs (€ ha^{-1})[b]	**n.s.**	**1356**	**1416**	**73.35**
Unit costs root yield (€ t^{-1})[b]	*******	**21.13**	**18.26**	**1.69**
Unit costs sugar yield (€ t^{-1})[b]	*******	**125.1**	**106.8**	**9.92**

a. n.s. = not significant; *, **, *** = significant at p ≤ 0.05, ≤0.01, ≤ 0.001.
b. Costs mentioned exclude the fixed costs e.g. tenancy for the field and the overhead of the farm. The overhead encloses profit margin, costs of sugar quota, assurances for crop and grower, buildings, maintenance of fields, field and ditch edges.

In the following, only data with significant main effects of grower and significant interactions of year and site (table 2.2) are presented. However, if the main effect of grower was significant, the year x grower interaction is shown for these variables as well.

In all years, the 'type top' growers had a significantly higher sugar yield (12.8, 13.8 and 13.6 t ha^{-1}) compared to the 'type average' (10.9, 11.2 and 12.1 t ha^{-1}) (figure 2.3).

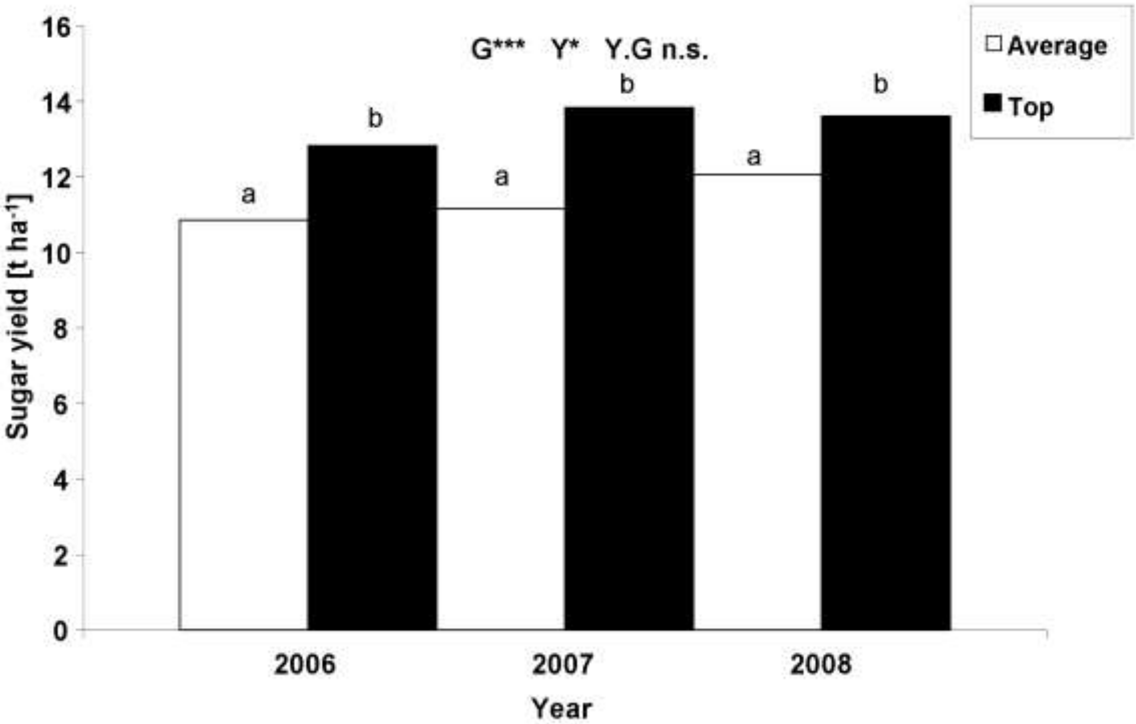

Figure 2.3. Effect of year and grower on sugar yield in Dutch sugar beet production; SUSY-project, 2006-2008. *n.s. = not significant; *,*** = significant at p ≤ 0.05, ≤ 0.001. Different letters indicate statistical differences within years*

The effect of grower on revenues was highly significant, while the year x grower x site interaction was not significant (table 2.2, figure 2.4). In all years and at both soil types, 'type top' growers had higher revenues compared to the 'type average'.

The effect of grower on soil tare was not significant, however, the year x grower interaction was (table 2.2, figure 2.5). The 'type average' growers had significantly higher soil tare in 2007 (9.9%) compared to 2006 (8.4%) and 2008 (8.1%).

The grower x site interaction significantly influenced seed costs (table 2.2). Seed costs were significantly lower on sandy soil for the 'type top' growers (195 € ha^{-1}) compared to the 'type average' (211 € ha^{-1}). The seed costs of 'type top' growers on clay soil (232 € ha^{-1}) did not differ significantly from those of 'type average' growers on clay soil (223 € ha^{-1}). The year x grower x site interaction had a significant influence on hand weeding costs (table 2.2). Fungicide and application costs of nutrients and pesticides were significantly higher for 'type top' growers in all years compared to 'type average' growers (figure 2.6). The differences between 'type top' and 'type average' growers for irrigation costs were not significant, but the year significantly influenced irrigation costs.

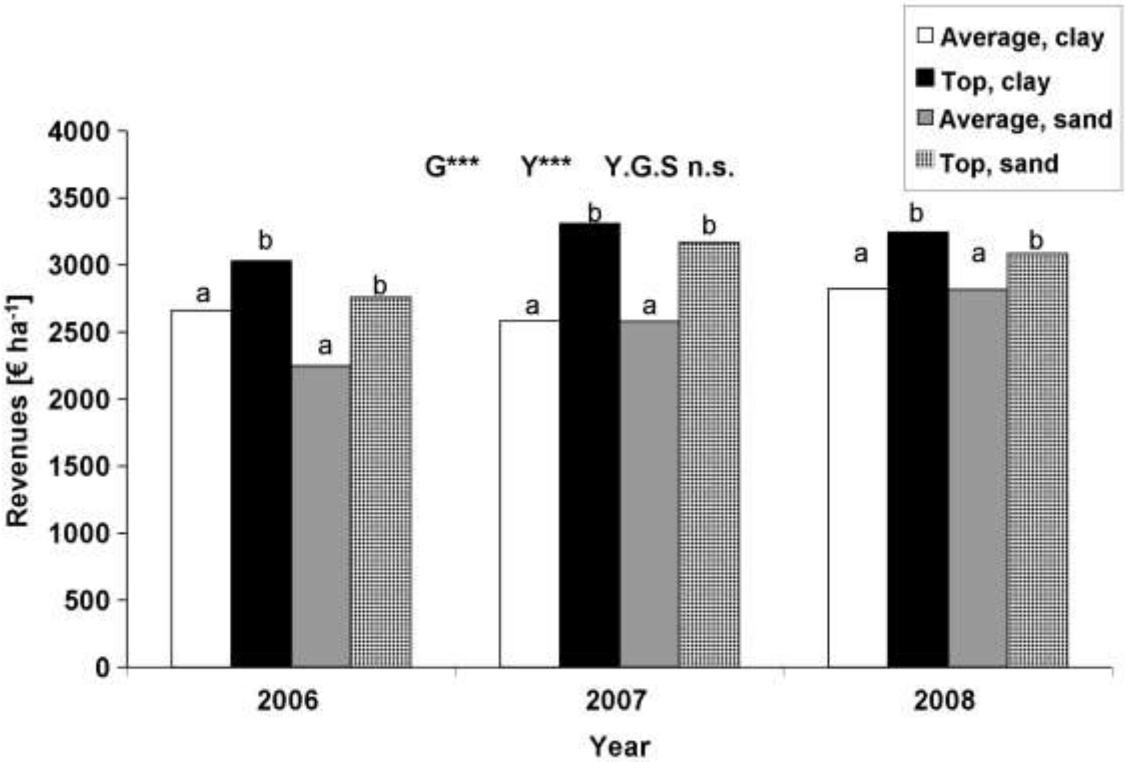

Figure 2.4. Effect of year, grower and site on revenues in Dutch sugar beet production; SUSY-project, 2006-2008. *n.s. = not significant; *** = highly significant at p ≤ 0.001. Different letters indicate statistical differences between grower types within years.*

The 'type top' growers had significantly higher (49 € ha^{-1}) total contracting and machinery costs compared to 'type average' (table 2.3, figure 2.7), the interaction grower x site being significant, too. On sandy soil, the total contracting and machinery costs were significantly higher for 'type top' (864 € ha^{-1}) compared to 'type average' growers (788 € ha^{-1}), while the effect was not significant on clay soil (847 and 844 € ha^{-1}) (figure 2.7).

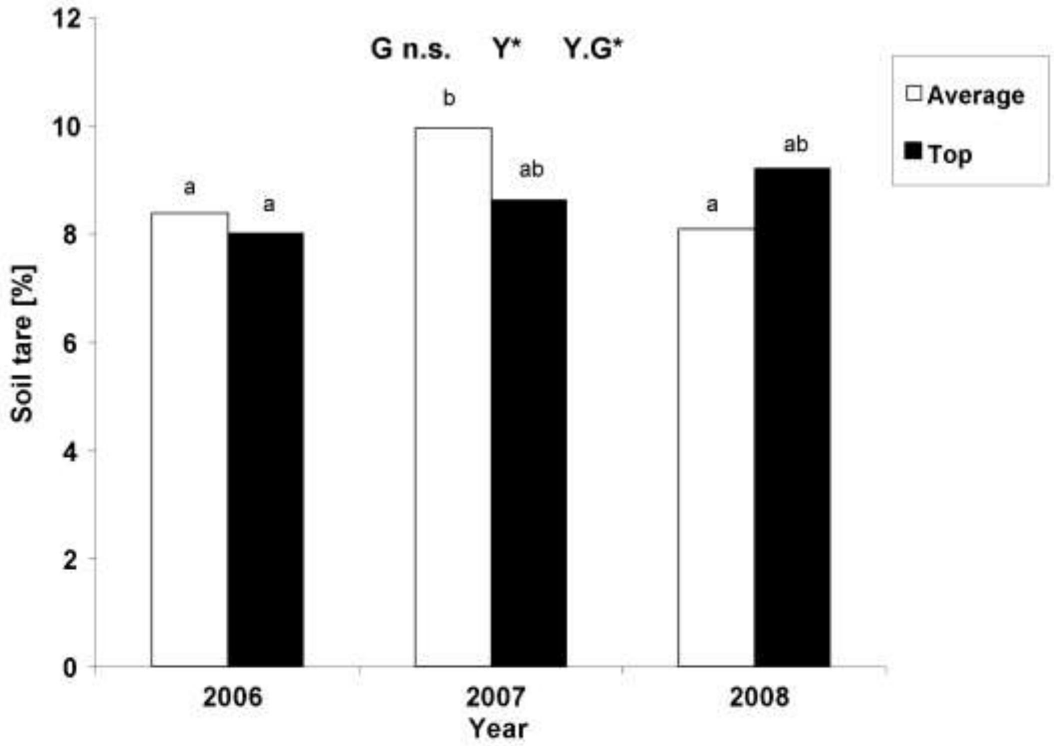

Figure 2.5. Effect of year and grower on soil tare in Dutch sugar beet production; SUSY-project, 2006-2008. *n.s. = not significant; * = significant at p ≤ 0.05. Different letters indicate statistical differences between years.*

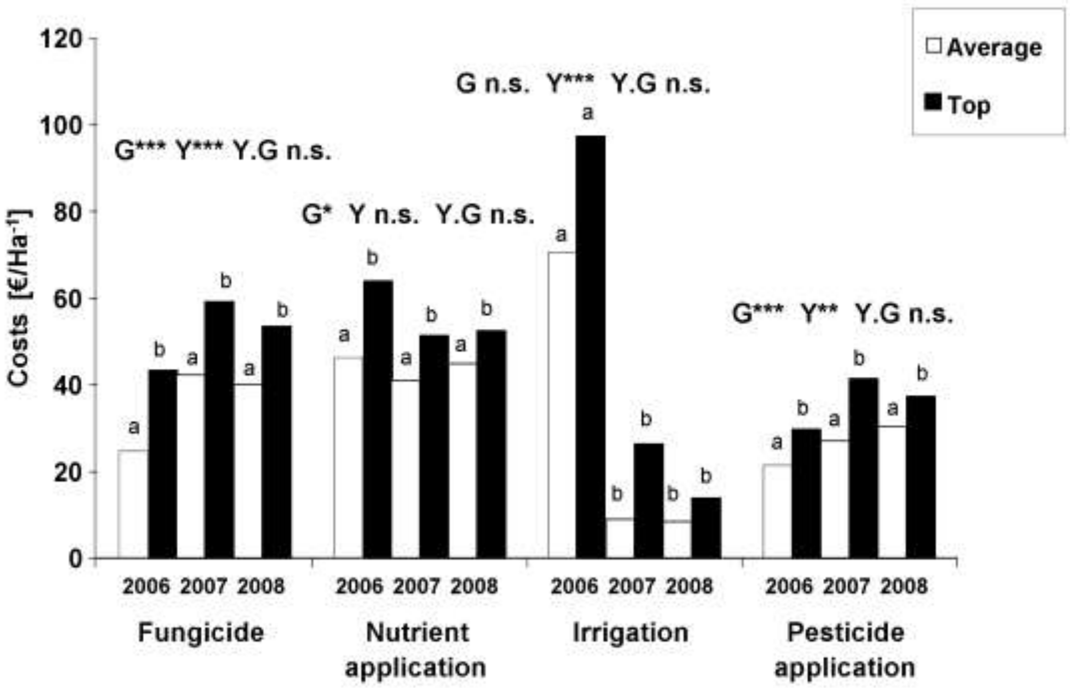

Figure 2.6. Effect of year (Y) and grower (G) on costs of fungicide, nutrient application, irrigation and pesticide application in Dutch sugar beet production; SUSY-project, 2006-2008. *n.s. = not significant; *, **, *** = significant at p ≤ 0.05, ≤ 0.01, ≤ 0.001. Different letters indicate statistical differences within each cost component and year.*

Neither grower nor the interaction year x grower x site had a significant effect on the total variable costs, although the non-significant differences were up to 200 € ha-1 (figure 2.8 A, table 2.3). However, the grower main effect significantly influenced both unit costs root and sugar yield. The ‘type top’ growers had lower unit costs compared to the ‘type average’ growers in each of the three years (figure 2.8 B-C, table 2.3).

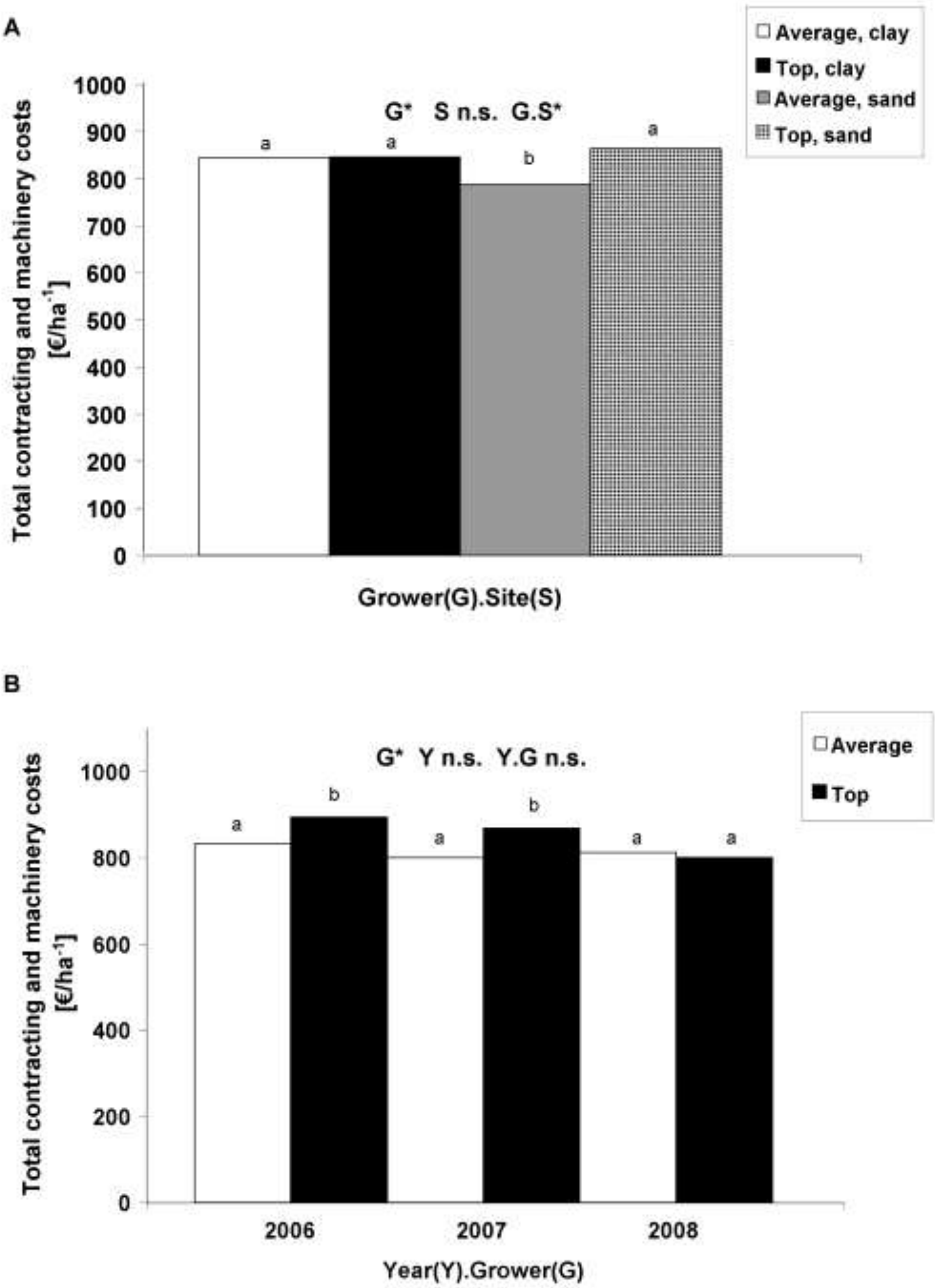

Figure 2.7. Effect of grower and site (A) and year and grower (B) on total contracting and machinery costs in Dutch sugar beet production; SUSY-project, 2006-2008. *n.s. = not significant; * = significant at p ≤ 0.05. Different letters indicate statistical differences between grower types.*

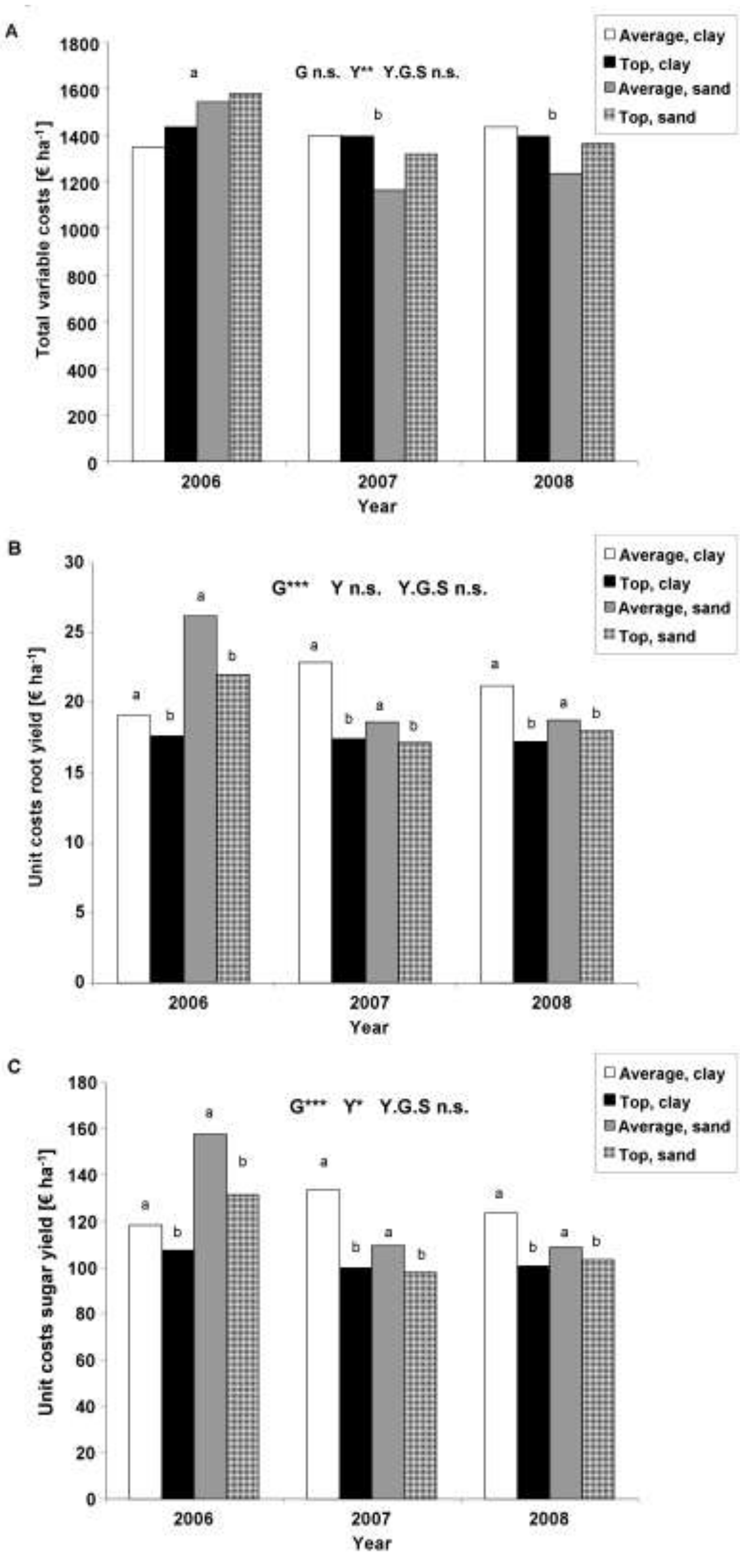

Figure 2.8. Effect of year, grower and site on total variable costs (A), unit costs root yield (B) and unit costs sugar yield (C) in Dutch sugar beet production; SUSY-project, 2006-2008. Costs mentioned exclude the fixed costs e.g. tenancy for the field and the overhead of the farm. The overhead encloses profit margin, costs of sugar quota, assurances for crop and grower, buildings, maintenance of fields, field and ditch edges. *n.s. = not significant; *, **, *** = significant at p ≤ 0.05, ≤ 0.05, ≤ 0.001. Different letters indicate statistical differences between years (A) and between soil and grower types within years (B-C).*

2.4.3 Regression analysis

The relation of total variable costs to costs of herbicide, hand weeding, insecticide, manure and fertiliser, ‘other’ costs, nutrient application and irrigation costs was significant (table 2.4). However, the strength (R^2) was considerable only for the costs for manure and fertiliser, ‘other’ and irrigation costs. The total variable costs were significantly related to the total direct growing and the total contracting and machinery costs.

Sugar yield had a significant relation only to seed, fungicide, drilling, and herbicide and pesticide application costs but with a very low R^2, except for fungicide costs. Finally, none of the cost components showing a significant correlation to sugar yield was significantly correlated to total variable costs and vice versa (table 2.4).

The non-relevant relation of sugar yield to cost and cultivation intensity in sugar beet is graphically demonstrated by two examples, the total variable costs and the fertilizing costs (figure 2.9 A-C).

Table 2.4. Regression analysis for cost components to total variable costs and sugar yield in Dutch sugar beet production; SUSY-project, 2006-2008 (*n=149*).

Cost component	Total variable costs[a]			Sugar yield[a]		
	Slope	R^2		Slope	R^2	
Seed (€ ha^{-1})	0.14	0.00	n.s.	0.02	0.06	**
Herbicides (€ ha^{-1})	0.79	0.04	**	0.00	0.01	n.s.
Hand weeding (€ ha^{-1})	1.20	0.06	**	0.01	0.02	n.s.
Fungicides (€ ha^{-1})	1.40	0.02	n.s.	0.03	0.13	***
Insecticides (€ ha^{-1})	8.60	0.03	*	0.05	0.02	n.s.
Manure and fertiliser (€ ha^{-1})	1.00	0.52	***	0.00	0.02	n.s.
Other (€ ha^{-1})	1.56	0.20	***	0.00	0.00	n.s.
Total direct growing costs (€ ha^{-1})	**1.10**	**0.79**	*******	**0.00**	**0.00**	**n.s.**
Soil treatment (€ ha^{-1})	0.44	0.01	n.s.	0.00	0.00	n.s.
Drilling (€ ha^{-1})	1.75	0.01	n.s.	0.04	0.05	**
Herbicide application (€ ha^{-1})	0.08	0.00	n.s.	-0.01	0.03	*
Mechanical weeding (€ ha^{-1})	-0.39	0.00	n.s.	-0.01	0.01	n.s.
Nutrient application (€ ha^{-1})	1.44	0.05	**	-0.01	0.01	n.s.
Irrigation (€ ha^{-1})	1.39	0.23	***	0.00	0.01	n.s.
Pesticide application (€ ha^{-1})	1.43	0.01	n.s.	0.03	0.08	***
Harvest (€ ha^{-1})	-0.07	0.00	n.s.	0.00	0.00	n.s.
Total Contracting and Machinery costs (€ ha^{-1})	**1.30**	**0.36**	*******	**0.00**	**0.00**	**n.s.**
Total variable costs (€ ha^{-1})[b]	**-**	**-**		**0.00**	**0.00**	**n.s.**

a. n.s. = not significant; *, **, *** = significant at p ≤ 0.05, ≤ 0.01, ≤ 0.001.
b. The costs mentioned exclude the fixed costs e.g. tenancy for the field and the overhead of the farm. The overhead encloses profit margin, costs of sugar reference, assurances for crop and grower, buildings, maintenance of fields, field and ditch edges.

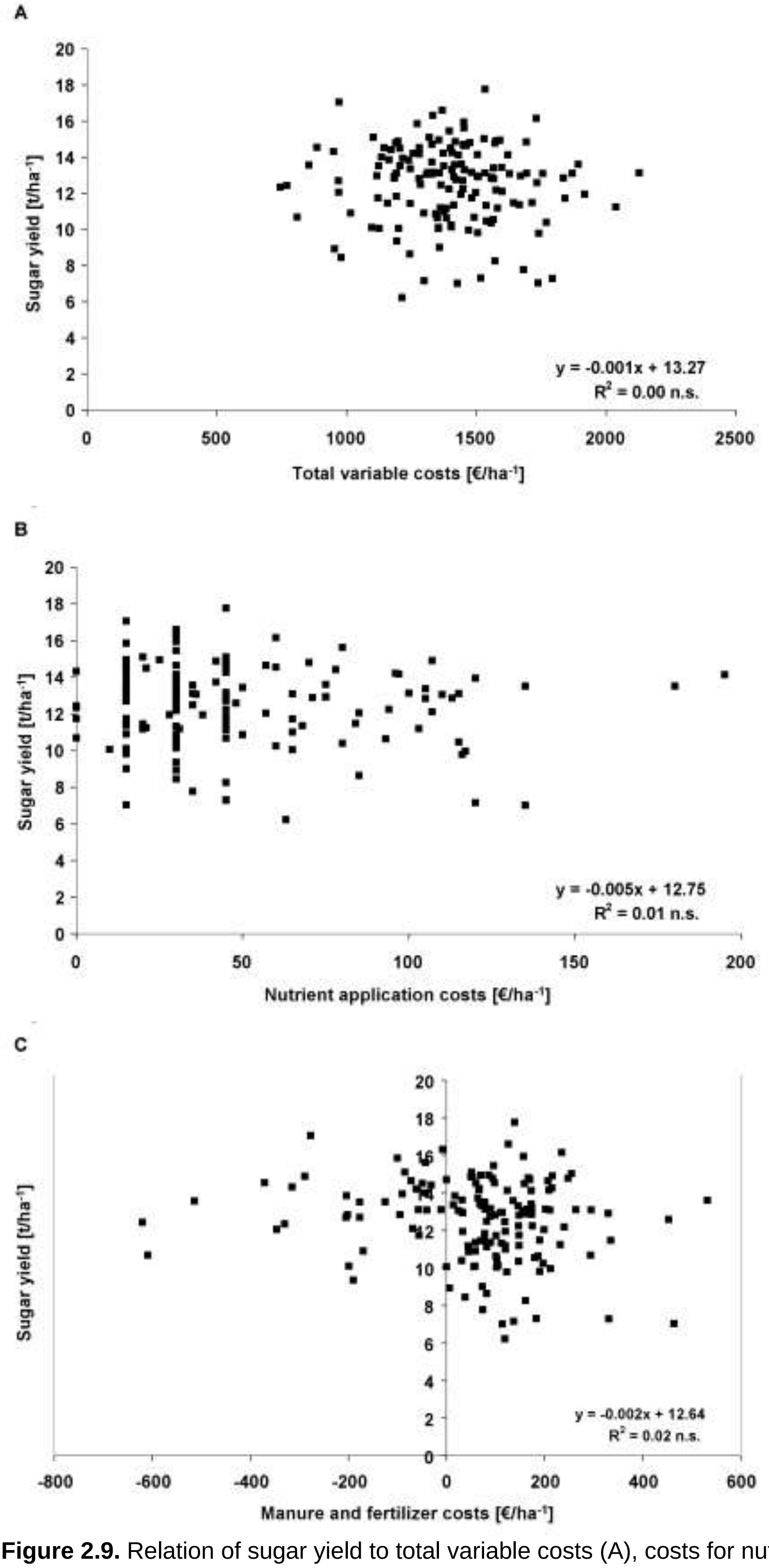

Figure 2.9. Relation of sugar yield to total variable costs (A), costs for nutrient application (B) and manure and fertiliser (C) in Dutch sugar beet production; SUSY-project, 2006-2008. *n.s. = not significant.*

2.5 Discussion

Many times in the history of Dutch agriculture, growers had to adapt to changing circumstances often initiated by economical impulses (Bieleman, 1992). For sugar beet growers, the reform of the EU sugar regime was a recent economical pulse (CR (EC) 1260/2001, 2001) forcing them to decisions concerning the cost and yield level of sugar beet production and even to decisions on continuing sugar beet production or not. The SUSY (Speeding Up Sugar Yield) project aimed to provide growers with knowledge on how to handle the price drop in sugar beet production. It investigated the causes and the costs of the differences in sugar yield, or growers' performance, in a pair-wise comparison. Farms in a pair were closely located to each other in all major sugar beet producing regions in The Netherlands. The selection based on yields in 2000-2004 caused the 'type top' (high yielding) growers having higher yields compared to the 'type average' (average yielding) during the project. However, it should be noticed that in each region at least one 'type average' grower was able to increase yield during the project, mainly due to a change in attitude towards sugar beet production, not being pleased called 'type average'. On the other hand, not all 'type top' growers were excellent growers and had opportunities to raise their yields, too.

In the project, growers with large sugar beet acreage had no higher sugar yields compared with sugar beet growers having a small acreage. Therefore, size of crop acreage can not be used to measure growers' performance. In this study, there was no influence of sugar beet acreage on the costs, either, since the costs were calculated for the treatments the farmers conducted themselves. These cost calculations were based on efficient equipment use in order to be able to compare farms with high and low contracting use. This methodology ignores the cost advantage of increasing farm size but enables the comparison of the 'type top' and 'type average' growers on an equal basis.

Most of the significant effects on yield, quality and cost variables were found for year and grower. Year effects on yield are well known in agriculture (Lobell et al., 2009) and in sugar beet production mainly determined by the weather (e.g. Märländer, 1991). However, since the weather is a given fact, the management by the grower becomes very important for crop performance. Independent of the year, the ‘type top’ growers harvested more sugar per hectare compared to the ‘type average’. These results imply that the influence of the grower can compensate for yield losses by biotic and abiotic variance. This effect was also observed for growers with arable farms equal in size, similar in soil and with equal start of cultivation on newly reclaimed farmland in the Noordoostpolder (NL). Here the factor grower was also responsible for the difference in yield (Zachariasse, 1974). Recent research found the same importance of growers’ management in Germany (Fuchs et al., 2008) and its importance under the circumstances provided by the weather (Märländer, 1991).

The grower probably also influenced plant development. In breeding, a negative correlation between sugar content and root yield was observed on trial fields (Hoffmann, 2006), while no relation was found in this study. The sugar content, although significantly influenced by grower, did not differ significantly between ‘type top’ and ‘type average’ growers. This implies that the ‘type top’ tend to achieve higher sugar content, but on average, the absolute difference between both grower types is not significant. So the general production management irrespective of grower type influences the relation of sugar content and root yield. Next to this, the high yielding effect of ‘type top’ growers is mainly due to a higher root yield. This confirms the results of yield increase over 20 years, on the same farm, found to be mainly dependent on an increase in root yield (Märländer, 1991).

Sugar content is important in the sugar beet payment and closely linked to beet quality (Huijbregts, 1999). Both sugar content and beet quality are positively rewarded by the Dutch sugar industry (Huijbregts and Tijink, 2008). Because the sugar content, although significantly influenced by grower, did not differ significantly between ‘type top’ and ‘type average’ growers, the beet price and the beet quality index did not differ, either. Since sugar content is a key factor for the calculation of the beet price, growers might focus on the sugar content. This could explain why there was a significant effect of grower type but no significant difference between grower types based on the least significant difference. This needs to be further investigated, because it is also possible that the sample size was too small to distinguish between a random or significant grower effect.

Due to their much higher sugar yield, the revenues of the ‘type top’ growers were 481 € ha^{-1} higher compared to ‘type average’ growers, while the total variable costs were equal for both grower types. This leaves a higher margin for ‘type top’ growers to cover fixed costs (which are not considered in this study) and might result in a higher income. A study on the total costs of 109 farms in Germany revealed the 25% highest yielding growers having lower costs compared to the 25% lowest yielding farms (Starcke and Bahrs, 2009). This difference can be due to the experimental set up. The German study selected the growers for an inquiry and divided them afterwards into high or low yielding groups irrespective of the region. In the SUSY project, the ‘type top’ and ‘type average’ grower of a pair were selected in the same region. As a consequence, both grower types encountered the same cost components specific for the region (e.g. extra soil treatment, irrigation and wind erosion prevention costs). The costs for soil treatment, irrigation and pesticide application were significantly influenced by year, however, this did not influence the total contracting and machinery costs. Likely, the variation in the machinery cost components (costs for drilling, herbicide and nutrient application, mechanical weeding and harvest) eliminated the year effect, because the total contracting and machinery cost contains all those cost components. The year effect on irrigation can be explained by the dry summer of 2006 and the year effect on soil treatment by the drought in spring 2007 which caused a need for extra seedbed preparations on clay soil. Fungicide costs and pesticide application costs, which are linked, were significantly influenced by year. This is due to the supervised control of foliar diseases resulting in year-dependent amounts of fungicides applied (Vereijssen, 2004). Contrary to the effect of year, the significant effect of grower on application costs of both nutrients and pesticides also caused a significant effect of grower on the total contracting and machinery costs.

With the total variable costs reflecting the input rate per hectare of sugar beet growing, the higher yields made the ‘type top’ growers more efficient in the production process, because their unit costs both for root and sugar yield were lower compared to the ‘type average’ growers. The same effect was observed for the nitrogen use efficiency. To produce one ton sugar, the ‘type top’ growers used on average 11.8 kg N while the ‘type average’ growers used 12.9 kg N. The nitrogen application rate varied for all growers from 36 to 1.5 kg N t sugar^{-1} (data not shown), which is in line with results of the study by Fuchs and Stockfisch (2009) for Germany. Higher yields provide ‘type top’ growers with a more efficient resource use, which is profitable for both the grower and the environment. For sugar beet production in the United Kingdom, Tzilivakis et al. (2005) also found, that a high yield could be obtained whilst minimising the environmental impact. A study on Dutch sugar beet production confirmed this and found ‘a persistent farmer’s management influence on efficiency’ (De Koeijer et al., 2002). The findings of the SUSY-project confirm that in sugar beet production the grower has a profound influence on economic and environmental sustainability.

The manure and fertiliser costs were low on average, but varied between years. This can be explained by an unique situation in The Netherlands. Due to a high intensity of animal production, combined with none or small sized arable activities of the cattle-breeders (CBS, 2008) and a strict legislation on nutrient supply on agricultural fields (Meststoffenwet, 2006; 2009), arable farmers are paid by cattle-breeders to apply manure to their crops (Van den Ham et al., 2007). It is not always possible to totally meet the sugar beet nutrient demand by manure, due to application time and uncertainty of mineral content of the manure at application time (Wilting, 2009b). However, with the use of the highest possible amounts of manure the grower can save on nutrition costs of sugar beet production, or even earn with the use of manure. This directly lowers the total variable costs. On the other hand, the use of manure saves the use of mineral nitrogen, a nutrient with a high energy density (Jensen and Kongshaug, 2003). Thus, the use of manure instead of mineral fertilisers contributes to a sustainable development of sugar beet production, both economically and environmentally.

The total variable costs for growers on sandy soils were higher in 2006 compared to the other two years on sandy soils. This cost increase is due to the irrigation costs in the dry summer. On the clay soils, where irrigation is not common, the total variable costs were more stable over the years. For the unit costs, the same pattern was observed, raising the question whether the high irrigation costs were paid back by a raise in yield or not. The regression analysis showed the irrigation costs significantly raising the total variable costs, while they did not influence the sugar yield. From this data set it is difficult to distinguish whether the irrigation costs are stabilizing the sugar yield in dry periods or are unnecessary costs, because there were no differences in irrigation between ‘type top’ and ‘type average’ growers. The sugar beet root growth in July and August was found to be dependent on the available water in the soil (Kenter et al., 2006) pleading for irrigation in dry periods. Dutch research also found an increase in root yield by irrigation, but there remains a risk that irrigation costs are not fully covered by the yield increase (Wilting, 2009a).

The costs components which significantly raised the total variable costs in the regression analysis had no influence on sugar yield, and vice versa. Thus, savings can be made on those costs which raise the total variable costs, like the above discussed irrigation and manure and fertiliser costs and the ‘other’ costs. The latter is a summation of minor cost components, like the costs for covering the beet clamp and growing green manure crops. The significant effect of this cost component on total variable costs was most likely due to the increased length of the campaign and frost period in 2008, which triggered some growers on the sandy soils to invest in beet clamp covering materials.

The best cost strategy in sugar beet production would be to reduce costs as much as possible, while maximising sugar yield. At this point, the growers’ management is crucial again. They can obtain a higher yield by optimizing the same level of inputs (Märländer, 1991) resulting in a more efficient production (De Koeijer et al., 2002).

In this study, the only savings which would obviously put the sugar yield at risk would be savings on fungicides costs. To handle these costs sustainably from both an economical and environmental point of view, an integrated pest management system was developed (Vereijssen, 2004).

Finally, there was no relation between the intensity of production measured by the total variable costs and the result of the costs that were made, the yield. Compared to other crops, like wheat and maize, this is a very sustainable characteristic of the sugar beet crop. The yield of wheat and maize is strongly linked to the intensity of production (Charles et al., 2006; Pingali and Rajaram, 1999). For those crops, the yield level is often determined by the maximum profit, when the additional costs are not paid back by the increased financial yield (Lobell et al., 2009). However, this study clearly shows that maximising sugar yield is the most profitable strategy for the growers, with optimising costs simultaneously. The differences in sugar yield observed were not caused by economical constraints. The best preparation of sugar beet growers for future uncertainties, like the end of the present EU sugar regime in 2015 (CR (EC) 318/2006, 2006) and presumably increasing demands of the society for environmental friendly production, is to raise the sugar yields.

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3 Pests and diseases contribute to sugar beet yield difference between top and averagely managed farms

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3 Pests and diseases contribute to sugar beet yield difference

3.1 Abstract

Crop yield has to increase to meet the expanding demand for food, feed and bio-energy, caused by world population growth and increasing wealth. Raising sugar yield is also the key to sustaining the profitability of the sugar beet crop. This paper describes the factors that impacted on yield differences between 26 ‘top’ and 26 ‘average’ growers based on four years yield data (2000-2004). In 2006 and 2007, the top growers had 20% higher sugar yields compared to their neighbouring average growers. *Heterodera schachtii* and *Beet necrotic yellow vein virus* (BNYVV) were mainly found on clay soils. Top growers on clay soil had significantly lower infestation levels of *H. schachtii* (4.4x lower, P = 0.008), BNYVV (2.7x lower, P = 0.016) and other foliar symptoms (*Pseudomonas*, *Phoma betae* and *Verticillium* spp. combined) (1.5x lower, P<0.001), than the average growers, respectively. On sandy soils, infestation levels of *Meloidogyne* spp. (P = 0.016), *Cercospora beticola* (P = 0.005) and *Erysiphe betae* (P = 0.027) were significantly lower (5x, 1.4x and 1.8x, respectively) for the top growers. The top growers on clay or sand sowed 5 and 6 days earlier respectively, and made more fungicide applications and thus used more fungicides than the average growers. Insect pests were not observed at levels damaging for sugar yield: Insecticidal seed treatments provided sufficient control of insect pests. In multiple regression, 35% of the variance in sugar yield on clay soils was explained by *H. schachtii* and BNYVV infestation levels and by sowing date. On sandy soils, the infestation levels of *Heterodera betae* and *Aphanomyces cochlioides*, number of fungicide applications and sowing date explained 71% of the variance in sugar yield. Despite crop protection measures, the calculated yield losses due to pests and diseases for the top growers were 30.2 and 13.1% and for average growers were 37.1 and 16.7% on sandy and clay soils, respectively. Therefore, pest and disease infestation levels partly explained the differences in sugar yield between top and average growers analysed. The skills and knowledge of the grower are important to reducing damage by pests and diseases. Communication of knowledge, obtained by research, towards

growers is vital for the long-term raising of yield and increasing of productivity in sugar beet, as well as in other crops.

3.2 Introduction

The world population is expected to grow to a level of 9 billion people by 2050 (UN-DESA, 2009). Both population growth and increasing wealth cause an increase in the global demand for food, feed and bio-energy (FAO, 2002; FAO, 2009). Theoretically, agriculture in the world can produce enough to meet this future demand in a sustainable way, although it requires efficiency and, among others, a raise in yield (Godfray et al., 2010; Jaggard et al., 2010).

In each region in the world and for each crop, yield gaps or difference in yield levels occur with growers' management as a dominant factor (Lobell et al., 2009). Even on similar farms with an equal starting point in time on fresh reclaimed soil, growers' management was found the major key for farm profitability (Zachariasse, 1974). The recent reform of the European Union's Common Agricultural Policy (CAP) implied a 39.7% decrease in sugar beet price for growers (Zeddies, 2006). With the same yields the impact on farmers' income would be substantial. For this reason the Dutch sugar industry and the Institute of Sugar Beet Research (IRS) initiated a project on the competitiveness of the sugar beet crop in the Netherlands. Our SUSY (Speeding Up Sugar Yield) project aimed to find ways to increase sugar yield and to identify cost savings. Data gathered from high yielding ('top') growers were compared with data from neighbouring average yielding ('average') growers.

Analysis of the costs and yields in the SUSY-project revealed no difference in total variable costs (financial input levels) between both grower types, concluding that raising sugar yield is possible with identical inputs. The only significant factors influencing sugar yield, which were significantly higher for top growers, were fungicide and their application costs, indicating the importance of pests and diseases (Hanse et al., 2010). The attainable sugar yield is the sugar yield limited by the natural physical environment (e.g. temperature, available water and light) of the crop (Cook, 2000). Under Dutch climate conditions the attainable sugar yield was estimated at a maximum of 23 Mg per hectare (De Wit, 1953). More recent research calculated 24 Mg sugar per hectare for Germany (Kenter et al., 2006). Despite this tremendous potential, the Dutch sugar beet growers achieved only an average of 10.6 Mg sugar per hectare in the period 2002-2006 (Van Swaaij, 2007). Yield losses in sugar beet due to plant pathogens and pests are estimated in general to be 26% with, and more than 80% without, crop protection (Oerke and Dehne, 2004). Therefore pests and diseases may explain the yield gap in Dutch sugar beet production.

The objective of this study was to identify the differences between top and average growers and to estimate the importance of pathogens and pests in Dutch sugar beet production. This was performed with data collected from the commercial fields of selected growers, where all important variables in growing sugar beet come together. Therefore, data were collected on the parameters of soil physics, soil fertility, soil health, rainfall, sowing (date, depth, distance), field establishment, canopy closure, pests and diseases, nutrient uptake, yield and quality, harvest losses and exact field size (GPS). From these variables, those related to crop protection were evaluated and presented here.

3.3 Materials and Methods

3.3.1 Pair study

The data were obtained within the framework of the study ‘Speeding Up Sugar Yield’ (SUSY) of the Dutch Institute of Sugar beet Research, IRS, Bergen op Zoom. The pair-wise comparison comprised 26 pairs of growers in both 2006 and 2007. Each pair was formed by a top and an average grower, based on historic sugar yields of the period 2000-2004. Farms of the growers within a pair were located closely together on the same soil type (average distance between fields of a pair was 5.5 km, with a maximum of 29.6 and minimum of 0.19

km). Pairs were located throughout the Netherlands on both sandy (<5% clay) and clay soils (>5% clay) in sugar beet producing regions.

A grower was considered to belong to the top group when the sugar yield in the period 2000-2004 was on average and in each single year among the 25% of the highest sugar yields in the region where the farm was situated. A grower was considered to belong to the average group when the sugar yields in the same period were among the mid 50% of average sugar yields in the region. Pairs of top and average farmers were formed if there was at least an arbitrarily chosen difference of 1.5 Mg ha^{-1} sugar yield based on the 5 years average between those two growers. For each grower one field per year was included in the study. The data of the number of fungicide applications and the amount of fungicide used, sowing and harvesting date were given by the growers participating in the study.

3.3.2 Soil samples

From each field, 2.5 kg soil per 2 ha (0-25 cm) was collected by sub-sampling 60-70 randomly distributed cores with a 1.5 cm diam. auger in February – March before sugar beet was sown. Soil from each field was air-dried, ground when necessary, homogenised, divided into 5 lots and stored at room temperature for further analysis. This procedure was followed for all the analyses done, except for the bioassay for *Aphanomyces cochlioides* Drechs. and the quantification of free living nematodes. These latter soil samples were not dried, but were stored at 4 °C and analysed shortly after sampling.

3.3.3 Detection of Beet Necrotic Yellow Vein Virus

To determine the presence of rhizomania (*Beet necrotic yellow vein virus*, BNYVV) in the soils taken in 2007, 3 pots (7 x 7 x 6.2 cm l×w×h; 0.21 l) were filled with the sampled soil and nutrients were added (slow release Osmocote; NPK 16-8-11 + trace elements). Sugar beet seedlings (10-14-days-old, grown in trays with pasteurised sand) of susceptible variety

Blenheim (VanderHave Sugar Beet Seed B.V.) were grown in the pots in a climate room at 23 ^{o}C for 16 h in light conditions (20,000 lux) and 16 ^{o}C for 8 h in the dark. Watering was done via individual dishes under the pots to prevent cross-contamination. After 10 wk, the bioassay was terminated.

Soils tested positive for rhizomania (in 2007 and all soils in 2006) were used in dilution series to estimate the viral inoculum concentration in the soil sample. Pots (7x7x6.2 cm; 0.21 l) were filled with soils diluted with pasteurised sand (1/10; 1/100; 1/1000, dried soils mixed in an inflated plastic bag, and nutrients were added (slow release Osmocote; NPK 16-8-11 + trace elements). Plants were grown in pots in the same way as in the test for the presence of rhizomania. After 6 wk individual pots were sampled.

When pots were sampled, leaves were removed and the roots rinsed with tap water to remove soil particles. All roots of individual plants were pressed (hand press NIFA Instruments) and 1:10 diluted with extraction buffer (LOEWE Biochemica GmbH) as described by Tuitert (1990).

Presence of *Beet necrotic yellow vein virus* (BNYVV) in roots was detected with double antibody sandwich ELISA exactly following the manufacturer's instructions (LOEWE Biochemica GmbH). After adding of a substrate (4-Nitrophenylphosphate Na_2-salt), the extinction was measured at 405 nm after 1 h and 2 h at room temperature. Absorption values (OD) above 0.050 OD were considered as positive for rhizomania. Root sap of highly and non-infected sugar beet plants served as controls. The most probable number (MPN) was calculated with the statistical package GenStat (Payne et al., 2009) following Tuitert (1990).

3.3.4 Bioassay of soil suppression against Rhizoctonia solani Kühn

One percent (w/w) of a 21-days-old oat meal culture (OMC) of *R. solani* AG 2-2IIIB, IRS code 02-337, prepared according the method described by Bakker et al. (2005), was mixed with the soil samples to be tested for infestation in an inflated plastic bag (clay soils rolled to fine particles). Twelve PVC tubes (diam. 2 cm, height 15 cm) were filled with 75 g of the soil to be tested. Non- and naturally *R. solani*-infested soil samples and non-infested soil from each sample served as controls. In each tube one seed (pelleted with hymexazol, 14.7 g active ingredient and thiram, 4 g active ingredient per 100,000 seeds to control infection by seed and soil borne fungi) of variety Aligator (SES Europe N.V./S.A.) was sown. Seed emergence and *R. solani*-diseased plants were scored 2 and 4 wk after sowing on a scale 0 = healthy to 3 = dead. A disease-suppressive soil was defined as a soil in which disease-development was suppressed after four weeks of growing sugar beet in an artificial infested soil. Plants were grown in a climate room at 23 ^{o}C for 16 h in light (20,000 lux) and 16 ^{o}C for 8 h in dark. Soil was kept moist during the bioassay.

3.3.5 Bioassay for determination field infestation by Aphanomyces cochlioides

Field soil was used to fill 10 pots (7x7x6.5 cm; 0.19 l) on each pot 4 seeds (pelleted without hymexazol (active against *Aphanomyces* spp.) and with thiram, 4 g active ingredient per 100,000 seeds; for protection against *Pythium* spp. and seed borne fungi) of variety Aligator (SES Europe N.V./S.A.) were sown and emerged in the pots. Plants were grown in a climate room at 23 ^{o}C for 16 h in light (20,000 lux) and 16 ^{o}C for 8 h in the dark. The soil was kept humid to stimulate infection by *A. cochlioides*. Diseased plants were counted each week and the percentage of seedlings infected by *A. cochlioides* was calculated. Plants were scored under the microscope for infection. After 5 wk the experiment was terminated.

3.3.6 Quantification of nematodes

3.3.6.1 Free-living nematodes

After homogenizing the soil, sub-samples of 100 ml and 1000 ml soil were taken for extraction of free-living nematodes. Nematodes were extracted from the soil according to (Oostenbrink, 1960) and placed on a cotton wool filter with the organic fraction at room temperature for 1 (the 1000 ml sub-sample) and 3 d (100 ml sub-sample) at room temperature. The 1000 ml sub-sample was investigated for the presence of *Ditylenchus* spp. From the 100 ml sub-sample nematodes were identified following Bongers (1994) and counted in duplicate under a microscope, using 2× 10 ml aliquot portions. The cotton wool filters were stored for another 11 d at room temperature and investigated again for nematodes, examining 2× 10 ml aliquot portions (Bezooijen, 2006).

3.3.6.2 Beet cyst nematodes

For the extraction of *Heterodera schachtii* Schmidt and *Heterodera betae* Wouts, Rumpenhorst & Sturhan soil samples were dried (14 h at 40 ^{o}C). Samples were ground, homogenised and 2 subsamples of 100 ml were taken, sieved wetted and centrifuged with kaolin powder for 5 min. at 1,800 *g*. The supernatant was poured onto a cotton filter. Subsequently a saturated $MgSO_4$-solution was added to the subsamples, it was homogenised and the suspension was centrifuged again for 3 min. at 1800 *g*. The supernatant was poured again on the cotton filter; cysts were collected on the filter and were counted under a binocular microscope at 12.5× magnification and subsequently crushed (Bühler crusher) in 10 ml water. Eggs and larvae in 1 ml water (if <1000 eggs and larvae) or 0.1 ml (if >1000 eggs and larvae) were counted in duplicate under a microscope (Bezooijen, 2006). All samples from one field were averaged to the infestation level for the whole field expressed in eggs and larvae per 100 ml soil (e+l/100 ml soil).

3.3.7 Scoring of foliar symptoms

Scoring of fungal leaf symptoms was carried out at least three times during the season at 3-4-wk-intervals or directly after fungicide application, starting at the end of July. For each field, 100 randomly selected plants were assessed for fungal leaf infestations of *Cercospora beticola* Sacc., *Ramularia beticola* Faut. & Lamb., *Erysiphe betae* (Vañha) Weltz. and *Uromyces beticola* (Bell.) Boerema, Loer. & Hamers. All four fungi were assessed on the same plant. Scoring started directly after the first fungicide application of the farmer, at the same date the field of the other farmer in the pair was scored, irrespective of fungicide application. The last scoring occurred within 7-14 d before harvest. Per field the maximum severity was taken in the analysis.

For the disease assessment of *C*. *beticola* the Agronomica whole plant diagram or field key from Italy was used with a 0-5 scale (Battilani et al., 1990; Vereijssen et al., 2003). The same assessment scale was also used for the assessment of *R*. *beticola* and *U*. *beticola*.

The disease assessment, for *E*. *betae* were on a 0-2.5 scale using an adapted Agronomica whole plant diagram.

Other foliar disease symptoms including *Pseudomonas*, *Phoma betae* Fr. and *Verticillium* spp. were estimated whole field in classes 1 (few) to 3 (many). *Verticillium dahliae* Kleb. was found the causal agent of the severe yellowing necrotising leaves called ‘yellow necrosis’ in the Netherlands (Schneider, 2010; Schneider et al., 2010).

3.3.8 Determination of sugar yield

Sugar content multiplied with the net sugar beet yield results in the sugar yield in Mg per hectare. Since harvest losses occur during the mechanical harvest of sugar beet, sugar yield based on factory delivered sugar beet do not represent the total grown sugar yield (Hanse and Tijink, 2010). Therefore, sugar yield was combined with the total harvest losses to obtain the total sugar yield. Losses are due to the breakage of taproots, losses of whole beets and losses due over topping. The harvest losses were measured using the protocol for harvest losses (Brinkmann, 1982), adapted to 400 sugar beets.

3.3.9 Statistical analysis

If variables were not normally distributed they were transformed using:

1) $y = \ln(x+1)$: *Trichodoridae*, *Pratylenchus*, *Meloidogyne*, *E*. *betae*, *R*. *beticola* and difenoconazole on both soil types, *H*. *schachtii,* BNYVV, *U*. *beticola* cyproconazole and trifloxystrobin on clay soil, *H*. *betae* and *C*. *beticola* on sandy soils.

2) $y = \arcsin(\sqrt{\frac{x}{100}})$: *A*. *cochlioides* and other foliar symptoms;

3) Box-Cox transformation with λ = 2.5: *Rhizoctonia* index on sandy soils;

4) no transformation: sugar yield, *Rhizoctonia* index on clay soil, *C*. *beticola* on clay soil, *U*. *beticola* on sandy soils, cyproconazole and trifloxystrobin on sandy soils, pH, number of fungicide applications and date of first application, epoxiconazole, fenpropimorph, previous sugar beet crop, sowing and harvest date on both soil types.

Differences between top and average growers were analysed by a Mixed Models approach. Grower type was a fixed effect and pair number and year random effects.

The effect of pathogens was estimated using multiple regression. General Linear Regression was used and variables were added to the model stepwise. A variable was only left in the model if the model had improved significantly and the effect of the variable on the dependent variable was significant. All statistical analyses were done separately for both soil types, as a result of initial statistical analysis. For the statistical analysis the GenStat package (12th edition) was used (Payne et al., 2009).

3.4 Results

The pairs of top and average growers differed on average by 2.3 and 2.4 Mg ha^{-1} in average sugar yield (2000-2004) for clay and sandy soils, respectively (Table 3.1). During 2006-2007, the top growers had significant higher sugar yields on both clay and sandy soils (2.6 and 2.3 Mg ha^{-1}, respectively) than average growers.

Table 3.1. The average sugar yield for four years (2000-2004) applied for selection of top and average growers compared to the sugar yield realised during the SUSY-project (2006-2007) on clay versus sandy soils.

	Clay		Sand	
	2000-2004	2006-2007[a]	2000-2004	2006-2007[a]
Average (Mg ha^{-1})	10.0	11.3	8.8	10.5
Top (Mg ha^{-1})	12.3	13.9	11.2	12.8
LSD 5%	0.41	0.95	0.55	0.77
F-probability	<0.001	<0.001	<0.001	<0.001

a. Sugar yield delivered to the sugar factory, without harvest losses.

The top growers used a cruciferous catch crop more often [oil radish (*Raphanus sativus* L. subsp. *oleiformis* Pers.) or white mustard (*Sinapsis alba* L.) sown between seasons of regular planting] compared to the average growers (Table 3.2). Catch crops were used more often on clay soils, although a large proportion of the growers (53% on clay and 68% on sandy soils) did not sow any catch crop.

Only two growers on clay soil sowed a partially nematode-resistant sugar beet variety while one top grower sowed a sugar beet variety without specific resistance in 2006. On sandy soils all varieties sown were partially rhizomania-resistant, and both top and average grower of four pairs used varieties partially resistant to *R*. *solani*.

On all fields *C*. *beticola* was present with an infestation level of 1.37 (on a 0-5 scale; Table 3.3). At least one of the other foliar symptoms (*Pseudomonas*, *P*. *betae* and *Verticillium* spp. combined) was also found on all fields. *U*. *beticola* and *E*. *betae* were present on 86% and 81% of the fields with a mean infestation level of 0.32 and 0.30, respectively (both on 0-5 scales; Table 3.3). *R*. *beticola* was found in 54% of the fields. For all leaf-infecting diseases there were almost no differences in incidence between sandy and clay soils. *H*. *schachtii* and Rhizomania (BNYVV) were mainly found on clay soils, while *H*. *betae*, *Trichodoridae* and *A*. *cochlioides* were mainly found on sandy soils. BNYVV was detected in only 10% of the sandy soils fields but the infestation level was too low for quantification. *Pratylenchus* spp. were abundant on both soil types and present in 93% of the fields investigated. *Meloidogyne* spp. were present in 57% of the fields with varying levels of infestation. No infestation with *Ditylenchus* spp. or damage by insects was found in the fields investigated.

Table 3.2. Use and type of catch crop before sugar beet growing and the type of sugar beet variety sown by top and average growers during the SUSY-project (2006 -2007).

Soil type	Grower	Catch crop before sugar beet			Sugar beet variety resistant to:			
		Cruciferous	Non-cruciferous	None	Rhizomania	*Rhizoctonia*[a]	Beet cyst nematode[a]	None specific
Clay	Average	5	8	19	31	-	1	-
	Top	12	5	15	30	-	1	1
Sand	Average	2	2	16	12	8	-	-
	Top	6	3	11	12	8	-	-

a. Rhizoctonia and beet cyst nematode tolerant varieties also have rhizomania resistance.

Table 3.3. Mean, median, maximum and minimum of plant pathogen infestation and percentage infected fields of the growers of the Dutch SUSY study.

Pathogen	Infestation level				Infested fields		
	Mean	Median	Maximum	Minimum	Total no.	Clay (%)	Sand (%)
Heterodera schachtii[a]	206	0	6700	0	46	70	8
Heterodera betae[a]	11	0	665	0	13	0	33
Trichodoridae[b]	10	1	201	0	51	36	75
Pratylenchus[b]	414	210	1933	0	93	89	100
Meloidogyne[b]	75	2	1917	0	57	52	65
BNYVV[c]	1.4	0.0	13.8	0.0	46	69	10
Aphanomyces cochlioides[d]	25	0	100	0	38	11	80
Cercospora beticola[e]	1.37	1.26	3.89	0.10	100	100	100
Ramularia beticola[e]	0.36	0.13	2.03	0.00	54	55	53
Uromyces beticola[e]	0.32	0.06	1.63	0.00	86	84	88
Erysiphe betae[f]	0.30	0.06	1.59	0.00	81	81	80
Foliar symptoms[g]	1.3	1.0	3.0	1.0	100	100	100

a. eggs + larvae 100 ml^{-1} soil; b. number of nematodes 100 ml^{-1} soil; c. MPN = most probable number of infective units 100 ml^{-1} soil; d. % diseased plants; e. Maximal severity: 0 = no infection to 5 = all leaves dead; f. Maximal severity: 0 = no infection to 2.5 = all leaves dead; g. index of symptoms: 1 = few to 3 = many.

Natural infestation in the bio-assay of *R*. *solani* was found in 1.6% and 15% of clay and sandy soils, respectively. Soil of all fields proved conducive to *R. solani* infection, however with a large variation in degree of suppressiveness (Table 3.4). A high degree of suppressiveness (low disease index, max = 1) was found in 17% of the samples, although it could not protect all seedlings from *R. solani* infection. The level of soil suppressiveness in clay soils was higher than in sandy soils (P = 0.017).

On clay soils, the top growers produced higher yields compared to average growers (Table 3.5). Top growers had significantly lower infestation levels of *H. schachtii* (P = 0.008), BNYVV (P = 0.016) and other foliar symptoms (*Pseudomonas*, *P*. *betae* and *Verticillium* spp. combined; P <0.001) by factors of 4.4x, 2.7x and 1.5x, than the average growers, respectively. For the other pathogens, the infestation levels did not differ significantly between grower types. The top growers sowed sugar beet 5 days earlier (P = 0.035) and had 1.4x more fungicide applications (P = 0.003) and thus used also 1.4x more epoxiconazole (P = 0.033) and 1.5x more fenpropimorph (P = 0.025) fungicide applications.

On sandy soils the top growers had a higher yield compared to the average (Table 3.5). Infestation levels of *Meloidogyne* spp. (P = 0.016), *C*. *beticola* (P = 0.005) and *E*. *betae* (P = 0.027) were significantly lower (5x, 1.4x and 1.8x, respectively) for the top growers. No significant differences in infestation levels were observed for the other pathogens. The top sowed 6 days earlier (P = 0.008) and made 1.7x more fungicide applications (P<0.001) and used 1.7x more epoxiconazole and fenpropimorph (P = 0.022) than the average growers. The first fungicide application by top growers was 10 days (P = 0.035) earlier compared than average growers.

Table 3.4. Bioassay results of soil suppression against *Rhizoctonia solani* and natural infestation of *R. solani* in soils of sugar beet production fields in the SUSY-project (2006-2007).

Soil type	Infestation	Mean[a]	Median[a]	Maximum[a]	Minimum[a]	Infested fields (%)
Clay	Natural	0.00	0.00	0.25	0.00	1.56
	Artificial	1.52	1.52	2.73	0.17	-
Sand	Natural	0.04	0.00	0.50	0.00	15.0
	Artificial	2.28	2.43	3.00	0.42	-

a. index: 0 = healthy to 3 = dead. Positive controls showed no suppression and a disease index 2.0 and 2.1 in 2006 and 2007, respectively.

On sandy soils, the best multiple regression model revealed significant influences of *H*. *betae*, fungicide applications, *A*. *cochlioides* infestation and sowing date on sugar yield (Table 3.6). This model explained 71% of the variance in sugar yield on sandy soils. Additional parameters did not change the model significantly. By selecting the *H. betae* infestation as the first model term, the explained variance of sugar yield remained 71% and the significance of the individual model terms did not change. When sowing date was left out of the model the explained variance dropped to 68%.

On clay soils, multiple regression explained 35% of the sugar yield variance (Table 3.6). The model showed the significant influence of BNYVV, *H. schachtii* and sowing date on sugar yield. Further addition of variables to the model caused no significant changes of the model. The coefficient of determination was 0.22 when sowing date was omitted from the model. On clay soil, a variety without resistance to rhizomania was grown on one field (Table 3.2). To estimate the effect of the data from this field (MPN 100 ml^{-1} soil = 1.03; sugar content at harvest 14.4%), all data from this field was left out of a next multiple regression model. However, the result of multiple regression did not change (Table 3.6).

Table 3.5. Probability of difference between and (back) transformed means of sugar yield and sugar beet pathogen infestation levels in fields of top and average growers of the Dutch SUSY study on sand and clay soils.

Variable	Sand			Clay		
	Average	Top	F-probability	Average	Top	F-probability
Sugar yield (Mg ha^{-1})[a]	11.0	13.2	<0.001	12.0	14.4	<0.001
Heterodera schachtii (eggs + larvae 100 ml^{-1} soil)	-	-	-	70	16	0.008
Heterodera betae (eggs + larvae 100 ml^{-1} soil)	3	1	0.167	-	-	-
Trichodoridae (# 100 ml^{-1} soil)	4	3	0.357	1	2	0.080
Pratylenchus (# 100 ml^{-1} soil)	438	472	0.862	72	55	0.447
Meloidogyne (# 100 ml^{-1} soil)	10	2	0.016	5	5	0.935
BNYVV (MPN 100 ml^{-1} soil)	-	-	-	0.72	0.27	0.016
Aphanomyces cochlioides (% diseased plants)	71	53	0.220	-	-	-
Rhizoctonia index (index 0-3)	2.40	2.37	0.821	1.59	1.46	0.376
Cercospora beticola (Max. severity 0-5)	1.81	1.29	0.005	1.29	1.15	0.257
Ramularia beticola (Max. severity 0-5)	0.27	0.23	0.503	0.31	0.34	0.540
Uromyces beticola (Max. severity 0-5)	0.42	0.26	0.166	0.32	0.18	0.072
Erysiphe betae (Max. severity 0-2.5)	0.32	0.13	0.027	0.34	0.20	0.079
Foliar symptoms (1-3)	1.1	1.0	0.573	1.6	1.1	<0.001
Sowing date	11-4	5-4	0.008	4-4	30-3	0.035
Harvest date	31-10	3-11	0.301	21-10	24-10	0.419
Previous sugar beet crop (years ago)	4.7	5.0	0.683	4.9	5.4	0.220
Fungicide applications (#)	1.1	1.9	<0.001	1.2	1.7	0.003
First fungicide application (date)	17-8	7-8	0.035	14-8	8-8	0.134
cyproconazole (g ha^{-1})	5	5	0.972	0.5	0.5	0.931
difenoconazole (g ha^{-1})	2	3	0.411	0.8	2	0.226
epoxiconazole (g ha^{-1})	62	104	0.022	74	105	0.033
fenpropimorph (g ha^{-1})	186	308	0.022	213	311	0.025
trifloxystrobin (g ha^{-1})	12	12	0.972	0.6	0.6	0.942
pH KCl	5.3	5.1	0.291	7.3	7.3	0.522

a. Sugar yield corrected for harvest losses.

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Table 3.6. Multiple regression equations and parameter estimates of sugar yield to pest and disease variables on sand and clay soils in Dutch sugar beet production. Data SUSY-project 2006-2007.

Soil type	Regression equation[a]	Model		C			m			n			p			q		
	Sugar yield =	P	R^2	Mean	SE	P[b]	Mean	SE	P[b]	Mean	SE	P[b]	Mean	SE	P[b]	Mean	SE	P[b]
Clay	C - m(*H. schachtii*) - n(BNYVV) - p(Sowing date)	<0.001	0.35	21.57	2.11	***	0.29	0.08	***	1.25	0.33	***	0.07	0.02	***			
	C - m(*H. schachtii*) - n(BNYVV)	<0.001	0.22	14.43	0.41	***	0.24	0.09	**	1.02	0.35	**						
Clay[c]	C - m(*H. schachtii*) - n(BNYVV) - p(Sowing date)	<0.001	0.35	21.54	2.15	***	0.29	0.08	***	1.25	0.33	***	0.07	0.02	***			
	C - m(*H. schachtii*) - n(BNYVV)	<0.001	0.23	14.44	0.41	***	0.25	0.09	**	1.03	0.35	**						
Sand	C + m(Fungicide applications) - n(*H. betae*) - p(*A. cochlioides*) - q(Sowing date)	<0.001	0.71	15.97	2.15	***	1.20	0.28	***	0.41	0.12	**	1.01	0.38	*	0.04	0.02	*
	C - m(*H. betae*) + n(Fungicide applications) - p(*A. cochlioides*) - q(Sowing date)	<0.001	0.71	15.97	2.15	***	0.41	0.12	**	1.20	0.28	***	1.01	0.38	*	0.04	0.02	*
	C + m(Fungicide applications) - n(*H. betae*) - p(*A. cochlioides*)	<0.001	0.68	11.56	0.67	***	1.38	0.28	***	0.34	0.12	**	1.26	0.38	**			

a. Data of variables *H. schachtii*, *H. betae* and BNYVV (ln x + 1)-transformed, *A. cochlioides* arcsin- transformed and sowing date non-transformed.
b. Significance: *** = p ≤ 0.001; ** = p ≤ 0.01; * = p≤ 0.05.
c. Data of the only field no rhizomania-resistant variety was sown, left out of analysis.

3.5 Discussion

The higher yield of the top growers is inherent to the selection criterion of at least 1.5 Mg sugar ha^{-1} difference in average sugar yield (2000-2004) between the top and average grower within a pair. This high-yielding effect of top growers clearly continued in both years that the SUSY-project was conducted. The top growers had higher yields under similar production circumstances (soil, climate and region) and the same levels of total inputs expressed monetarily (Hanse et al., 2010). We supply evidence that part of the yield difference between the two types of growers can be attributed to pests and diseases. Relatively more fields on sandy soils were naturally infested with *R*. *solani* than on clay soils where the level of soil suppressiveness was higher (P = 0.017). On both soil types soil suppressiveness against *R*. *solani* was found independent of grower type. The occurrence and extent of soil suppressiveness against *R*. *solani* in sugar beet fields was measured in this project. The occurrence of soil suppressiveness (17% of the field samples), demonstrated its existence in sugar beet fields. However, further research is needed to determine its usefulness as a tool for control of *R. solani* in the field. To date control of *R*. *solani* depends mainly on agronomical measures and the use of partially resistant varieties (Buttner et al., 2002). This also explains why both top and average growers used partially resistant varieties in the regions were *R*. *solani* crown and root rot occurs.

Insect pests were not observed at levels damaging to sugar beet in the fields studied. This can be ascribed to the insecticide treatment of the seeds in those areas where insect pests can cause yield losses (Heijbroek and Huijbregts, 1995b). When the insecticides in seed pellets are no longer available, severe yield losses by the Pygmy beetle (*Atomaria linearis* Steph.) (Kuethe, 1998) or *Beet yellows virus* and *Beet mild yellowing virus,* both mainly transmitted by *Myzus persicae* Sulz., can occur (Stevens et al., 2004).

Although a large proportion of the growers did not use a catch crop before growing sugar beet, the top growers used a cruciferous catch crop more often. These catch crops can be used as an agronomical measure to decrease the population densities of *H*. *schachtii* (Niere,

2009) and *H*. *betae* (Raaijmakers, 2009) if resistant varieties are used. The benefits in economical terms can vary from small to substantial, depending on initial infestation levels. The costs compared to the total variable costs in sugar beet production are negligible. On clay soils *H*. *schachtii* infestation levels in the top growers' fields were significantly lower. Long-term use of cruciferous catch crops could explain this. On both soil types multiple regression showed a significant negative influence of beet cyst nematode infestation level on sugar yield. Reducing the infestation level of beet cyst nematodes in general (by e.g. growing resistant catch crops) and growing varieties partially resistant to beet cyst nematode is a possibility for raising sugar yields on both soil types.

On clay soils BNYVV inoculum concentrations were lower for the top growers. Except for one field in 2006, rhizomania-resistant varieties were grown on all clay soil fields. Plants of partially rhizomania-resistant varieties can still be infected by BNYVV (Scholten et al., 1994; Heijbroek et al., 1999), which might lead to an increase of inoculum potential in the soil. Although the BNYVV infestation levels found in this study were low, they were found to be negatively correlated with sugar yield in the multiple regression on clay soils. The multiple regression model did not change when the data from the field without a rhizomania-resistant variety was left out of the analysis. The finding of a negative influence of BNYVV infestation on clay soil sugar yield, even when resistant varieties were grown, causes concern. It may be supposed that the continuous growing of partially resistant varieties has selected for resistance breaking strains (Liu et al., 2005) and requires further investigation. On sandy soils the rhizomania infestation level had no influence on sugar yield, since on only 10% of the fields BNYVV was detected, but the infestation level was too low for quantification. The BNYVV vector (*Polymyxa betae* Keskin) is favoured by warm and humid conditions. Sand warms faster than clay but also dries out much faster. This would prevent infection by zoospores and explains the low MPN values detected.

The multiple regression explained up to 35% of the variation in sugar yield on clay soils, with *H*. *schachtii* and BNYVV as the most important pathogens.

In addition to the already mentioned negative effect of *H*. *betae*, the number of fungicide applications increased, and the infestation with *A*. *cochlioides* and sowing date decreased, sugar yield on sandy soils. The top growers had significantly more fungicide applications and were more effective controlling *C*. *beticola* and *E*. *betae*. This explains the significant effect of the number of fungicide applications on sugar yield. In the Netherlands a system of supervised control was developed to assure sugar yield and prevent unnecessary or untimed fungicide applications (Vereijssen et al., 2007). Since the top growers sprayed 10 days earlier, it seems that they pick up this extension message earlier.

The infestation levels of *A*. *cochlioides* obtained from the climate room test showed a negative relation with sugar yield, while in the field no severe *A*. *cochlioides* symptoms were observed. Earlier research showed that the fungicides on the seed pellet were sufficient to control *A. cochlioides* damage to seedlings on conducive soils, but in severely infested trial fields plant losses occurred later in the season (Heijbroek and Huijbregts, 1995a). More research is needed on *A*. *cochlioides* on sandy soils to clarify the relation between the measurements in the climate room and the reduced yield, which occurs without hardly any symptoms in the field.

In total the multiple regression explained 71% of the variance in sugar yield on sandy soils and 68% when the sowing date was left out.

On both soil types early sowing is profitable for sugar yield. The earlier sowed sugar beet fields had higher yields, which may be due to an increased interception of the yearly available radiation due to earlier canopy closing (Werker and Jaggard, 1998; Kenter et al., 2006), but also to a partial escape from BNYVV and *H. schachtii* damage (Webb et al., 2000; Stevens et al., 2006) on clay soils. On sandy soils, the effect of early sowing might be explained by the optimised radiation uptake. An other explanation could be the development of resistance by the seedlings, before *A*. *cochlioides* and *R*. *solani* activity is enhanced by the warming of the soil (Asher and Hanson, 2006).

Reducing the impact of pathogens is important for speeding up sugar yields. The variance in sugar yield explained by pests and diseases is lower on clay soils than on sandy soils. On both soil types, but especially on clay soils also the soil structure is important for sugar yield formation. On both soil types, other agronomy factors such as sowing performance and harvest losses, influence sugar yield, in addition to the continuous reduction of yield by pests and diseases.

The achieved yields, including crop protection measures, of top and average growers on sandy and soils were 57.4 and 47.8% and on clay soils 62.6 and 52.2% respectively, of the attainable sugar yield in the Netherlands, being 23 t ha^{-1} (De Wit, 1953). The yield loss due to pests and diseases can be estimated from the explained variance in sugar yield on sandy and clay soils (71 and 35%; Table 3.6). Thus, in spite of the crop protection measures already taken, yield losses to pests and diseases for top growers are still 30.2 and 13.1% and for average growers 37.1 and 16.7% on sandy and clay soils respectively. The average yield losses (24%) due to pest and diseases in sugar beets when crop protection measures are conducted, found in this study are quite similar to the estimated 26% yield losses world wide (Oerke and Dehne, 2004). However, a huge difference exists between soil types and grower types. Optimizing crop protection can increase sugar yield (3.6% on clay and 6.9% on sandy soils) in the Netherlands, when the average growers improve towards the level of the top growers. Even the top growers can improve their efforts in crop protection (e.g. growing a beet cyst nematode partial resistant variety, which is also omitted by most top growers with high nematode infestation), their figures (30.2 and 13.1%) are still very high. From other studies on increasing yield and comparing farmers in sugar beet in Sweden (Berglund et al., 2002) and starch potato in the Netherlands (Wustman, 2003) it was stressed that pests and diseases were important. However, a clear figure of yield loss compared to attainable yield could not be deduced, except for sugar beet in Sweden where 1%-point of fungal attack was reported to lower sugar yield by 0.4 Mg per hectare. Other studies mainly focused on the inputs made by the growers to use those in estimating the cost (Starcke and Bahrs, 2009) or efficiency of production (Fuchs and Stockfisch, 2009), and did not determine field variables. By comparing similar farms with an equal starting point in time on soils freshly reclaimed from the sea (so without soil borne plant pathogens), agronomical variables were measured in addition the inputs, but no data on pests and diseases were collected (Zachariasse, 1974). Clearly there is an influence of the grower on the infestation levels of pests and diseases in sugar beet production, which contributes to the difference in sugar yield between the top and average growers in the SUSY-project. The skills and knowledge of the growers, or grower performance is crucial to achieve high yields. Recently in animal science the importance of attitude was stressed (Jansen et al., 2009). This effect was also noticed in the SUSY-project, where some of the average growers were able to increase yield during the project, mainly due to a change in attitude towards sugar beet production (Hanse et al., 2010). The pathogen infestation levels in the fields of those growers could not explain their lower yields in the past and several of them started fungicide applications when they joined the project. The possibility of raising yields suddenly by a change in attitude is an intriguing point of agricultural production. It raises the question whether the average sugar beet growers are average performing for all the crops on their farms or excellent growers of e.g. potatoes. This calls for a total farm approach in stead of a single crop approach like the SUSY-project. This project yielded much information on yield reducing factors of sugar beet production, suggesting that it is worthwhile to conduct pair-wise comparisons of growers with measurements in the fields for other crops as well. To provide sufficient food for the expected 9 billion people in 2050, crop yields have to be raised. Grower performance is worth attention because getting average (or even below-average) growers to the level of top growers will have a ‘large and inexpensive effect on productivity’ (Jaggard et al., 2010). Supporting evidence is clearly shown in this publication. Higher yields, with the same costs, also increase the profitability for the grower (Hanse et al., 2010).

The communication of knowledge to growers about how and when to conduct the right crop protection measures remains vital in raising yields and safeguarding food, feed and bio-energy production.

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4 Analysis of soil characteristics, soil management and sugar yield on top and averagely managed farms in sugar beet (*Beta vulgaris* L.) production in the Netherlands

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4 Analysis of soil characteristics, soil management and sugar yield

4.1 Abstract

Within the Speeding Up Sugar Yield (SUSY) – project soil management and soil characteristics were investigated as possible causes of yield difference between 26 ‘type top’ and 26 ‘type average’ growers, top and average performance being based on past yield data. Growers were pair-wise selected so that pairs were located at close distance and had the same soil type. In the project years 2006 and 2007 the top growers had 20% ($P < 0.001$) higher sugar yields than the average growers.

Mean saturated hydraulic conductivity in the subsoil (Ks) was significantly higher for ‘type top’ growers than for ‘type average’ growers, 0.49 and 0.31 m day^{-1}, respectively. Mean Ks was below a damage threshold level of 0.10 m day^{-1} on 34% of the average growers’ fields and on 27% of the top growers’ fields. Ks was 0.00 m day^{-1} on 9% of all fields. The relative importance of this figure is discussed in this paper. In multiple regression analysis without the factor grower type, 15.3% of the variability of Ks was explained by a model with the terms fine sand fraction (50-105 μm) in the subsoil and depth of primary tillage (D_{pt}; m).

‘Type top’ growers basically made use of comparable equipment, but applied lower tyre inflation pressures and a lower number of field operations for seedbed preparation and their drilling date was earlier in time compared with ‘type average’ growers. This did not result in a significant difference in mean air-filled porosity at field capacity in the topsoil (AP) between grower types although the number of fields with an topsoil AP in the 10-15 cm layer below 10% was lower in the group of top growers (13 fields) than in the group of average growers (18 fields).

Direct effects of soil management on AP could be established in statistical analysis without the factor grower type, but may have been influenced because both management characteristics and AP appeared to be strongly related to top soil clay content.

A statistical model with AP of the topsoil and Ks of the subsoil could explain 24.9% of the variation in sugar yield in Dutch sugar beet production. Therefore under the given conditions

of soil type (clay content), a better soil structure can be influenced by the grower, resulting in a higher sugar yield.

4.2 Introduction

The recent reform of the EU sugar market caused a 39.7% price drop of sugar beet in 2009 compared to 2006 (EC, 2001; Zeddies, 2006). Studies on the total variable costs in Dutch sugar beet production proved that potential costs reduction is possible up to of 20% (Pauwels, 2006), and that sugar yield was independent of the costs made by growers (Hanse et al., 2010). Thus it was concluded that improvement of competiveness should be found in maximisation of sugar yield and in optimizing costs.

The potential sugar yield in The Netherlands is 23 Mg ha^{-1} (De Wit, 1953) and in Germany 24 Mg ha^{-1} (Kenter et al., 2006). As the average sugar yield achieved by Dutch growers was 10.6 Mg ha^{-1} in the period 2002-2006, there is great potential for further improvement. Additionally, a large variation in average yields of growers in the same area exists, according to records of the sugar industry (Agricultural Service, 2007). The pair study ‘Speeding Up Sugar Yield’ (SUSY) was conducted to improve the average yield in the Netherlands by studying possible causes of sugar yield differences in a pair-wise comparison of neighbouring growers that had high yields (‘type top’) and average yields (‘type average’) under the same conditions of soil type and climate. In this study top growers had 20% higher yields compared with the average growers in the same region (Hanse et al., 2010).

The sugar beet crop requires high-quality seedbeds (Hakansson et al., 2006), is susceptible for top soil compaction (Koch et al., 2009) and benefits from a profile enabling rooting to deep soil layers (Windt, 1995). Therefore diverse temporal soil structure parameters were measured in the SUSY pair study, providing data about the actual status of the soil structure on 104 sugar beet fields in the Netherlands.

The effects of soil compaction on yield and quality varies in crops and are related to depth and severity at which it occurs, as well as to seasonal effects and crop stage (Batey, 2009).

For topsoil air-filled porosity at field capacity (AP) a damage threshold of 10% (v/v) is often reported (Bakker and Hidding, 1970; Grable, 1971; Boone et al., 1986). For the saturated hydraulic conductivity (Ks) of the subsoil, a damage threshold of 0.10 m day^{-1} was established (Lebert et al., 2004). Below those damage thresholds crop yield levels can be adversely influenced by soil structure.

The aim of this paper is to present: a) the soil characteristics of sugar beet production fields in the Netherlands; b the differences in management aspects, soil characteristics and crop characteristics on farms managed by 'type top' and 'type average' growers; and c) the relationships between observed soil management, soil characteristics and subsequent sugar yield.

4.3 Materials and methods

4.3.1 Selection of grower pairs and plots

Two types of growers were selected for the study, 'type top' and 'type average' growers. A grower was considered 'type top' when his sugar yields in the period 2000-2004, were consistently greater than the 75th percentile of the sugar yields in the region. Likewise, a grower was considered 'type average' when his sugar yields were consistently between the 25th and 75th percentile of the sugar yields. Pairs were formed by one 'type top' and one 'type average' grower, with a difference in sugar yield of at least 1.5 Mg ha^{-1} based on the mean yield in the period 2000-2004.

For the study 26 pairs (52 growers) were selected who participated both in 2006 and in 2007. Growers were pair-wise selected so that pairs were located close together (average distance was 5.5 km) and had similar soil and field characteristics. Pairs were located all over The Netherlands on various soil types in sugar beet producing regions. Per grower three representative plots on one field per year were selected, on which all measurements and observations were done. Plots did not include headlands, field sides, crop nursery tramlines and field parts, recognisable as deviant shortly after sowing.

4.3.2 Soil management observations and soil measurements

To explain possible differences found in soil structure characteristics, a survey on various soil management parameters was conducted under 'type top' and 'type average' growers. Recorded were: rear tyre inflation pressure during primary tillage (P_{pt}), depth (D_{pt}) of primary soil tillage, width ($TW_{st\ front}$ and $TW_{st\ rear}$) and inflation pressure ($P_{st\ front}$ and $P_{st\ rear}$) of front and rear tyres and number of passes for seedbed preparation (n_{st}).

Intrinsic soil characteristics that influence soil structure and yield, such as pH, $CaCO_3$ content, organic matter content, clay content, silt and sand content were determined from samples taken from the topsoil (0-30 cm) and the subsoil (30-45 cm) to be used as covariates in the statistical analysis of the effect of soil structure on sugar yield.

Soil structure was characterised by the penetration resistance in spring, the total porosity and the air-filled porosity in the topsoil, and the saturated hydraulic conductivity in the ploughpan area. Penetration resistance (PR) was measured by taking 6 penetrations up to 80 cm depth per plot, using an Eijkelkamp electronic penetrometer (cone top angle 60 degrees; base area 1.0 cm^2) in spring, soon after drilling. Total porosity (P) and air-filled porosity at -10 kPa soil water matric pressure (AP) were determined according to Kuipers (1961). The soil was sampled in the 10 – 15 cm depth layer early in the growing season (April-June). In all sampling, on each plot 8, cores of 100 cm^3 were taken at random.

The saturated hydraulic conductivity (Ks) was determined according to Klute and Dirksen (1986), using an Eijkelkamp soil water permeameter. The measuring time was chosen to be maximal 24 hours. Sampling was done in the layer with highest penetration resistance (PR_{ks}) observed in the soil profile up to 60 cm depth (2006) or 45 cm depth (2007), assuming Ks to be lowest in that layer. On each plot 7 cores of 100 cm^3 were collected for the determination of Ks. In some plots, where high penetration resistance was clearly not caused by compaction but by a layer of different soil texture (sand), the measured Ks was excluded from statistical analysis (in 2006) or the Ks samples were taken just above the layer with different soil texture (in 2007).

4.3.3 Crop measurements

Sowing date (D_s) and subsequent canopy closure date usually have a large effect on sugar yield were recorded to be used as a covariate in yield analysis. The canopy closure date (D_{cc}) was devined as the first date on which sugar beet leaves of adjacent rows touched each other and was assessed 5-6 times in May-June.

Maximum rooting depth (RD) was determined in summer, once on each plot, by visual assessment of the soil profile up to 120 cm depth, in an excavated pit.

Sugar yield ($SY_{harvest}$) was obtained by multiplying the mean sugar content with the mean root yield of the total field under investigation. $SY_{harvest}$ was positively corrected for the total harvest losses, resulting in the total sugar yield (SY). Harvest losses, due to the breakage of taproots, losses of whole beets and deep topping, occur during the mechanical harvest of sugar beets and were measured using the protocol for harvest losses (Brinkmann, 1982; Vandergeten et al., 2004), adapted to a sample size of 400 sugar beet.

4.3.4 Analysis of the data

To reveal the general situation of the soil characteristics found on Dutch sugar beet production fields, Ks and AP data for each soil type were compared with the threshold values for soil compaction that are suggested in literature and the relationship with soil texture was evaluated.

Statistical analysis was used to evaluate the differences between ‘type top’ and ‘type average’ growers and the more generalized relationships between soil management, soil characteristics, crop characteristics and crop growth

For all statistical analysis the statistical package GenStat (Payne et al., 2008) was used. Non-normally distributed variables were transformed to variables with a normal distribution using logarithmic transformation (pH, P_{pt}, D_{pt}, clay content, silt content and $CaCO_3$ content). Box-Cox transformation was used for organic matter content (λ=-0.8 for organic matter content of the topsoil and λ=-0.2 for organic matter content in the subsoil), and arcsin transformation after an initial ln (x+1) transformation for Ks.

The differences in characteristics of soil management, soil type, soil structure and crop growth between 'type top' and 'type average' growers were analysed using the Mixed Models procedure (REML) separately for each characteristic. In these analyses the fixed factor was grower type and the random factor was chosen to be region + year + pair number to keep the 'type top' and 'type average' growers belonging to the same pair together and correct for region and year influences.

In an effort to confirm relationships between soil management and the resulting soil and crop characteristics found between 'type top' and 'type average' growers, multiple regression was used without the factor grower type. By excluding grower type in the analysis interference of differences between grower types in other management such as nutrients and crop protection, with the effects of soil were avoided. Some intrinsic soil characteristics, such as pH, $CaCO_3$ content, organic matter content and soil texture, and the crop characteristic sowing date, were investigated as covariates in the statistical analysis.

4.4 Results

4.4.1 Soil characteristics of sugar beet fields in the Netherlands

On 9% of all fields covering all soil types, Ks was found 0.00 m day^{-1} (Figure 4.1). The mean Ks per field was for 43% of loam, 17% of loamy sand, 53% of sandy loam, 44% of silt loam and all silty loam fields below 0.10 m day^{-1}. Similarly, 31% of all the fields, 34% of 'type average' fields and 27% of 'type top' fields had a Ks below 0.10 m day^{-1} (Figure 4.1; table 4.1).

The share of the fields with a mean AP below 10% (v/v) was 44%, 35%, 81%, 100% and 100% for silt loam, sandy loam, loam, clay loam and silty clay loam soils, respectively (table 4.1). These differences between soil type reflect the strong dependency of AP and clay content (R^2 = 0.79; P < 0.001), which is illustrated in figure 4.3. Mean AP was below 10% (v/v) in 25% of the fields of 'type top' growers and in 35% of the 'type average' growers' fields (Figure 4.2).

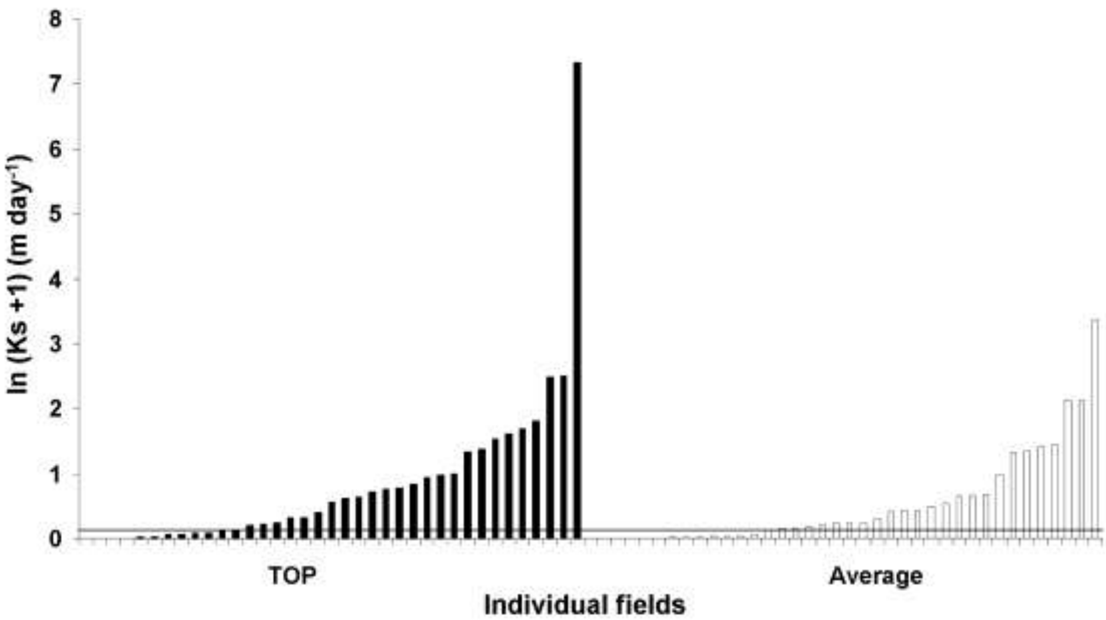

Figure 4.1. Distribution of the field average of the saturated hydraulic conductivity (Ks, m day-1) of soils in Dutch sugar beet production. The line represents the transformed ln (0.10 +1) m day-1 damage threshold (Lebert et al., 2004). Data ln(Ks+1) transformed, *SUSY-project 2006-2007.*

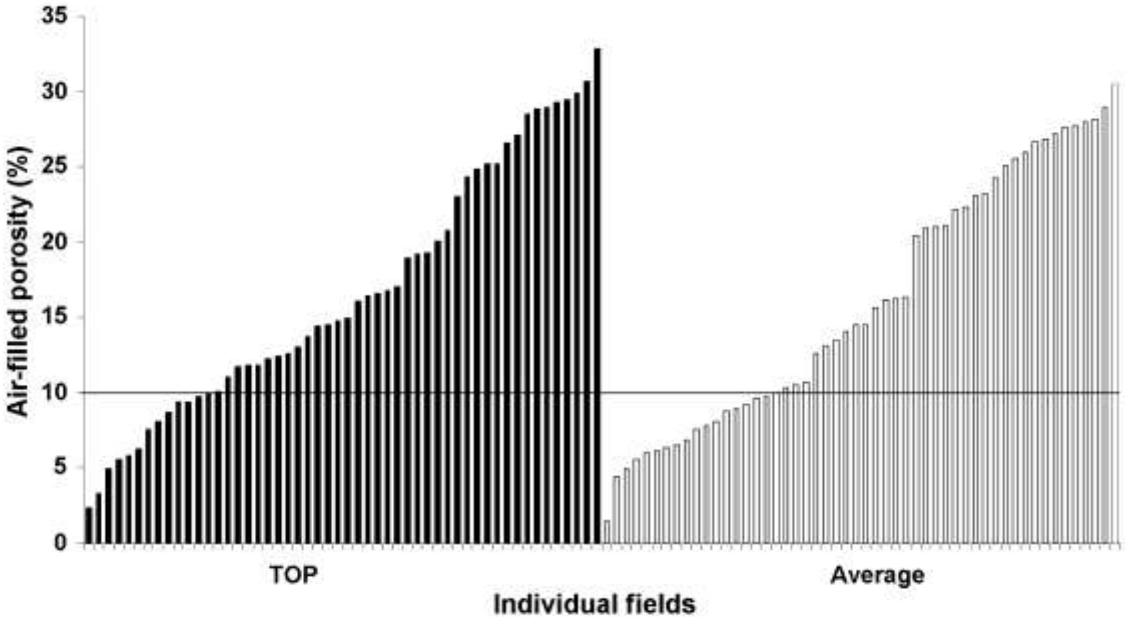

Figure 4.2. Distribution of the field average of the air-filled porosity (AP, %) of soils in Dutch sugar beet production. The line represent the 10% (v/v) damage threshold (Bakker and Hidding, 1970; Boone, 1986 and Grable, 1971). *Data SUSY-project 2006-2007*.

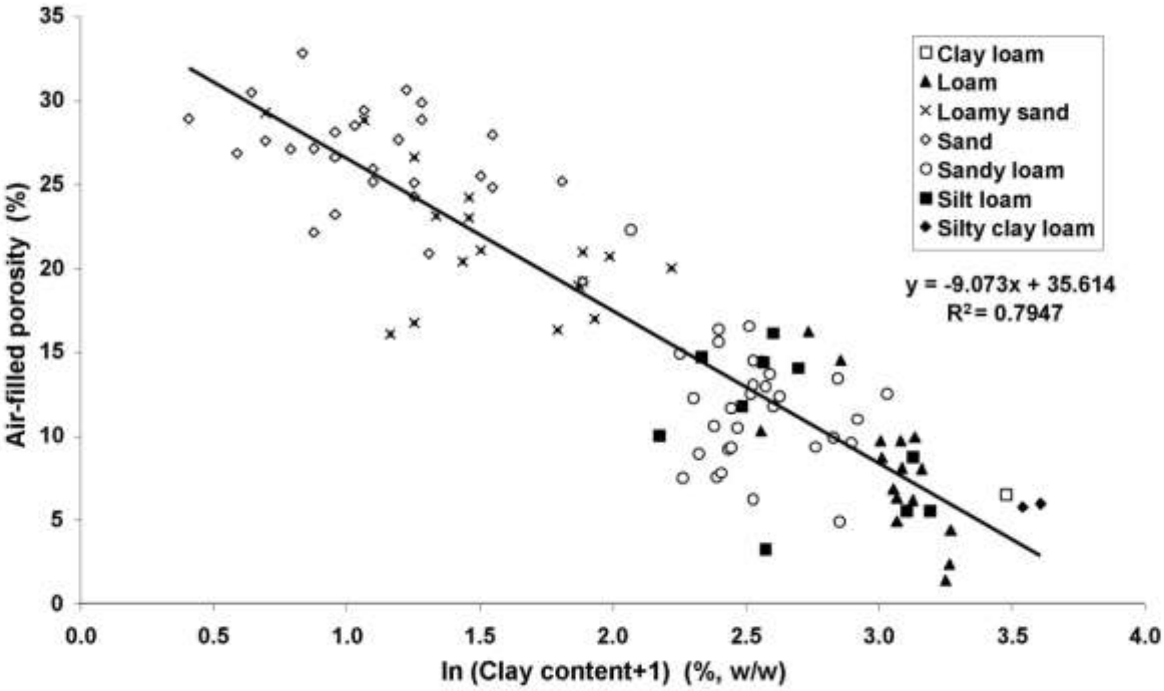

Figure 4.3. Relation of air-filled porosity (%) to natural log transformed clay content (%, w/w) on fields (n=104) in the SUSY-project (2006-2007).

Table 4.1. Topsoil (0-30 cm) analytical data of the fields (n=104) in the SUSY-project (2006-2007).

Soil type[a]	Fields (#)	Organic material (%, w/w)	$CaCO_3$ (%, w/w)	pH	Arithmetic mean AP[b] (%)	Arithmetic mean Ks[b] (m day^{-1})
Sand	27	8.0	0.1	5.1	26.7 (18.1 - 34.1)	2.85 (0.00 - 78.2)
Loamy sand	17	5.0	0.8	6.0	21.3 (13.9 - 30.6)	2.06 (0.00 - 21.9)
Sandy loam	31	2.9	4.6	7.4	11.8 (3.5 - 23.9)	0.80 (0.00 - 32.5)
Silt loam	10	5.1	2.3	6.8	10.4 (2.7 - 17.1)	168.7 (0.00 - 4508)
Loam	16	4.0	5.1	7.3	8.0 (1.0 - 16.7)	1.50 (0.00 - 16.2)
Clay Loam	1	4.7	9.4	7.4	6.5 (4.8 - 7.8)	0.56 (0.00 - 1.65)
Silty clay loam	2	7.7	4.8	7.3	5.9 (4.9 - 7.1)	0.01(0.00 – 0.01)

a. Soil textural classes according to the USDA system (Soil Survey Staff, 1993).
b. Minimum and maximum of all measured values between brackets.

4.4.2 Differences between 'type top' and 'type average' growers

The only significant difference in intrinsic soil characteristics between 'type top' and 'type average' growers was a small difference in pH (table 4.2), indicating that the objective to compare these grower types on the same soil type has been achieved.

Soil and crop management differed between grower type. While tractor weight and tyres used (TM_{st}, $TW_{st\ front}$ and $TW_{st\ rear}$) were equal, top type growers used lower tyre inflation pressures (P_{pt}, $P_{st\ front}$ and $P_{st\ rear}$), needed less passes for seedbed preparation (n_{st}) and were earlier with sowing (D_s) than average type growers.

Statistically significant differences ($P < 0.05$) in soil structure between grower types were observed only for the total porosity of the top soil, P, and the saturated hydaulic conductivity in the subsoil, Ks. The difference in P was relatively small, but P was significantly higher for 'type top' growers compared with 'type average' growers, respectively 49.0 and 48.2% (table 4.2). The air filled porosity at field capacity, AP, showed a trend to be higher for 'type top' growers than for 'type average' growers. However, as AP is generally considered to have a closer relationship with yield than P, AP was also considered in the analysis of factors that could be responsible for yield differences (section 4.3.3). Ks was significantly higher for 'type top' compared with to 'type average' growers' fields, respectively 0.49 and 0.31 m day^{-1}

(table 4.2). The depth of highest penetration resistance and the penetration resistance at Ks sampling depth were equal for both grower types.

Crops of 'type top' growers showed earlier canopy closure (D_{cc}), deeper rooting (RD), and higher sugar yield than crops of 'type average' growers. All crop growth variables were significantly different between both grower types: SY and RD were higher, while sowing date and canopy closure date were significantly earlier for 'type top' growers.

4.4.3 Effects of soil type and management on soil structure and subsequent crop growth

Statistical models could be established in which soil management aspects explained up to 33% of the variance of AP (table 4.3). However, just as AP (Figure 4.3), also the management characteristics of seedbed preparation appeared to be strongly related to the clay content of the top soil. With increasing clay content of the topsoil, tyre inflation pressures ($P_{st\ front}$ and $P_{st\ rear}$) decreased, the width of the tractor tyres ($TW_{st\ front}$ and $TW_{st\ rear}$) increased, the tractor weight (TM_{st}) decreased and the number of passes for seedbed preparation (n_{st}) increased (table 4.3). When both topsoil clay content and the management variables were taken together into multiple regression models, all of the soil management variables ($P_{st\ front}$, $P_{st\ rear}$, $TW_{st\ front}$,$TW_{st\ rear}$, TM_{st} and n_{st}) did not add more than 1% extra to the explained variance of AP by topsoil clay content (79.5%).

Ks increased with decreasing fine sand fraction (50-105 μm) and with increasing depth of primary tillage (mainly ploughing). A statistical model with the parameters could explain 15.3% of the variance of Ks (table 4.4). Model calculation with a fine sand content of 37% (mean in the experiments) suggest that Ks increased by 58% when D_{pt} increased from 0.27 m (mean of average growers) to 0.29 m (mean of top growers).

Table 4.2. Characteristics of soil, soil management, soil structure, crop management and crop growth for 'type top' and 'type average' growers. *Data SUSY-project 2006-2007.*

Soil and crop characteristics	**Predicted means[a] for**		
	'type average'	**'type top'**	**F-prob.**
Top soil			
Clay content (%, w/w)[b]	7.9	7.7	0.484
Silt content (%, w/w)[b]	15.3	15.6	0.952
$CaCO_3$ content (%, w/w)[b]	1.4	1.3	0.347
Organic matter content (%, w/w)[c]	3.5	3.6	0.564
pH[b]	6.5	6.4	0.018
Soil management			
Inflation pressure rear tyre (P_{pt}; kPa)[b]	117	107	<0.001
Depth primary tillage (D_{pt}; m)[b]	0.27	0.29	0.004
Seedbed preparations (n_{st})	1.3	1.1	<0.001
Tractor weight (TM_{st}; kg)	4877	4877	0.991
Inflation pressure front tyre ($P_{st\ front}$; kPa)	112	99	<0.001
Inflation pressure rear tyre ($P_{st\ rear}$; kPa)	103	87	<0.001
Width front tyre ($TW_{st\ front}$; m)	0.42	0.43	0.185
Width rear tyre ($TW_{st\ rear}$; m)	0.66	0.65	0.207
Crop management			
Drilling (date)	8-4	3-4	<0.001
Soil structure			
Depth of highest penetration resistance (m)	0.37	0.37	0.648
Penetration resistance at Ks sampling depth (PR_{Ks}, MPa)[b]	2.57	2.62	0.586
Saturated hydraulic conductivity (Ks, m d^{-1})[d]	0.31	0.49	0.042
Top soil total porosity (P, %)	48.22	48.97	0.033
Top soil air-filled porosity (AP, %)	17.8	18.4	0.064
Crop growth			
Canopy closure (CC, date)	16-6	11-6	<0.001
Root depth (RD, m)	0.61	0.69	<0.001
Sugar yield (SY, Mg ha^{-1})	11.6	13.9	<0.001

a. backtransformed in case of transformation.
b. data ln(x+1) transformed.
c. data Box-Cox transformed (λ=-0.8).
d. data arcsin(ln(x+1)) transformed.

Table 4.3. Parameter estimates and summary statistics of linear regression relating the seedbed preparation management variables to clay content (%, w/w) and Air-filled porosity to seedbed preparation management variables of the top soil in Dutch sugar beet production fields. *Data SUSY-project 2006-2007.*

variate	ln(clay content (%, w/w) +1) [a]						Air-filled porosity [b]					
			Constant		Explained variance	P			Constant		Explained variance	P
	Estimate	s.e.[c]	Estimate	s.e.[c]	%		Estimate	s.e.[c]	Estimate	s.e.[c]	%	
Pressure front tyre ($P_{st\ front}$; kPa)	-0.29	0.03	1.66	0.06	29.9	<0.001	10.24	0.92	5.68	1.04	28.3	<0.001
Width front tyre ($TW_{st\ front}$; m)	0.02	0.01	0.37	0.02	1.3	0.023	-3.94	3.44	17.97	1.51	0.1	0.253
Pressure rear tyre ($P_{st\ rear}$; kPa)	-0.29	0.02	1.54	0.05	35.3	<0.001	12.29	0.99	4.90	1.00	33.2	<0.001
Width rear tyre ($TW_{st\ rear}$; m)	0.10	0.01	0.45	0.03	14.0	<0.001	-14.97	2.10	26.08	1.44	13.8	<0.001
Tractor weight (TM_{st}; kg)	-288.5	77.3	5416	176	4.0	<0.001	0.00	0.00	6.87	1.98	6.9	<0.001
Seedbed preparations (n_{st})	0.27	0.03	0.64	0.08	17.0	<0.001	-6.84	0.82	24.59	1.08	18.2	<0.001

a. Model: y = b0 + b1 x ln(clay content (%, w/w) +1).
b. Model: Air-filled porosity = b0 + b1 x variate.
c. s.e. is the standard error of parameter estimates.

Table 4.4. Description, estimated values and standard errors for the parameters in multiple linear regression[a] for the saturated hydraulic conductivity (Ks) of the subsoil in Dutch sugar beet production[b]. *Data SUSY-project 2006-2007.*

Parameter	Description	Estimate	s.e.	Probability
b_0	Constant	-0.1386	0.0541	0.011
b_1	Coëfficient for 50-105 µm subsoil sand content (%, w/w) (X_1)	-0.0008	0.0002	<0.001
b_2	Coëfficient for ln (Depth primary tillage (D_{pt}; m) + 1) (X_2)	0.0662	0.0163	<0.001

a. Model: arcsin(ln (Ks+1)/100) = $b_0 + b_1 \times X_1 + b_2 \times X_2$.
b. Explained variance 15.3%.

The effect of soil structure on sugar yield was best described by a statistical model with the terms AP, the interaction of AP and sowing date and the interaction of Ks and fine sand fraction in the subsoil. Such a model explained 24.9% of the variation of the sugar yield (table 4.5). A model with only sowing date explained 13.4%, a model with only AP explained 2.0% and a model with only Ks explained 4.6% of the variance in sugar yield (data not shown). Penetration resistance did not explain any of the variance in sugar yield.

Table 4.5. Description, estimated values and standard errors for soil structure parameters in multiple linear regression[a] for the sugar yield (SY) in Dutch sugar beet production[b]. *Data SUSY-project 2006-2007.*

Parameter	Description	Estimate	s.e.	Probability
b_0	Constant	12.54	0.28	<0.001
b_1	Coëfficient for air-filled porosity (AP, %) (X_1)	0.4829	0.0710	<0.001
b_2	Coëfficient for air-filled porosity (AP, %) x sowing date (X_2)	-0.0051	0.0007	<0.001
b_3	Coëfficient for arcsin(ln (Ks+1)/100) x subsoil 50-105 µm sand content (%, w/w) (X_3)	0.3299	0.0880	<0.001

a. Model: SY = $b_0 + b_1 \times X_1 + \ldots + b_3 \times X_3$.
b. Explained variance 24.9%.

4.5 Discussion

The pair study 'Speeding Up Sugar Yield' (SUSY) studied possible causes of sugar yield differences in a pair-wise comparison of neighbouring 'type top' and 'type average' growers. The 'type top' growers yielded 2.3 Mg ha^{-1} more sugar compared to the 'type average' growers, while the intrinsic soil properties did not differ for both grower types. Thus the 'type top' growers performed better under the same environmental conditions and Hanse et al. (2010) showed that they had comparable costs to the 'type average' growers too. Part of the difference in sugar yield can be attributed to soil structure. The soil structure, topsoil AP and subsoil Ks, explained (although in interaction with sowing date and subsoil sand content) 24.9% of the total sugar yield in Dutch sugar beet production. Thus the effect of soil structure is interwoven with the positive effect of early sowing date on sugar yield. The latter is due to an increased interception of the yearly available radiation due to earlier canopy closing (Werker and Jaggard, 1998; Kenter et al., 2006). A better soil structure thus might facilitate early sowing.

A better use of equipment by the 'type top' growers was observed at seedbed preparation, were the used equipment (TM_{st}, $TW_{st\ front}$ and $TW_{st\ rear}$) was comparable but the inflation pressure ($TP_{st\ front}$ and $TP_{st\ rear}$) and the number of passes (n_{st}) to prepare the seedbed were significant lower for the 'type top' growers. However, this did not result in significant higher AP for the 'type top' growers. For AP, values below 10% are considered restricting crop growth (Bakker and Hidding, 1970; Grable, 1971; Boone et al., 1986). In this study 30% of the fields had a topsoil AP below this damage threshold, all of these soils had a clay content of 8.6% or more indicating also the strong relationship of AP with clay content. The strong relationship of both soil management characteristics and AP with clay content may have hindered discovery of the effects of soil management on AP.

On the clay soils with low AP the sugar yields are already on a high level, but could be improved when the aeration is optimised by soil saving traffic (Lamers et al., 1986; Vermeulen and Klooster, 1992; Vermeulen and Mosquera, 2008). On the other hand the sugar beet crop requires a slight compression of the topsoil for improved plant establishment and soil root contact (Tijink and Märländer, 1998). Growers on clay soil interact already to the relation of AP and clay content, which is shown by the reduction of tyre inflation pressure with increasing clay content in the topsoil. The results of this study show that future research on AP and pair wise comparison of farmers for soil structure should use clay content as a covariate in the analysis of the data.

Contrary to AP, 'type top' growers had a significantly higher Ks (subsoil structure) compared to 'type average' growers. Since the D_{pt} and subsoil sand content explain limited amount (15%) of the variance in Ks, it is likely that not all causes of the variance in Ks are revealed in this study. The influence of tyre inflation pressure on soil compaction is found in research all over the world (Davies et al., 1973; Soane et al., 1982; Van den Akker, 1998). Rear tyre inflation pressure at primary tillage (P_{pt}), mainly ploughing, was significant lower for the 'type top' growers, too. Although P_{pt} had no significant effect on the Ks in this study, the higher values for Ks of the 'type top' growers might be influenced by their equipment use. However, not only equipment use (low tyre inflation pressure and tillage depth) is important, also the soil conditions, mainly water content, under which the operations take place (Arvidsson and Hakansson, 1996; Batey, 2009). This factor was not included in this study for impossibility to measure soil conditions at 52 fields at the time operations take place, but for some grower pairs astonishing differences between top and average growers in soil conditions could be observed by eye.

Ks measured in the subsoil can be used as a indicator of subsoil compaction (Dawidowski and Koolen, 1987; Arvidsson, 2001). Subsoil compaction is of major concern in the present policymaking of the EU in developing the new soil directive (EC, 2006). The data on the Ks found in this study provide information on the extent of subsoil compaction in sugar beet growing in the Netherlands to feed policymaking. Ks was found below the damage threshold of 0.10 m day^{-1} (Lebert et al., 2004) on 31% of the fields, all located on clayey soils, while on 9% of all fields Ks was found 0.00 m day^{-1}. These figures seem to indicate severe subsoil compaction. However, a study in Lower Saxony (Germany) found 17% of the fields in the range of harmful soil compaction, all of them with subsoil Ks below the 0.10 m day^{-1} damage threshold (Brunotte et al., 2008). However visual structure analysis of these fields' profile revealed normal soil functioning. Only on tramlines and headlands harmful soil compaction was found. Similar results were obtained in Nordrhein-Westfalen (Germany) were visual structure analyses reduced the harmful subsoil compacted fields from 37% to 24% (Weyer, 2007). Thus laboratory analyses of soil samples might indicate agricultural fields under risk of harmful soil compaction, but they likely overestimate the amount of fields actually suffering harmful soil compaction. In this study, on all soil types, fields were found where one or more of the 3 plots had a Ks of 0.00 m day^{-1}, indicating spatial variability in local Ks and subsoil compaction on fields. Spatial variability on investigated fields is often reported (Strudley et al., 2008). The effect of this patchiness probably explains the rather low effect of Ks on sugar yield (4.6%). The effect of subsoil compaction on yield was reported 3-5% in other studies as well (Chamen et al., 2003). Although the effect of subsoil compaction on yield is rather small, it has a long lasting nature (Hakansson and Reeder, 1994). Therefore, subsoil compaction can also influence yield of other crops, grown in rotation with sugar beet. Crops differ susceptibility to soil compaction and the average yearly yield loss is estimated 11.4% (Arvidsson and Hakansson, 1996). It can be expected that the effect of Ks in the subsoil will affect yields more severe in seasons with excessive rainfall. In those seasons the 'type top' growers are in a better position to escape the negative effect of too much water in sugar beet production.

Ks in this study could be partially explained by the nature of the subsoil (50-105 µm subsoil sand content (%, w/w)) and the depth of primary tillage (D_{pt}). Ks and D_{pt} were both significant higher for 'type top' growers. Soil compaction can be alleviated by tillage operations (Spoor et al., 2003; Hamza and Anderson, 2005; Batey, 2009). However for those operations loosening is at depths through or just below the compacted zone. In this study the Ks was measured below the depths of the farmers' tillage operations. This leaves the question whether tillage treatments just above the compacted zone, effects biological or physical processes increasing Ks. The predicted effect (58%) of 0.02 m increased tillage depth on subsoil Ks is substantial.

Whereas other authors found a significant effect of top soil penetration resistance on sugar yield (Koch et al., 2009), penetration resistance of the top soil had no effect on sugar yield in this study. This is most likely due to the deeper primary tillage operation, alleviating too high top soil penetration resistance on fields in this study. Fields were mainly ploughed, with primary tillage depths ranging from 0.19 – 0.43 m. Other researchers also found a significant effect of ploughing on sugar yield (Koch et al., 2008; Bollman and Sprague, 2009; Koch et al., 2009).

Finally, next to a good soil structure, other variables, like the management of pests and diseases, have proven important in the SUSY pair study for improving sugar yield too (Hanse et al., 2011). For future pair studies of growers next to the already mentioned clay content, research should find a way to exclude these other yield influencing variables. Then the effect of growers management on soil structure, and of soil structure on yield can be estimated without bias.

4.6 Conclusions

- The fields of higher yielding ‘type top’ growers had higher Ks and thus less subsoil compaction compared to the ‘type average’ growers.
- Ks influenced sugar yield. Low Ks values were found on about one third of the fields in this study indicating the extent of the subsoil compaction in Dutch sugar beet production.
- Depth of primary tillage and the nature of the soil (sand content subsoil) explained the Ks.
- ‘Type top’ growers made better use of the same equipment at seedbed preparation, although the AP in topsoil of ‘type top’ growers was not different from average growers.
- AP depended strongly on clay content in the topsoil. Clay content explained also tyre inflation pressure at seedbed preparation. Thus the growers interacted with the soil type.
- In dependency of subsoil sand content and sowing date, Ks and AP explained 24.9% of variance in sugar yield.

4.7. References

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5 Harvesting losses ... How to yield this hidden financial potential

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5 Harvesting losses … How to yield this hidden financial potential

5.1 Abstract

As part of the pair study SUSY (Speeding Up Sugar Yield) harvest yield losses were measured during 3 years (2006, 2007, and 2008) on in total 150 sugar beet fields in the Netherlands. Losses by overtopping, root breakages, and of whole beet were measured according the IIRB standard measuring method. Average losses (3 t ha^{-1}) were on a similar level as in an earlier study in 1976. The same holds for the maximum losses (up to 10 t ha^{-1}). Results will be presented and ways to help practise to yield this hidden financial potential.

5.2 Introduction

Within the SUSY (Speeding Up Sugar Yield) pair study sugar beet growers with a high yielding history (‘type top’) were compared with neighbouring average yielding growers (‘type average’) (Hanse, et al., 2010). During the three years of the SUSY-project (2006-2008) harvest losses were measured to correct the yield data and to obtain updated data of harvest performance on fields. The last available data on harvest losses in Dutch sugar beet production originated from 1976. Then average harvest losses were 3 t ha^{-1} ranging from 0.3 to 10.1 t ha^{-1} with mainly 6 row harvesters (Andringa and Bouma, 1977).

Mechanical harvest of sugar beets implies to find an optimum between harvesting the grown crop without losses, meeting high quality standards: undamaged and low tare in a cost efficient way (Tijink, 2007). Sugar beets in the Netherlands are mainly lifted by 6 row tanker harvesters owned by contractors.

In theory, reducing harvest losses could easily raises the amount of paid sugar beets and thus reduce unit costs sugar beet, due to the fact that more of the grown sugar beets are delivered to the factory and not left in the field. Therefore it should be known how large the harvest losses are and whether progress is made over the last 30 years or not.

5.3 Materials and methods

Harvest losses were measured on 150 fields during the SUSY-project (2006-2008). Each year on 52 fields (both 26 fields of ‘type top’ and ‘type average’ growers) measurements were done, except for 2008 when on 46 fields harvest losses were collected. Harvest losses were measured according the IIRB standard measuring method, adapted to 400 beets (Brinkmann, 1982; Vandergeten et al., 2004). Measurements were done at or shortly after harvest time.

In the SUSY-project, costs of growing sugar beets were recorded, including harvest costs (Hanse et al., 2010).

Data were analysed using the statistical package GenStat, 12th edition (VSN International Ltd.). Linear mixed models were used to analyse the effect of year, grower, soil type and their interactions in the fixed model. The given pair number, region and their interaction were used as random terms to analyse the 'type top' and 'type average' within a pair directly with each other.

5.4 Results and discussion

During the SUSY-project at 93% of the fields sugar beets were lifted by contractor owned machines, while only a few growers harvested the sugar beets with own equipement. On average the cost for sugar beet lifting were 347 € ha^{-1} (range: 249-410 € ha^{-1}), including transportation from the field to the storage clamp. Harvest costs were with 25% a considerable part of the total variable growing costs in Dutch sugar beet production (Hanse et al., 2010).

Average harvest losses of the 2006-2008 period are shown in figure 5.1. The results indicate that 2.9 t ha^{-1} sugar beets was left in the Dutch sugar beet fields. The minimum total losses found were 0.45 t ha^{-1}, the maximum 9.1 t ha^{-1}. Those results are in line with the losses found 30 years ago (Andringa and Bouma, 1977). Despite an era of engineering and steadily increasing sugar yield, the absolute level of harvest losses stayed the same.

With an acreage of about 70,000 ha only reducing the 0.56 t ha^{-1} of whole beet losses, may result in nearly 40,000 tons of extra sugar beets to be processed in the Netherlands. The maximum of whole beet losses was found 4.62 t ha^{-1}, which is a financial loss of 162 € ha^{-1}, about half the harvest costs.

The same holds for the 0.68 t ha^{-1} of losses due to overtopping. Since 2006 the top tare is not fined (nor paid) by the Dutch sugar industry, making those losses unnecessary. Reducing the losses due to root breakages might be the hardest of all three. Those losses depends, besides good machine adjustment, also on the conditions under which the sugar beets are harvested.

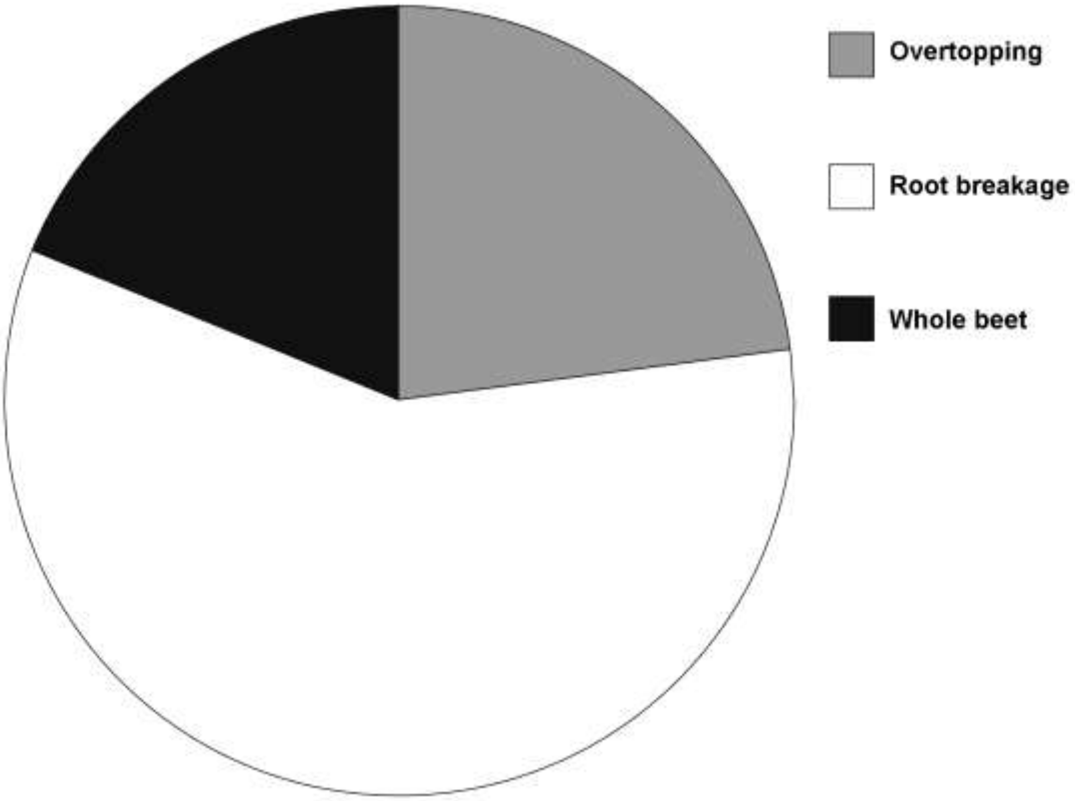

Figure 5.1. Average harvest losses in Dutch sugar beet growing. Average total losses were 2.9 t ha^{-1}. Data SUSY-project 2006-2008 (n=150).

The total harvest losses and losses due to root breakage did not differ significantly between 'type top' and 'type average' growers (table 5.1). The losses due to overtopping and whole beet losses did differ significantly between grower types, both were lower at the fields of 'type top' growers. This might be due to a more even or less gappy stand of the sugar beets.

Table 5.1. Harvest losses on the fields of 'type top' and 'type average' growers in Dutch sugar beet production. Data SUSY-project 2006-2008.

Grower type	Harvest losses by:			
	Overtopping (t ha^{-1})	Breakages (t ha^{-1})	Whole beet (t ha^{-1})	Total (t ha^{-1})
Top	0.55	1.71	0.34	2.72
Average	0.70	1.60	0.57	3.03
P	0.007	0.121	<0.001	0.088
lsd 5%	0.08	0.19	0.09	0.35

The considerable amount of yield left in the fields urged for improvement of the awareness of the growers and harvester drivers about the harvest losses. The IRS initiated in cooperation with the Dutch sugar industry a series of field days and an harvester driver instruction day. On these days the central theme was how to reduce harvest losses and what is the allowed quality concerning top tare. During the field days the effect of machine adjustment was demonstrated by small clamps of sugar beet, harvested with the same machine with different adjustments. In addition those different adjustments were demonstrated with that machine in the field.

The instruction day of harvester drivers was also organised in cooperation with three harvester manufacturers, and the union of contractors. From each brand one machine was present in the field and 32 drivers got the challenge to reduce, all together, the harvest losses with the machine of their own brand assisted by technicians of the manufacturer. Thus they were not only in the role of student but were also able to share and exchange their skills and experience with their colleagues.

The idea behind creating awareness of both growers and drivers for the harvest losses was that they can cooperatively reduce the harvest losses to the minimum possible under the given circumstances. Both the field days and the harvester drivers' instruction day were highly appreciated by the participants.

5.5 Conclusions

With on average 2.9 t ha^{-1} a considerable amount of yield was left in the fields of Dutch sugar beet growers. The harvest losses in the SUSY-project were as high as they were 30 years ago. The 'type top' growers did not have lower total harvest losses as had the 'type average' growers. Reducing the harvest losses is a relatively easy and efficient way to improve harvested yields and profitability of the sugar beet crop. It takes both grower and driver of the harvester to reduce harvest losses.

Demonstrations, training and extention service was aimed to reduce harvest losses in the Netherlands.

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6 Epilogue

6 Epilogue

6.1 Introduction

The recent reform of the European Union's Common Agricultural Policy (CAP) implied an 39.7% decrease in sugar beet price for growers (Zeddies, 2006) and cause a substantial impact on farmers' income. Therefore, the Dutch sugar industry and sugar beet research initiated a project on the competitiveness of the sugar beet crop in the Netherlands. This SUSY (Speeding Up Sugar Yield) project from 2006-2008 aimed at finding options to increase sugar yield and to identify cost savings. Data gathered from type top (high yield) growers were compared with data from neighbouring type average (average yield) growers.

The analysis revealed no difference of total variable costs (input levels) between the crops of both grower types, while the type top growers had 2 t ha^{-1} higher sugar yields for all years of the study, concluding that raising sugar yield is possible with identical input (Hanse et al., 2010).

The analysis of differences in yield unexpectedly showed a 24% reduction of sugar yield by pests and diseases, despite crop protection measures (Hanse et al., 2011a). Another important, but rather elastic, factor turned out to be the temporal soil structure, explaining 24.9% of the variation in sugar yield. The saturated hydraulic conductivity of the subsoil was below the damage threshold in 31% of the fields and the air-filled porosity in 30% of the fields. The type top growers' fields had a significant better temporal subsoil structure compared to those of the type average grower (Hanse et al., 2011b). Finally, at harvest 3 t ha^{-1} of sugar beets remained on the fields of both type top and type average growers with no significant difference between both grower types for the total losses (Hanse and Tijink, 2010).

The respective results have been compiled in three articles (one published, one accepted, one submitted).

This epilogue deals with the not yet published agronomical variables and the management influence of the grower on those variables. Those agronomical factors concern fertilization (chapter 6.2), sowing (chapter 6.3) and weed control (chapter 6.4) of the sugar beet crop. The aim is to (1) differentiate between type top growers and type average growers and (2) to analyse the potential influence of agronomical factors on the sugar yield.

6.2 Fertilization with main and trace elements

6.2.1 Materials and methods

The data were obtained within the project ‘Speeding Up Sugar Yield’ (SUSY) of the Dutch Institute of Sugar Beet Research, IRS, Bergen op Zoom comparing pair-wise fields with different yield capacity. In both 2006 and 2007, 26 pairs (52 growers) were available. In 2008, data of 23 ‘type top’ and 22 ‘type average’ growers were available. This was due to the exclusion of 2 pairs from which the ‘type average’ sold the sugar quota and of 3 growers which did not fully complete the questionnaire.

Each pair was formed by a field of a type top and a type average grower, based on the sugar yields of 2000-2004. Farms of the growers within a pair were located closely together on the same soil type (average distance between fields of a pair was 5.5 km, with a maximum 29.6 and minimum 0.19 km). Pairs were located throughout The Netherlands on both sandy (<5% lutum) and clay soils (>5% lutum) in sugar beet producing regions.

A grower was considered to belong to the type top group when the sugar yields were on average during 2000-2004 and in each single year consistently greater than the 75th percentile of the sugar yields in the region the farm was situated. Likewise, a grower was considered ‘type average’ when the sugar yields were consistently between the 25th and 75th percentile of the sugar yields. Pairs of type top and type average farmers were formed based on a difference in sugar yield of at least 1.5 tons ha-1 (5 years average). Regions were defined as agricultural area’s with 4,000 – 10,000 ha of sugar beet production (6-10% of the total sugar beet production area) on a comparable soil type. For each grower one field per year was included in the study. For more details, see the material and methods section of the publication on costs and yields in chapter 2 for more details (Hanse et al., 2010).

Data on fertilizer application were recorded by the growers. At maximum expansion of leaf canopy (BBCH 46), all leaves of 5 randomly chosen successive plants were sampled in four replicates. Leaves were washed, air dried and analysed for mineral content. At harvest, 20 sugar beets were randomly collected from the clamp and washed, air dried and analysed for mineral content. Both, leaf and root content of Na, K, Mg, Ca, P, Mn, Zn, Fe, Cu, B was determined in dry matter using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) and of Co, Mo using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Soils were sampled in February-March and early June and analysed for mineral availability with $CaCl_2$-extraction and near infrared spectroscopy (NIRS). The leaf, root and soil content data is only available for 2006 and 2007 and based on 104 fields, in total. All chemical analyses for leaf, root and soil content of main and trace elements were done at Blgg AgroXpertus (Oosterbeek, The Netherlands). The sugar beet quality components, sugar content, Na, K and amino-N in roots were analysed in the sugar factory’s tare house, according to the standardized method in the Netherlands (De Bruin et al., 2006).

Non normal distributed data (Soil N February-March, Available N April, Soil N June, Soil K_2O February-March and soil K_2O and leaf Ca, Co, Fe, Mg, Mn, S, Zn and dry matter content and root Ca, Co, Fe, Mg, Mn, S and N-total) were ln(x+1) or ln(x+280) (Mineralised N) transformed in order to obtain normalised variables. Presented means and estimated constants are all back transformed.

Data were analysed using the statistical package GenStat, 12th edition (VSN International Ltd.). Linear mixed models were used to analyse the effect of year, grower, site and their interactions in the fixed model. The given pair number, region and their interaction were used as random terms to analyse the type top and type average growers’ effect within a pair directly with each other (Thissen, 2009).

Linear regressions were calculated to estimate the effect of single variables on sugar yield.

6.2.2 Results

Both type top and type average growers applied the same amount of B, K_2O, MgO, Na_2O, N, P_2O_5 and SO_3 to sugar beet (Table 6.1). The only significant difference was found for Mn, however the type top growers applied only 0.05 kg Mn ha^{-1} more. Linear regression showed that none of the elements applied had a significant effect on sugar yield, except for K_2O. However, the slope equals zero and the coefficient of correlation (R^2) was very low. Applied K_2O had no influence on root yield and sugar content, too and was thus estimated as non-relevant (data not shown).

Table 6.1 Application of elements from mineral and organic fertilizer by type top and type average growers and effect on sugar yield, linear regression (y = ax + b). *SUSY-project, the Netherlands, 2006-2008.*

Element	Grower type			Effect on sugar yield		
	Average	Top	Significance[a]	a	R^2	Significance[a]
B (kg ha^{-1})[b]	0.24	0.26	n.s.	-0.28	0.00	n.s.
K_2O (kg ha^{-1})	177	166	n.s.	0.00	0.03	*
MgO (kg ha^{-1})	30	42	n.s.	-0.10	0.00	n.s.
Mn (kg ha^{-1})	0.02	0.07	*	1.72	0.00	n.s.
Na_2O (kg ha^{-1})[c]	20	24	n.s.	-0.14	0.02	n.s.
N (kg ha^{-1})	128	123	n.s.	-0.26	0.01	n.s.
P_2O_5 (kg ha^{-1})[d]	51	36	n.s.	0.00	0.02	n.s.
SO_3 (kg ha^{-1})	20	24	n.s.	-0.16	0.02	n.s.

a. n.s. = not significant; * = significant at $p \leq 0.05$.
b. significant soil type effect ($p \leq 0.05$; clay 0.10 and sand 0.39 kg ha^{-1}).
c. significant soil type effect ($p \leq 0.01$; clay 3.5 and sand 118.1 kg ha^{-1}).
d. significant soil type effect ($p \leq 0.01$; clay 22.2 and sand 81.4 kg ha^{-1}).

Table 6.2 Soil N and K_2O contents in February-March and June (0-60 cm) on fields of type top and type average growers. *SUSY-project, the Netherlands, 2006-2007.*

	Grower type		Significance[a]
	average	top	
Mineral N February-March (kg ha^{-1})	36	36	n.s.
Available N April (kg ha^{-1})[b]	176	192	n.s.
Mineral N June (kg ha^{-1})	180	174	n.s.
Mineralised N (kg ha^{-1})[c]	12	-18	n.s.
K_2O February-March (kg ha^{-1})	207	235	n.s.
Available K2O April (kg ha^{-1})[b]	440	445	n.s.
K_2O June (kg ha^{-1})	243	270	n.s.

a. n.s. = not significant.
b. Applied (see Table 6.1.1) plus mineral N respectively K_2O February-March.
c. Mineral N in June minus Available N April.

There were no differences between the fields of both grower types for crop available N and K_2O at all sampling dates (Table 6.2) and none of the variables had influence on linear regression, too (data not shown).

At the end of August, the crops of type top growers had taken up significant more Mg and Zn, and less Fe in the leaves compared to the type average growers (Table 6.3). Although the dry matter content of the leaves was the same for both grower types. For all growers participating, leaf dry matter yield varied between 2.0 and 8.0 t ha^{-1}, with an average of 4.9 t ha^{-1} and were significantly higher for type top growers. Linear regression showed a significant effect of leaf dry matter yield, Ca, K, Mg and Mn content on sugar yield. However, only the leaf K content had a positive slope and thus a positive effect on sugar yield.

Only the root Ca content at harvest was significantly lower in the crops of type top growers compared to type average growers (Table 6.4). Contents of all other elements were on similar levels in the crops of both grower types. The root dry matter content did not differ between both grower types. However, due to the higher root yield of the type top growers' crop, the root dry matter yield was significantly higher, too. Zn, Na and Mn were the only elements in the root having a significant effect on sugar yield, although the coefficients of correlation were very low.

The amino-N content in freshly harvested sugar beet was closely positive related to the total-N content in the sugar beets (figure 6.1). The average root yield (including tops, excluding harvest losses) for the crops of all fields was 76.7 t ha^{-1} causing a nitrogen removal of 110 kg N ha^{-1} (Table 6.5). The leaves (on average 42.5 t ha^{-1}) removed 118 kg N ha^{-1}. Due to the same total N and dry matter content in both leaves and roots (Tables 6.3 and 6.4) the crops of the type top growers had a removal of 129 and 123 kg N ha^{-1} and the crops of the type average growers 108 and 98 kg N ha^{-1}, respectively for leaves and roots.

Table 6.3 Content of mineral elements in dry matter of sugar beet leaves harvested at maximum expansion of leaf canopy (end of August; BBCH 46) on fields of type top and type average growers. *SUSY-project, the Netherlands, 2006-2007.*

Element	Mean	Grower type			Effect on sugar yield		
	(max – min)	Average	Top	Significance[a]	a	R^2	Significance[a]
B (mg kg^{-1})	38.3 (61 – 24)	37.3	38.7	n.s.	0.01	0.00	n.s.
Ca (g kg^{-1})	11.2 (19 – 5)	11.2	10.7	n.s.	-2.06	0.05	*
Co (µg kg^{-1})	100.1 (584 – 42)	99.4	91.4	n.s.	-0.36	0.01	n.s.
Cu (mg kg^{-1})	7.6 (13 – 4)	7.89	7.76	n.s.	-0.04	0.00	n.s.
Fe (mg kg^{-1})	237.1 (1173 – 82)	235	198	**	0.13	0.00	n.s.
K (g kg^{-1})	42.0 (61 – 23)	41.4	42.3	n.s.	0.05	0.04	*
Mg (g kg^{-1})	4.7 (11 – 1)	4.84	5.25	*	-1.71	0.07	**
Mn (mg kg^{-1})	48.5 (365 – 12)	53.8	58.8	n.s.	-0.97	0.12	***
Mo (mg kg^{-1})	1.0 (2.5 – 0.3)	0.97	0.97	n.s.	0.67	0.02	n.s.
Na (g kg^{-1})	17.1 (31 – 6)	16.3	18.1	n.s.	-0.02	0.00	n.s.
N-total (g kg^{-1})	24.2 (35 – 15)	24.4	25.0	n.s.	-0.10	0.04	n.s.
P (g kg^{-1})	2.7 (5 – 1)	2.77	2.78	n.s.	0.14	0.00	n.s.
S (g kg^{-1})	2.8 (5 – 2)	2.72	2.81	n.s.	0.23	0.00	n.s.
Zn (mg kg^{-1})	52.5 (308 – 18)	58.9	69.3	*	-0.49	0.04	n.s.
Dry matter (%)	11.8 (20.9 – 9.4)	11.7	11.7	n.s.	-2.30	0.02	n.s.
Dry matter (t ha^{-1})	4.9 (8.0 – 2.0)	4.5	5.2	***	0.97	0.33	***

a. n.s. = not significant; *,**,*** = significant at p ≤ 0.05, ≤ 0.01, ≤ 0.001.

Table 6.4 Content of mineral elements in dry matter of sugar beet roots at harvest on fields of type top and type average growers. *SUSY-project, the Netherlands, 2006-2007.*

Element	Mean	Grower type			Effect on sugar yield		
	(max – min)	Average	Top	Significance[a]	a	R^2	Significance[a]
B (mg kg^{-1})	10.2 (14 – 7)	10.2	10.0	n.s.	0.16	0.01	n.s.
Ca (g kg^{-1})	1.8 (5 – 1)	1.7	1.6	*	-0.24	0.00	n.s.
Co (µg kg^{-1})	82.4 (460 – 38)	73.6	75.2	n.s.	0.29	0.01	n.s.
Cu (mg kg^{-1})	3.3 (5 – 1)	3.3	3.2	n.s.	0.02	0.00	n.s.
Fe (mg kg^{-1})	218.9 (1844 – 41)	173.2	189.6	n.s.	0.39	0.03	n.s.
K (g kg^{-1})	7.6 (12 – 5)	7.5	7.6	n.s.	0.09	0.00	n.s.
Mg (g kg^{-1})	1.2 (2 – 0.8)	1.2	1.2	n.s.	-3.88	0.03	n.s.
Mn (mg kg^{-1})	23.7 (169 – 7)	25.3	25.8	n.s.	-1.13	0.08	**
Mo (mg kg^{-1})	0.2 (1.6 – 0.2)	0.2	0.2	n.s.	-0.01	0.00	n.s.
N total (g kg^{-1})	5.8 (10 – 4)	5.8	6.0	n.s.	-1.07	0.01	n.s.
Na (g kg^{-1})	0.5 (1.4 – 0.1)	0.5	0.5	n.s.	-2.33	0.08	**
P (g kg^{-1})	1.2 (1.9 – 0.8)	1.2	1.2	n.s.	0.19	0.00	n.s.
S (g kg^{-1})	0.4 (0.6 – 0.2)	0.4	0.4	n.s.	-2.07	0.00	n.s.
Zn (mg kg^{-1})	21.6 (80 – 8)	24.0	26.3	n.s.	-0.73	0.04	*
Dry matter (%)	24.4 (28.5 – 19.4)	24.1	24.4	n.s.	0.26	0.04	*
Dry matter (t ha^{-1})[b]	18.7 (25.6 – 9.6)	16.7	20.2	***	0.61	0.90	***

a. n.s. = not significant; *,**,*** = significant at p ≤ 0.05, ≤ 0.01, ≤ 0.001.
b. Net root yield including top, excluding harvest losses.

Table 6.5 Leaf and root fresh weight and N-removal on fields of type top and type average growers. *SUSY-project, the Netherlands, 2006-2007.*

	Mean	Grower type		Significance[a]
		Average	Top	
Fresh leaf weight (t ha^{-1})	42.5	38.5	45.0	***
N-removal with leaf (kg ha^{-1})	118	108	129	***
Fresh root weight (t ha^{-1})[b]	76.7	69.1	82.8	***
N-removal root (kg ha^{-1})	110	98	123	***

a. *** = significant at $p \leq 0.001$.
b. Net root yield including top, excluding harvest losses.

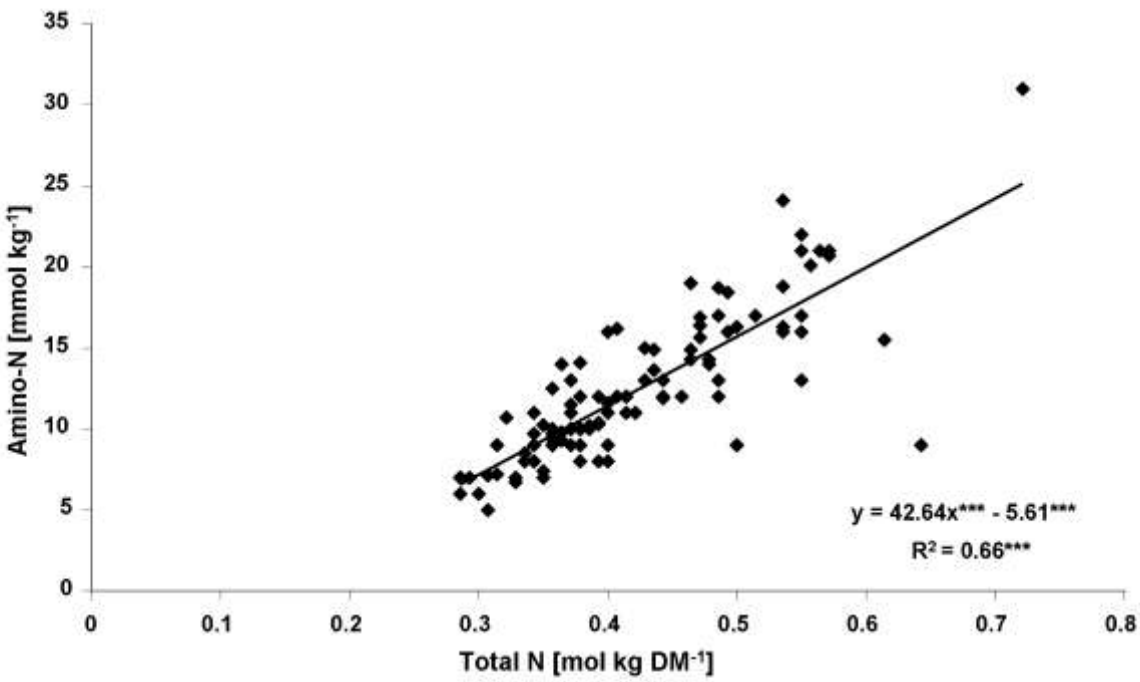

Figure 6.1 Relation of amino-N to total N in the dry matter of freshly harvested sugar beet roots. *** = significant at $p \leq 0.001$. *Data SUSY-project, The Netherlands, 2006-2007.*

6.2.3 Discussion

Only a few significant effects were found for the mineral content of leaves and roots. The negative effect of leaf Mg and Mn and root Mn and Zn content can be explained by higher levels in leaves and roots on sandy soils. Although the soil effect was not significant for each element, the levels were respectively 1.7x, 2.7x, 1.5x and 3.1x higher on sandy soils. The sandy soils had lower yield levels compared to clay soils (Hanse et al., 2010) so that the effect can be physiologically explained by concentration. Na is one of the elements determining the technical quality of sugar beet roots, explaining the negative effect of root Na content on white sugar yield, while Na interferes with the extractability of sugar from the molasses (Huijbregts, 1999).

Fertilization of sugar beets did not differ between the type top and type average growers in this project. No substantial effects of applied elements on sugar yield were found, since all were already in the optimal range for a high sugar yield (Wilting, 2010), i.e. fertilization did not restrict sugar yield. A likely explanation is the strict legal regulation on fertilisation in the Netherlands (Meststoffenwet, 2006; Meststoffenwet, 2009). This regulation causes a lot of farmers' attention for fertilisation (Ham et al., 2007). There is no need to change factors already optimised to increase yields. In order to increase yields, farmers' attention should go to the factors restricting yield, like pests and diseases (Hanse et al., 2011a), soil structure (Hanse et al., 2011b), harvest losses (Hanse and Tijink, 2010), sowing quality (chapter 6.3) and weed control (section 6.4).

Average root yield in the Netherlands increased from 57 t ha^{-1} in 2001 to 72 t ha^{-1} in 2008 and 79 t ha^{-1} in 2009, with sugar yields respectively 9.1, 12.3 and 14.0 t ha^{-1} (Van Swaaij, 2007; IRS, 2010). With the above mentioned growers' attention for fertilisation, growers express often their concern that due to recent years' yield increase, the nitrogen supply becomes limiting. Based on data from the SUSY project, the amino-N content in sugar beet roots was found a predictor of the removal of total-N from the fields (R^2 = 0.66). In 2001, 2008 and 2009, respectively, amino-N content decreased from 15.1 mmol kg^{-1} to 11.3 and 11.1 mmol kg^{-1}(IRS, 2010), implying a removal of 95, 98 and 106 kg N ha^{-1} with sugar beet roots. Due to the increased quality of the sugar beet during the years as a result of breeding efforts (Loel et al., 2010) the N demand stays on similar levels. There is a clear link between sugar beet yield level and sustainable production (Koeijer et al., 2002; Tzilivakis et al., 2005; Fuchs and Stockfisch, 2009). The data from the SUSY project is in line with the findings of those authors and show that breeding efforts for improved quality are not only profitable but also sustainable.

6.3 Sugar beet sowing

6.3.1 Materials and methods

Sowing and harvest date were taken from the registration of the growers joining the SUSY-project (see section 6.3.1). Canopy closure date was determined by the staff of the agricultural department of the sugar industry by visiting the fields 5 to 6 times in the period from May to June. Directly after sowing, sowing depth and seed placement in compressed (below the loose seedbed) and in humid (not dried by the weather) soil was recorded from 10 randomly chosen sites on each field. On each field four plots were randomly chosen, not disturbed by other measurements, 15 m long and 6, 12 or 18 rows wide, depending on the width of the sowing machine. During two months after sowing, plots were visited 4 times. Plants were counted after emergence in 2-4 leaf stage. At the fourth visit the drilling distance was recorded by measuring the cumulative distance from plant to plant on 4 times 10 m in the plots. From the data obtained, the average sowing distance and missing plants and field emergence rate were calculated. For comparison purposes data on sowing depth and distance were recorded by the growers. In 2006-2007, data of 104 fields were obtained. Non normal distributed data (missing seeds, seed in compressed soil, seed in humid soil and plant density) were ln(x+1) transformed in order to obtain normalised variables. Presented means and estimated constants were all back transformed. Data were analysed using the statistical package GenStat, 12th edition (VSN International Ltd.). Linear mixed models were used to analyse the effect of year, grower, site and their interactions in the fixed model. The given pair number, region and their interaction were used as random terms to analyse the type top and type average growers effect within a pair directly with each other (Thissen, 2009).

Linear regressions were calculated to estimate the effect of single variables on sugar yield.

6.3.2 Results

The type top growers sowed sugar beets significantly five days earlier compared to the type average growers. Also the canopy closure date was significantly five days earlier (Table 6.6). The harvest date did not differ between both grower types. The measured sowing characteristics were not different for both grower types, except for the percentage seeds in both compressed and humid soil and the plant density being significantly higher for type top growers. The sowing depth specified by the growers resulted in a significantly lower depth for type top growers, while the measured sowing depth showed no difference between both grower types.

Table 6.6 Sowing characteristics on sugar beet fields of type top and type average growers in Dutch sugar beet production. *SUSY-project, the Netherlands, 2006-2007.*

Sowing characteristics	Grower type		
	Average	Top	Significance[a]
Sowing date	8-4	3-4	0.002
Canopy closure date	15-6	10-6	<0.001
Harvest date	26-10	29-10	0.237
Missing seeds (%)	12.0	11.5	0.581
Field emergence (%)	83.9	85.9	0.133
Sowing distance, measured (cm)	19.6	19.3	0.292
Sowing distance, growers' specification (cm)	18.8	18.8	0.702
Sowing depth, measured (cm)	2.8	2.8	0.649
Sowing depth, growers' specification (cm)	2.5	2.0	<0.001
Seeds in compressed soil (%)	71.5	91.3	0.007
Seeds in humid soil (%)	72.8	95.4	0.017
Plant density (# plants/ha)	85818	89321	0.050

a. probability no difference between grower types.

The seeds in compressed (R^2 = 0.06; P = 0.014) and humid soil (R^2 = 0.06; P = 0.012) were the only sowing characteristics having a significant influence on sugar yield, besides sowing date (R^2 = 0.14; P = <0.001). Seeds in compressed and humid soil were closely related (R^2 = 0.72; P = <0.001) (data not shown).

6.3.3 Discussion

An optimal plant density is important for affecting sugar beet yield and quality. A population density exceeding 70,000 plant ha^{-1} is required to obtain high sugar yields (Märländer, 1990; Van Swaaij, 2008). Both type top and type average growers had (on average) plant densities above 70,000 plants ha^{-1}. On only 3 fields (out of 104; 1 top and 2 average) plant density was below 70,000 plants ha^{-1}, but higher as 57,000 plants ha^{-1}. However, the crops of the type top growers had significant more plants per hectare compared to those of the type average growers. The above mentioned data are final plant densities and those figures do not reflect differences in emergence, which were observed more often and more severe at fields of type average growers. A delay in emergence has an influence on sugar yield, since the delayed plants accumulate less dry matter, due to increased intraspecific competition for light caused by shading of the earlier emerged plants (Stibbe and Märländer, 2002). The delay in emergence on type average growers' fields can be explained by sowing quality and sowing date. In this project, sowing quality comes to seed placement in compressed (below the loose seedbed) and in humid (not dried by the weather) soil, which are closely related. The type top growers place significantly more seeds in humid soil, providing more optimal circumstances for the seeds to germinate and being less dependent on rainfall after sowing. The earlier sowing date of the type top grower also facilitates sowing of the seeds in humid soil. Quality of sowing was recorded independent of sowing machines' maintenance status, which can have an high impact on sowing performance (Wilting, 2008). Here, the grower's management is of major importance, he has to check the seed placement in the soil during sowing, even when a proper maintained sowing machine is used. However, the seedbed quality should allow for seed placement in the humid soil. Here, too, the growers' management in preparing the seedbed plays an important role. So, the very best results will still be obtained when the sowing machine is properly maintained, the seedbed is of high quality and the grower checks whether the seeds are placed below the loose seedbed in the humid soil.

Type top growers sowed their sugar beets significantly five days earlier. Earlier sowing does not influence the development rate until establishment (Stibbe and Märländer, 2002), but it explains the significant earlier canopy closure (five days) on the type top growers' fields. The advantage of earlier sowing of the type top growers' crop is an earlier closure of canopy, followed by a significant increase, not only of the radiation interception, but of the yield, too (Werker and Jaggard, 1998; Kenter et al., 2006). Next to that, earlier sowing can lead to a partial escape from pathogens (Webb et al., 2000; Asher and Hanson, 2006; Stevens et al., 2006; Hanse et al., 2011a).

The harvest date was not different for both grower types, consequently, the gain has to be set at seasons' start.

6.4 Weed control

6.4.1 Materials and methods

Data on weed control, herbicide, active ingredient and amounts used, applications and application date were taken from the SUSY-growers' registration (see section 6.2.1).
During the season, after canopy closure (June) and before harvest (September) the result of weed control efforts were evaluated by a scale 1 to 10 (1 = very poor; 10 = excellent weed control) on 50 randomly chosen sites of the field. Also the amount of bolters and weed beet was recorded on 50 sites of 400 m^2 each, randomly chosen on the field. For small fields (< 3 ha) total number of bolters and weed beet were counted on field level. In total, data of 104 fields were available for analysis in 2006 and 2007.
All data were non-normal and ln (x+1) transformed in order to obtain normalised variables, except for total pre-sowing and pre-emergence applications (ln (x+24) transformed) and the fifth post-emergence application, total applications and total post-emergence applications, which were proved to be normally distributed. The result of weed control in September was arcsin (x/10) transformed in order to obtain a normal distribution. Presented means and estimated constants are all back transformed. Data were analysed using the statistical package GenStat, 12th edition (VSN International Ltd.). Linear mixed models were used to analyse the effect of year, grower, site and their interactions in the fixed model. The given pair number, region and their interaction were used as random terms to analyse the 'type top' and 'type average' within a pair directly with each other (Thissen, 2009). Linear regressions were calculated to estimate the effect of single variables on weed control in September and sugar yield.

6.4.2 Results

Data of weed control efforts did not differ between type top and type average growers' crops (Table 6.7). The total dosage of herbicides and number of herbicide sprayings was comparable for both grower types. The same holds for the application time in days after sowing of the first six applications, except for the pre-sowing and pre-emergence applications, were the type top growers apply one day significantly earlier before sowing. This variable contained the herbicide applications before sowing (glyphosate) and the application of soil active herbicides after sowing, before emergence of the sugar beets, like metamitron, clomazone and chloridazone (only on clay soils). The applications before sowing can be conducted before or after seedbed preparation (clay soils) or before the main soil tillage (sandy soils). The pre-sowing and pre-emergence applications were taken together because both variables separately resulted in two, too small data sets for a reliable statistical analysis.

Linear regression showed only for the pre-sowing and pre-emergence application a significant effect on the result of weed control (September), with a R^2 of 0.14, while all other parameters did not show a significant effect (Table 6.7). The amounts of none of the used active ingredients could explain the variation in the result of weed control in June and September for more than 10% calculated by linear regression (data not shown).

When the efforts in weed control were financially weighted the costs of herbicides, herbicide application, manual and mechanical weed control were not different between both grower types, too. However the result of the weed control differed after canopy closure (June) and before harvest (September), being significantly better for the type top growers (Table 6.7).

Table 6.7 Difference between type top and type average growers for herbicide applications and their effect on the result of weed control in September. *Data SUSY-project, the Netherlands, 2006-2007.*

Weed control	Grower type			Effect weed control (September)	
	Average	Top	Significance[a]	R2	Significance[a]
Costs					
Herbicide (€ ha^{-1})	201	190	n.s.	0.02	n.s.
Application (€ ha^{-1})	92	98	n.s.	0.01	n.s.
Manual weed control (€ ha^{-1})	44	55	n.s.	0.03	n.s.
Mechanical weed control (€ ha^{-1})	19	18	n.s.	0.05	*
Herbicide application interval					
Post-sowing	9	9	n.s.	0.00	n.s.
Post-emergence	10	10	n.s.	0.00	n.s.
Herbicide applications (days after sowing)					
Total pre-sowing and pre-emergence	-4	-5	*	0.14	*
First post-emergence	19	18	n.s.	0.00	n.s.
Second post-emergence	29	27	n.s.	0.00	n.s.
Third post-emergence	38	35	n.s.	0.00	n.s.
Fourth post-emergence	47	45	n.s.	0.00	n.s.
fifth post-emergence	56	53	n.s.	0.00	n.s.
Sixth post-emergence	59	64	n.s.	0.01	n.s.
Total applications (#)	5	5	n.s.	0.01	n.s.
Total pre-emergence applications (#)	0.3	0.4	n.s.	0.02	n.s.
Total post-emergence applications (#)	4	4	n.s.	0.02	n.s.
Active ingredients herbicides (kg ha^{-1})	4.2	4.0	n.s.	0.00	n.s.
Results					
Bolters and weed beet June (# ha^{-1})	21.1	4.5	n.s.	-	-
Bolters and weed beet September (# ha^{-1})	4.2	3.2	n.s.	-	-
Result weed control June (0 = very poor; 10 = excellent)	7.7	8.5	***	-	-
Result weed control September (0 = very poor; 10 = excellent)	8.3	9.4	***	-	-

a. n.s. = not significant; *,*** = significant at p ≤ 0.05, ≤ 0.001.

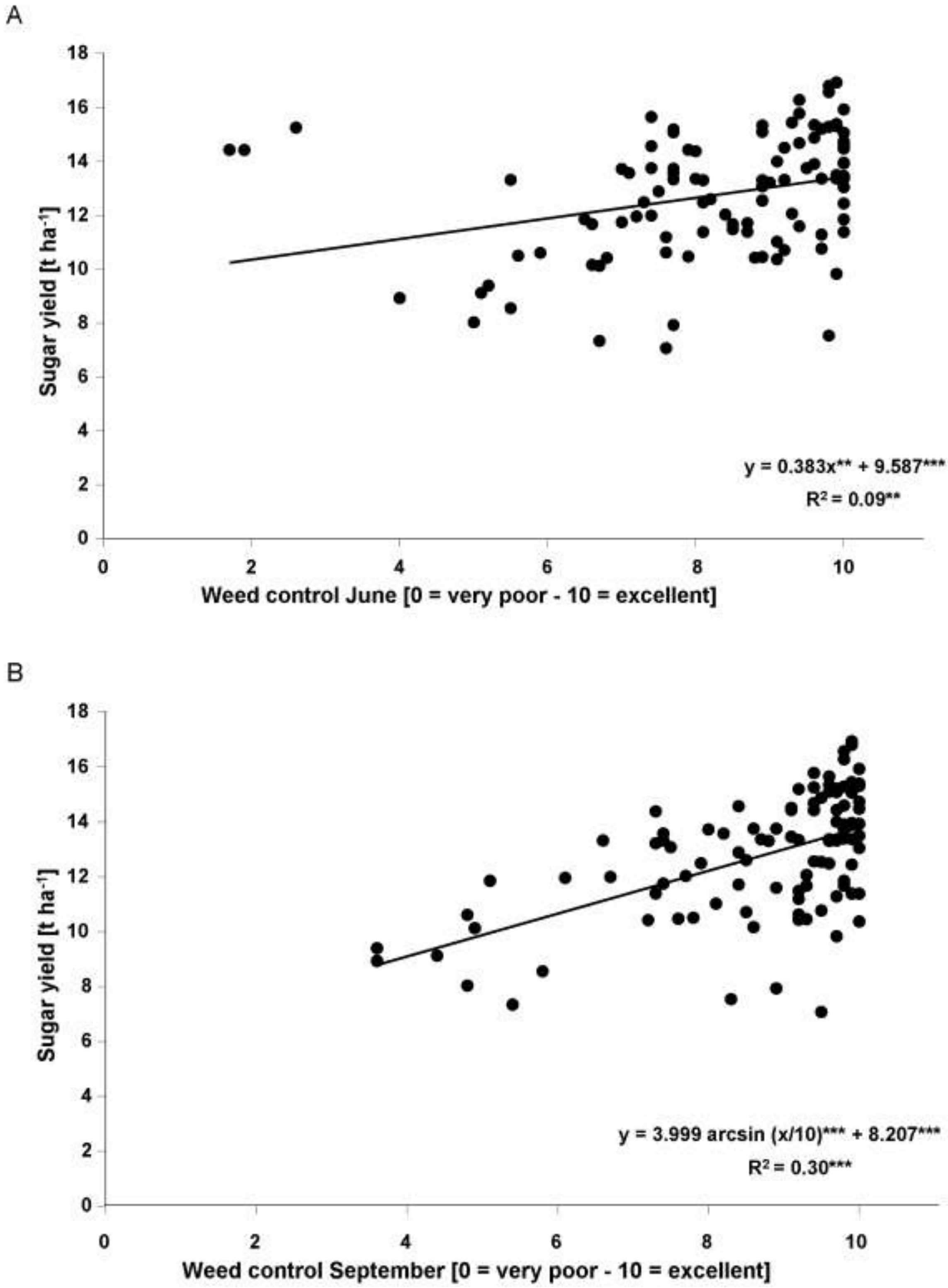

Figure 6.2 Effect of weed control on sugar yield, results judged after canopy closing (A) and befor harvest (B). ** and *** = significant at p ≤ 0.01 and p ≤ 0.001. *Data SUSY-project, the Netherlands, 2006-2007.*

The result of the weed control both after canopy closure and before harvest had a significant effect on sugar yield and explained 9% and 30% of the variation, respectively (figure 6.2). Applied total dosages of triallate, clomazone, clopyralid, desmedipham, S-metolachlor, ethofumesate, phenmedipham, dimethenamide-P, metamitron, chloridazone, triflusulfuron-methyl, and graminicides did not differ for type top and type average growers. Except for a small negative effect of clopyralid (R^2 = 0.016; P = 0.016), none of the active ingredients had an effect on sugar yield calculated by linear regression (data not shown).
According to the growers' registrations, many of the applications by growers were at normal dates with normal dosages, except for 6 growers (5 type average on clay and 1 type top on sand soil) which used a very high dosage in an early stage after drilling and 3 growers which used a rather soft dosage. In total, 3 applications had a non-usual composition (metamitron and S-metolachlor mixture).

6.4.3 Discussion

The weed control measurements in the sugar beet crops recorded in the SUSY-project are another clear example of growers' management influence. The costs of weed control are comparable between type top and type average growers (Hanse et al., 2010). Next, all the recorded inputs, like number of applications, type and amount of compounds used and interval of applications are similar for both type top and type average growers, except the pre-sowing and pre-emergence applications. Being the only variable significantly different between both grower types, the pre-sowing and pre-emergence applications also have a significant effect on result of the weed control efforts. Early in the season the difference in weed control between type top and type average is made.
By linear regression 30% of the variation in sugar yield was explained by the result of the weed control in September, this is despite the weed control efforts. Without weed control, yield losses in sugar beet due to competition with simultaneously emerging weeds can be 66% to more than 80% (Jursik et al., 2008; Kemp et al., 2009). However, in the fields of the

SUSY-project the amount of weeds in September do not only reflect the quality of the weed control. There is an effect of gappy stand and retarded growth due to pests and diseases, causing less competition of the sugar beet crop towards weeds (Hanse et al., 2011a). In those crops, weeds have more chances to develop later in the season. Despite the crop protection measures, the yield loss due to weed competition in arable farming was estimated 3% for Europe (Oerke and Dehne, 2004). Leaving out the estimated yield loss due to pests and diseases of sugar beet in the SUSY-project (24%) the yield loss due to weed competition is roughly about 6%.

For sugar beet, herbicide tolerant-varieties have been developed. With the use of these varieties growers could save on the costs of weed control, depending on the assumed technology fee and the costs of the conventional weed control (May, 2003; Märländer, 2005). Aside from a, theoretical, costs benefit, the use of those varieties facilitate the weed control, although it still requires management (Kemp et al., 2009). With the above described importance of growers' management and the influence of pests and diseases on the late emergence of weeds, the challenge remains whether to control weeds successfully and to avoid weed competition after canopy closure.

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7 Outlook

7 Outlook

Growing a crop is managing components of variance. The soil and weather (environment), agronomical and phytopathological aspects, and product prices, all add a part to the total variance of yield formation during the growing season. How well this variance can be managed, determines, within the crops' physiological limits, the obtained yield level. Before the start of a growing season, yield can be expected on certain levels, but no one can predict those with high accuracy. Even the best guess growers can make, is taking the average yield of the last few years.

The weather, although a given fact during the season, has a high influence on yield level. This often results in the significant effect of 'year' in studies on yield levels and agronomy. It is not possible to manage the weather. However the effects of the weather can be managed, since part of the weathers' influence comes indirectly via phytopathological, agronomical, and soil effects. Minimizing the effect of pests and diseases and optimizing soil and agronomical measures are the ways growers can minimize the effect of the weather.

The backbone of the presented research was comparing growers with a top yield and an average yield history, cultivating sugar beet under the same environmental conditions. The yield difference continued during the project. Surprisingly, the yield difference was not caused by economic constraints: both the type top and type average growers had comparable total variable costs. This very important finding implies that sugar beet production in a given environment or region has similar costs, independent of sugar yield. Furthermore, raising sugar yield is possible at the current cost level. Apparently, not the costs themselves influence sugar yield, but the details how and when measures are conducted make the difference. For a grower producing higher yield at the same cost level, more profit is made.

In contrast to costs, several factors were identified, which had an influence on yield level. When having identified the yield limiting factor(s) of a field, there might be an additional investment to elevate this factor. Growers better focus on these factors rather than on the level of costs. On the other hand, saving costs might be possible for cultivation factors being already optimized concerning yield level.

This study shows the importance of soil conditions, phytopathological and agronomical effects raising yield by a better cultivation management. The type top growers had a better soil structure, lower infestation of pathogens, and a better performance in agronomical measures differing among soil types, and individual fields thus having an unique fingerprint in their management.

Climate is predicted to change in North-West Europe. In sugar beet it can have a profitable effect on yield by increasing average temperature and CO_2 partial pressure. However, this effect depends on how the other sources of variance are managed. Higher temperatures might also cause an increased pressure of pests and diseases, and more periods with excessive rainfall demanding a better management of soil structure.

The climate change is pushing societies towards sustainable plant production of the whole crop rotation for which sugar beet is important in terms of economy. This PhD-thesis proves that for sugar beet the yield level is independent from the total variable costs of growing the crop. Therefore, the demand for economic sustainability can be met by raising yield and optimizing costs. If ecological factors are expressed per unit of product, raising yield can have a positive effect on environmental sustainability, too.

The profit is the difference of the total variable and fixed costs, and the revenues being the product of yield and product prices. In case of constant costs, a high yield is extremely important, to compensate low product prices in order to maximise the profit. Compared to many other crops, prices of sugar beet in the European Union are rather stable as a result of the sugar regime. For a grower, this causes less variance of profit, which is the highest at high yield level. At present it is unknown, whether the current European Union (EU) sugar regime will continue or change. In case the EU will opt for a free market, product prices will become highly volatile, urging much more than today for constant high yield level in each year.

In science, it is often thought that results without significant differences are not worth to publish. However, it is the interpretation of results which should be the basis of the decision to publish or not. The very important finding of this research project is that total variance costs are not significantly different between type top and type average growers demonstrates the impact of such "minor" findings. From it, the interpretation is that in sugar beet growers' management has to maximise yield. Therefore, a basis is needed to make the right decisions. Research should provide knowledge on how the quality of cultivation measures could be improved and optimized. In order to increase yield, breeding progress can develop specific solutions of integrated plant protection with the goal to minimize the use of pesticides. The yield and quality increase caused by breeding progress provides the grower additional tools to maximise yields in a sustainable way, too.

Finally, each field has its own history and thus its own set of yield reducing factors. The grower has to keep an overview to all these factors. Quality and timing are often the main growers' management tools to set the difference between a high or an average yield. Therefore, there is a future for the sugar beet: the grower can make it sweet by implementing the latest knowledge from science, and managing yield restricting variables.

8 Summary

8 Summary

The Dutch sugar industry and sugar beet research institute initiated the project SUSY (Speeding Up Sugar Yield) as a reaction to decreasing beet prices in relation to the reform of the European Unions sugar regime. The project was aimed at softening the reform's impact on growers income by improving their knowledge on raising sugar yield and identifying possible cost savings. From each sugar beet growing region in The Netherlands, 26 pairs of 'type top' (high yielding) and 'type average' (average yielding) farmers were selected, based on the average yield of the farm in 2000-2004. All measures of sugar beet cultivation, costs calculation and phytopathological, agronomical and soil characteristics were investigated from 2006 and 2007 on 75 fields of 'type top' and 74 fields of 'type average' growers in relation to yield and quality. The factors year and grower caused most of the significant effects on yield, quality and cost variables. The 'type top' growers had significantly 20% higher sugar yield in each year compared to 'type average' growers, but the total variable costs did not differ. This makes the 'type top' growers more efficient in resource use. Costs for manure and fertiliser, 'other' and irrigation significantly increased the total variable costs. With higher fungicide costs, sugar yield significantly increased. However, there was no significant relation between the intensity of sugar beet production and sugar yield so that the observed differences in sugar yield were not caused by economical constraints. Based on this study, it can be concluded that the most profitable strategy for the growers is maximising sugar yield and optimising costs.

Heterodera schachtii and *Beet necrotic yellow vein virus* (BNYVV) were mainly found on clay soils. Type top growers on clay soil had significantly lower infestation levels of *H. schachtii* (4.4x lower, P = 0.008), BNYVV (2.7x lower, P = 0.016) and other foliar symptoms (*Pseudomonas*, *Phoma betae* and *Verticillium* spp. combined) (1.5x lower, P<0.001) than the type average growers, respectively. On sandy soils, infestation levels of *Meloidogyne* spp. (P = 0.016), *Cercospora beticola* (P = 0.005) and *Erysiphe betae* (P = 0.027) were significantly lower (5x, 1.4x and 1.8x, respectively) for the type top growers. Type top growers on clay or

sand soils sowed 5 and 6 days earlier respectively, and made more fungicide applications than the type average growers. Insect pests were not observed at levels damaging for sugar yield: Insecticidal seed treatments provided sufficient control of insect pests. By multiple regression, 35% of the variance in sugar yield on clay soils was explained by *H. schachtii* and BNYVV infestation levels and by sowing date. On sandy soils, the infestation levels of *H. betae* and *Aphanomyces cochlioides*, number of fungicide applications and sowing date explained 71% of the variance in sugar yield.

Despite crop protection measures, the calculated yield losses due to pests and diseases were for the type top growers 30.2 and 13.1% and for type average growers 37.1 and 16.7% on sandy and on clay soils, respectively. Therefore, pest and disease infestation level partly explained the differences in sugar yield between type top and type average growers analysed. The skills and management of the grower are important to reducing damage by pests and diseases.

Mean saturated hydraulic conductivity in the subsoil (Ks) was significantly higher on fields of type top growers than of type average growers, 0.49 and 0.31 m day^{-1}, respectively. Mean Ks was below a damage threshold level of 0.10 m day^{-1} on 34% of the type average growers' fields and on 27% of the type top growers' fields. Ks was found 0.00 m day^{-1} on 9% of all fields. By multiple regression analysis without the factor grower type, 15.3% of the variability of Ks was explained by a model with the terms fine sand fraction (50-105 µm) in the subsoil and depth of primary tillage (D_{pt}; m).

Type top growers basically made use of comparable technical equipment, but applied lower tractor tyre inflation pressure and a lower number of field operations for seedbed preparation compared with type average growers. This did not result in a significant difference in mean air-filled porosity (AP) at field capacity in the topsoil between grower types although the number of fields with an topsoil AP in the 10-15 cm layer below 10% was lower in fields of top growers (13 fields) than of average growers (18 fields).

Direct effects of soil management on AP could be established by statistical analysis without the factor grower type, but may have been influenced because both management characteristics and AP appeared to be strongly related to top soil clay content.

AP of the topsoil and Ks of the subsoil explained 24.9% of the variation in sugar yield. Therefore, under the given conditions of soil type (clay content), a better soil structure can be influenced by the grower, resulting in a higher sugar yield.

Harvest losses were measured in 2006, 2007, and 2008 on 150 sugar beet fields in the Netherlands. Losses by overtopping, root breakages, and of whole beet were on average 2.9 t ha^{-1} and ranged from 0.45 t ha^{-1} to 9.1 t ha^{-1}. Although the type top growers had significant lower losses due to overtopping and whole beet losses, they did not have lower total harvest losses compared to the type average growers. Reducing the harvest losses is a relatively easy and efficient way to improve yield and profitability of the sugar beet crop.

Fertilization of sugar beet did not differ between the type top and type average growers in this project. No substantial effects of applied elements on sugar yield were found, since all were already in the optimal range for a high sugar yield. The amino-N content of sugar beet was found predicting the removal of total-N from the fields ($R^2 = 0.66$). Due to the increased quality of the sugar beet during the years as a result of breeding efforts, the N demand stays on similar level.

The type top growers had significant higher plant population per hectare compared to the type average growers. The delay in emergence on type average growers' fields can be explained by sowing quality and sowing date. Sowing quality from this project comes to seed placement in compressed (below the loose seedbed) and in humid soil (not dried by the weather), which are closely related. The type top growers place significantly more seeds in humid soil, providing more optimal circumstances for the seeds to germinate and being less dependent on rainfall after sowing. Here, the grower's management is of major importance, for using a properly maintained sowing machine, for preparing a high quality seedbed and for checking the seed placement in the soil during sowing.

Type top growers sowed their sugar beets significantly five days earlier. This resulted in an earlier closure of canopy with positive influence on yield and reducing the effect of pathogens. The harvest date was not different for both grower types, consequently, the gain has to be set at seasons' start.

The costs of weed control were comparable between type top and type average growers. Next, all the recorded inputs, like number of applications, type and amount of compounds used and interval of applications were similar for both type top and type average growers, except the pre-sowing and pre-emergence applications. Thus, difference in weed control between type top and type average growers is set early in the season. The yield loss due to weed competition was estimated to be about 6%. With the importance of growers' management on the late emergence of weeds, the challenge remains whether to control weeds successfully and to avoid weed competition after canopy closure.

This study clearly shows that there is no general key issue attention should be paid to but raising sugar yield demands a continuous dedication to the crop, an optimised grower's management, and a specific guidance by new knowledge generated by scientific research.

9 Curriculum Vitae

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Education

1986-1994	Primary school ‘Eben-Haëzer’, Emmeloord
1994-2000	Pre-university education, ‘Pieter Zandt’, Kampen. Examination in: Dutch, English, Biology, Chemistry, Mathematics, History and Geology.
2000-2006	Plant Science at Wageningen University; specialised in Crop Protection, major and minor in Nematology.

Experience

2006-2007	Process engineer at VDL Cultivit BV, Breda.
2007-2011	Project manager / Research agronomist at the IRS, Bergen op Zoom. Responsible for the project “Improving competitiveness of sugar beet cultivation”.
2009-2011	External PhD-student at the Institut für Zuckerrübenforschung (IfZ), associate institute of the Georg August-University, Göttingen (D), on improving competitiveness of sugar beet cultivation in the Netherlands.

Current position

Since January 2011	Project manager / Research agronomist sugar beet pathology and pests at IRS, Bergen op Zoom.

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A lot of thanks go to the institute IRS, making it possible to conduct a PhD study on and during my daily work, providing room for professional and personal development. Special thanks go to my colleagues at the IRS for all the work with which they contributed to the SUSY-project, direct or indirect during discussions on plans and methods or on distant sugar beet fields across the Netherlands during measurements and observations. All this work was an essential contribution to the success of the SUSY-project.

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Bram Hanse

Oudenbosch, March 2011