GENETIC PROGRESS OF DUTCH CROP YIELDS

Yield progress of varieties entered on the recommended lists in the period 1980-2015 for winter wheat, spring barley, starch potato and sugar beet

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Wageningen, 25-02-2019

Contents

1. Summary

The genetic yield progress of winter wheat (*Triticum aesticum*), spring barley (*Hordeum vulgare*), starch potato (*Solanum tuberosum*) and sugar beet (*Beta vulgaris*) in The Netherlands was estimated. The source of data (variety trials) and statistical methods were exactly the same as in Rijk et al (2013), but in the present analysis additional years (2011-2015 or 2016) were added to the period 1978-2010.

In general the outcomes were similar for both periods. The yearly yield increases through the introduction of new varieties were linear for winter wheat of, 90 kg of grain per ha per year (85% dry matter), being the same magnitude as in the period 1978-2010. Spring barley showed a progressive yield increase in the most recent decade of 90 kg grain per ha per year (85% dry matter) while we found a linear increase of 60 kg per ha per year in the previous study. The genetic progress for new starch potato varieties increased from a linear increase of 87 kg starch per ha per year to 110 kg. For sugar beet the comparisons between the two episodes could only be made for the *Rhizomania* and *Rhizoctonia* resistant varieties. For the *Rhizomania* resistant group a similar progress of 160-170 kg sugar per ha per year was found for both periods. For the *Rhizoctonia* resistant varieties (combined with *Rhizomania* resistance) the yearly increase decreased from 170 to around 0 kg of sugar per ha in the most recent decade, very much depending on only three newly registered varieties since 2004. In the nematode resistant category a progressive increase was found of 388 kg sugar yield per ha per year in the most recent decade.

Yield gaps between genetic potential yields and farm yields tended to increase for the crops investigated. An analysis of the maximum yielding variety of a crop per year resulted in a different pattern between cereals and root crops. Especially in winter wheat and to a lesser degree in spring barley the highest yielding varieties were reaching a plateau since the mid of the first decade of the 21st century. For starch potato and sugar beet such a development was not found. Testing varieties for the Dutch recommended variety list is always carried out in accordance with good agricultural practice. Thus a levelling off of the highest yielding variety in a year (for wheat and barley) while the genetic progress was found to be linear suggests a negative effect on yield of climate change.

2. Introduction

Crop yields are a result of interactions between genetics, environment and management (G×E×M). As in the Netherlands differences between potential yield and actual farm yields (yield gaps) are relatively small, progress in genetic potential is essential to further increase farm yields. This report is a continuation of the paper "Genetic progress in Dutch crop yields" (Rijk et al, 2013), which estimates the genetic yield progress for approximately the period between 1978 and 2010. In this report, the period between 2010 and 2015 (or 2016) has been added. Yields from variety trials were compared with the average farmers' yields derived from statistics. The analyses have been performed in exactly the same way as in Rijk et al (2013).

3. Material and methods

Except for ware potatoes, for which official yield trials have not been performed after 2004, yields from official Dutch variety trials were added to the already existing yield files for approximately the period 1978-2010 using the same criteria as in the previous study (Rijk et al, 2013).

2.1 Data

For the analysis of the contribution of breeding to yield improvement in winter wheat, spring barley, starch potato and sugar beet, data were collected from variety trials in the Netherlands from the late 1970's until the year 2016. The official variety trials were conducted by WUR, Field crops and the Institute of Sugar Beet Research (IRS). Farm yields were obtained from the official Dutch census data (http://statline.cbs.nl). Variety trials in the Netherlands are assumed to take place under optimum nutrient and crop protection management. They are generally not irrigated (see Appendix-1 for an overview of crops, information sources, time span, number of varieties and plot sizes), but the relatively even and high precipitation and often shallow ground water level ensure low water limitation. We thus use yield levels obtained in variety trials as an indicator of the yield potential of varieties, although this may be a slight underestimation.

For winter wheat and spring barley the grain yield was expressed in 85% dry matter, for starch potato the starch yield was used (and no longer the payment weight as in Rijk et al., 2013) and for sugar beet the sugar yield was used (fresh root yield times sugar concentration).

As the previous analysis from 1978 to 2010 did not reveal large regional differences, the winter wheat data were averaged over the three marine clay regions in the Netherlands, i.e., northern, central and south-western marine clay. Results were taken only from those trials treated against fungal diseases. Because of severe lodging, the year 2007 was discarded in the south-western trial results and farm yields.

Since 2014 no longer official variety trials of spring barley have been performed in the northern marine clay area. To make a reliable comparison between the period before and after 2014 only yield data were included from the south-western and central marine clay area. Table 1 shows which years could not be included for spring barley.

Starch potatoes are mainly grown on the north-eastern sandy soils and cleared peat lands, so we focused on this area. In 2014 and 2015 no official variety trials were carried out for starch potatoes. Only the starch yields of those varieties with a sufficient disease resistance and tested on both soil types in the same year were analysed. The threshold for a sufficient resistance against *Globodera pallida* pathotype 2 and 3 and the same score for resistance performance against *Synchytrium endobioticum* pathotype 1 and 2/6 is a score of seven on a one to ten scale. The yield of a variety on the two soil types was averaged per year before further analysis.

Sugar beet data were analysed for the entire country, because data did not allow a regional analysis. For sugar beet categories have changed compared to the previous analysis until 2010; varieties without any disease resistance were not tested any longer and nematode resistant varieties make up a new category as there were now a sufficient number of years to perform a solid analysis. Sugar beet trials were carried out on fields with *Rhizomania, Rhizoctonia* and *Heterodora schachtii* infestation (Table 1). For all other crops varieties were jointly tested, regardless of differences in quality (e.g. bread baking, beer brewing, or resistances (e.g. against *Globodera pallida*).

Table 1 Overview of crops and years included in the analyses

Crop	**Years**	**No data from**
Winter wheat	1978 – 2016	2007 (severe lodging)
Spring barley	1978 – 2016	1998, 2006-2008, 2012 (several reasons)
Starch potato	1984 – 2016	2014 and 2015 (no trials)
Sugar beet with resistance against:		
Rhizomania	1995 – 2015	
Rhizomania + Rhizoctinia	1998 – 2015	
Nematode (Heterodora schachtii)	1999 – 2015	

2.2 Statistical analysis

To assess the genetic progress in yields of new varieties, statistical analyses were performed with GenStat 14th edition (Payne et al., 2011). First both modified joint regression analysis (mjra) and residual (or restricted) maximum likelihood (reml) analysis were used to eliminate year (climate and/or management) effects from the genetic contribution to yield development. The fixed effects of the reml analysis were assigned to year and variety and the random effect to the interaction term year x variety which was the error in the reml model: $yield_{ij} = variety_i + year_j + error$.
The model of mjra was of the form: $yield_{ij} = variety_i + b_i \times year_j + error$. For each crop the method with the highest R^2 was used. The complementary year effect was attributed to change(s) in climate and/or crop management.

Next, linear regression models were estimated with the adjusted variety means as dependent variable and polynomials of the release year as independent variable. The release year of a new variety was defined as its first year in official variety trials (winter wheat, spring barley, starch potatoes and sugar beet).

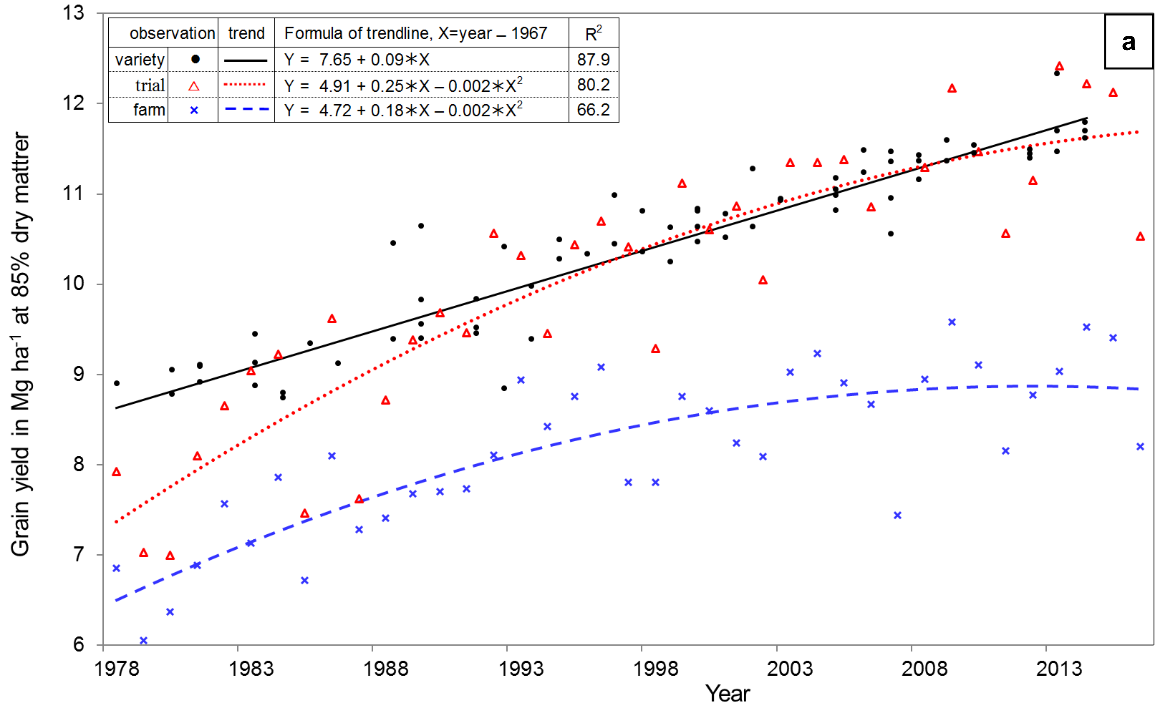
Varieties which were in trial for three years or shorter were excluded from the analysis, because it is assumed that these varieties did not meet the standards for further testing. Varieties which were included in the trials for only three years at the beginning or end of the investigated time span were also included in the analyses if it was known that they were included in the Dutch recommended variety list.

In all regression analyses no higher than quadratic polynomial terms were added if the addition of a quadratic term was not significant ($P>0.05$). When a quadratic term gave a significant improvement of the regression, also exponential and linear-exponential analyses were carried out to see whether these gave a significant improvement of the R^2.

In the interpretation of results it should be noted that variety trials are carried out on the best (parts of) fields, excluding spray tracks and head lands. In the figures, the yield of a new variety is assigned statistically (reml) to the year of the first test, while generally farmers adopt a new variety only from the moment it has been registered in the recommended variety list, provided enough seed is available. For specific reasons farmers may also sow varieties which already have been removed from the Dutch recommended variety list or use varieties from other countries which are not included in the Dutch recommended variety list.

4. Results and discussion

4.1 Winter wheat



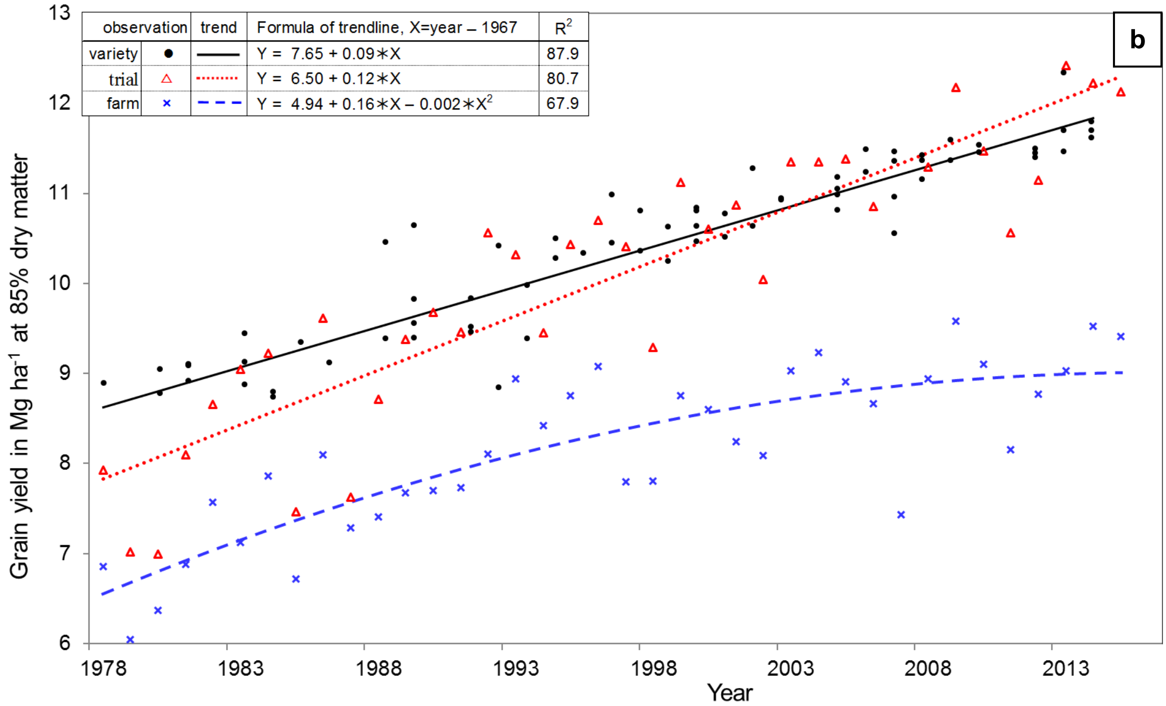


Fig. 4.1.1. Winter wheat grain yield in Mg ha^{-1} at 85% dry matter as an average of three marine clay regions in the Netherlands (South-west, Central and North) for 1978-2016 (a) and 1978-2015 (b). The blue dashed line (x observations) shows the progress in average farm yields based. The red dotted line (△ observations) shows the progress in average trial field yields. The solid black line shows the progress in reml corrected yields of varieties released in a particular year (• for year corrected yields for newly released varieties).

Compared to the analysis for the period1978-2010 the trend line of the farm yields has become concave rather than linear and now shows the same shape as in other Northwest European countries (e.g. Brisson et al., 2010, “Why are wheat yields stagnating in Europe? A comprehensive data analysis for France”). The annual genetic improvement was the same as in the previous analysis; an increase of 90 kg grain per ha per year at 85% dry matter. The trial year trend line (red), however, has a shape which depends on whether or not the year 2016 is included. In 2016 grain yields were low due to rainfall during the ripening period, causing a 700 kg per ha lower grain yield compared to the average of the previous ten years. The yield gap between variety trials and farm fields increased, whether or not the year 2016 was included. As genetic improvement shows a linear increase while farm yields show a concave pattern, climate change and/or crop management seem to play a role in explaining the increasing difference between potential yields and farm yields (yield gaps). In Appendix 2 the effect of climate change and crop management is summarized in the year effect. In the first decade of the investigated period the year effect was +40 kg grain per ha, whereas in the most recent decade the year effect was reduced to 0 kg. The farm yields also showed strongly decreasing year effects, i.e. 90 kg per ha per year in the first decade of the period and below 10 kg per ha per year in the most recent decade.

Variety trials are carried out according to good agricultural practice. Assuming that this management has not become systematically worse, it can be hypothesized from Fig. 4.1.2 that climate change is the most important factor causing the levelling off. This might be an important reason why winter wheat yields are no longer increasing on farms. In fact farm yields cannot fully benefit from the genetic progress because of adverse climate change.

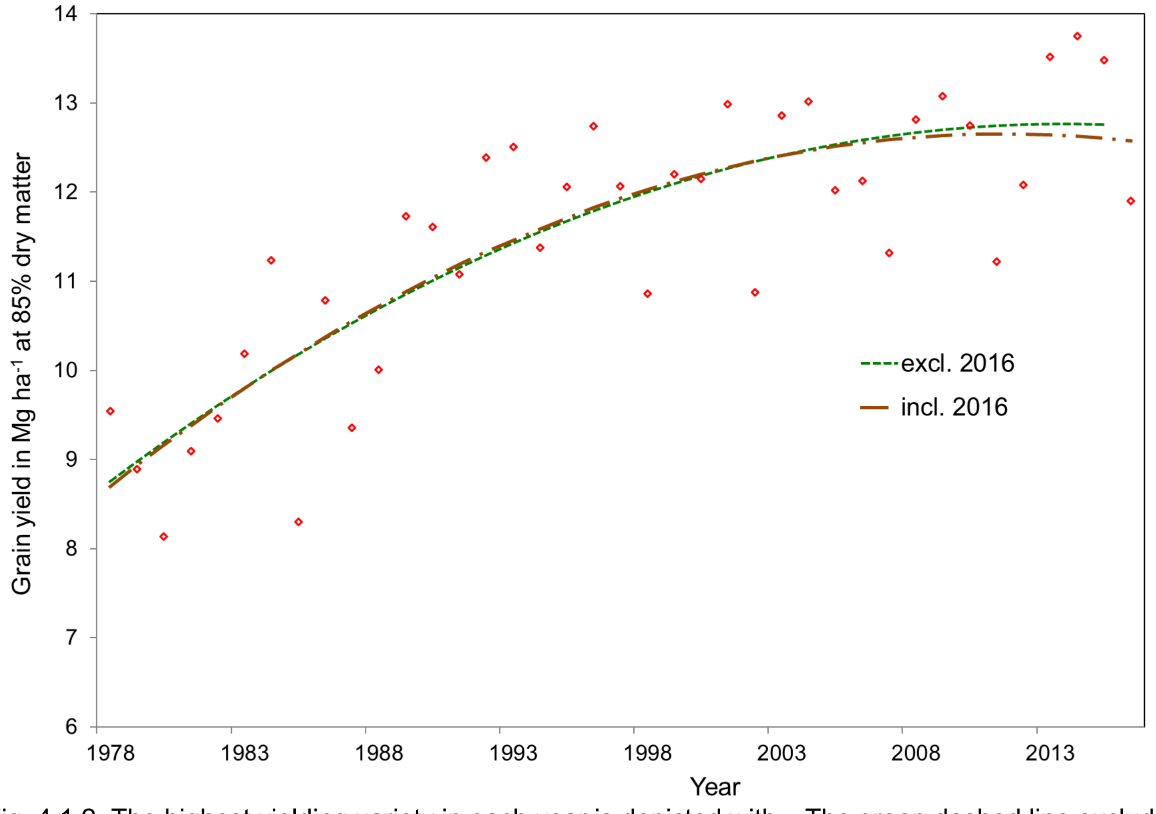


Fig. 4.1.2. The highest yielding variety in each year is depicted with ◇. The green dashed line excludes the year 2016 and the red intermittent dot-dash line includes 2016

4.2 Spring barley

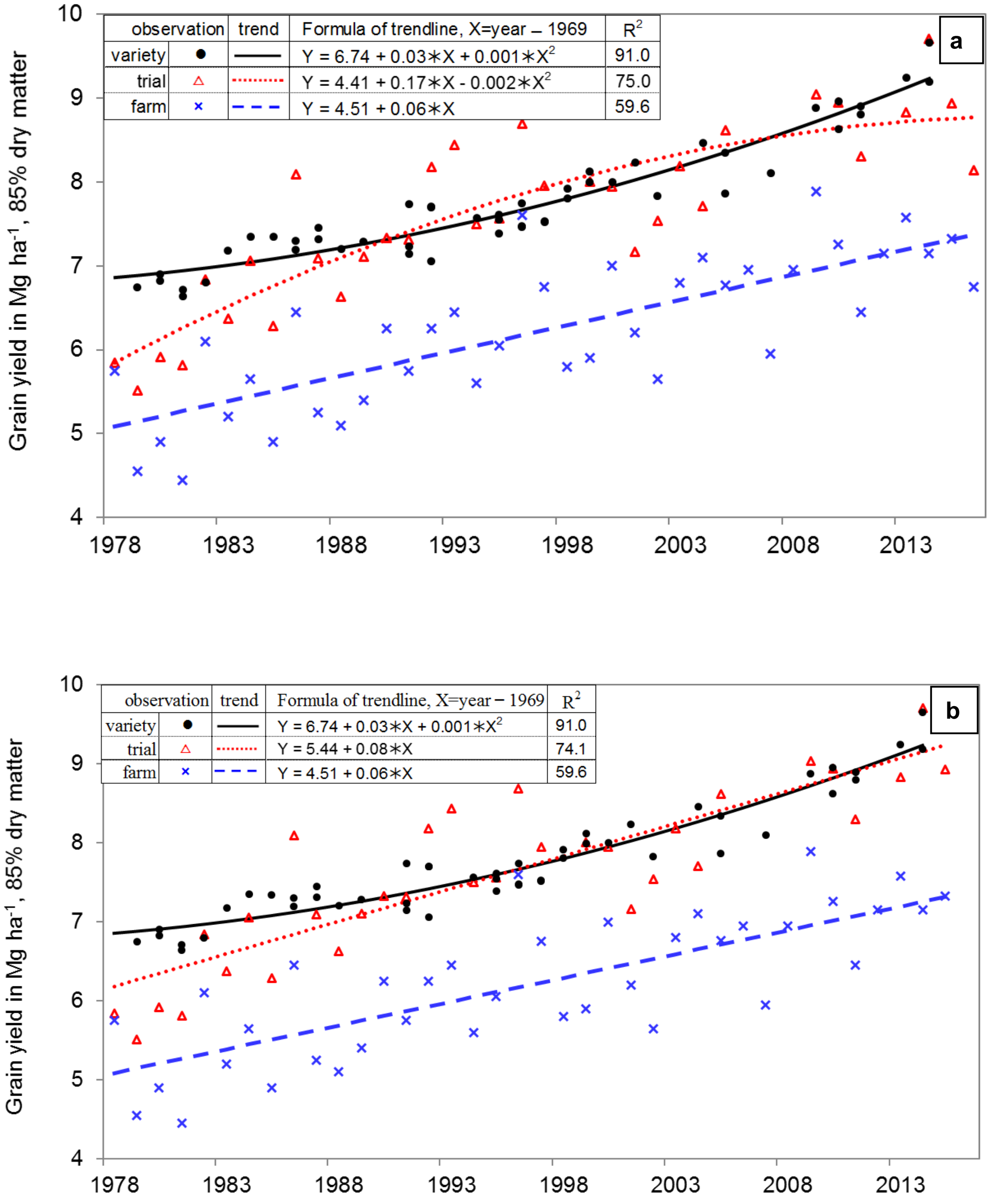


Fig. 4.2.1. Spring barley grain yield in Mg ha^{-1} at 85% dry matter as an average of two marine clay regions in the Netherlands (South-west and Central) for the periods 1978-2016 (a) and 1978-2015 (b). The blue dashed line (x observations) shows the progress in average farm yields based on statistics. The red dotted line (△ observations) shows the progress in average trial field yields. The solid black line shows the progress in reml corrected yields of varieties released in a particular year (• for year corrected yields for newly released varieties).

Since 2014 no more variety trials have been conducted in the northern marine clay area. Therefore these northern yield data have been excluded from this analysis and may make a comparison with the one presented in Rijk et al. (2013) somewhat difficult.

As with winter wheat it makes a difference as to whether or not the year 2016 is included in the trend analysis of the trial yields; inclusion results in a concave curve, exclusion in a linear course, revealing a widening yield gap with the farm yields. Contrary to winter wheat, farm yields of spring barley progressed linearly. And, the genetic progress has even been accelerating, which was not evident from the previous analysis (1978-2010) in which the northern marine clay region was still included.

Although spring barley shows slightly different trends than winter wheat, also here there are indications that following the GxExM concept, assumed good crop management (M) and increasing genetic yield potential (G), climate (E) may explain the shape of the curves in Fig. 4.2.2.
Appendix 3 shows that the year effect (assigned to climate change plus crop management) shifts from a positive effect of 90 kg grain per ha per year into a negative effect of 70 kg. For farm yields this implies that the genetic improvement cannot be fully utilised because of adverse climate change.

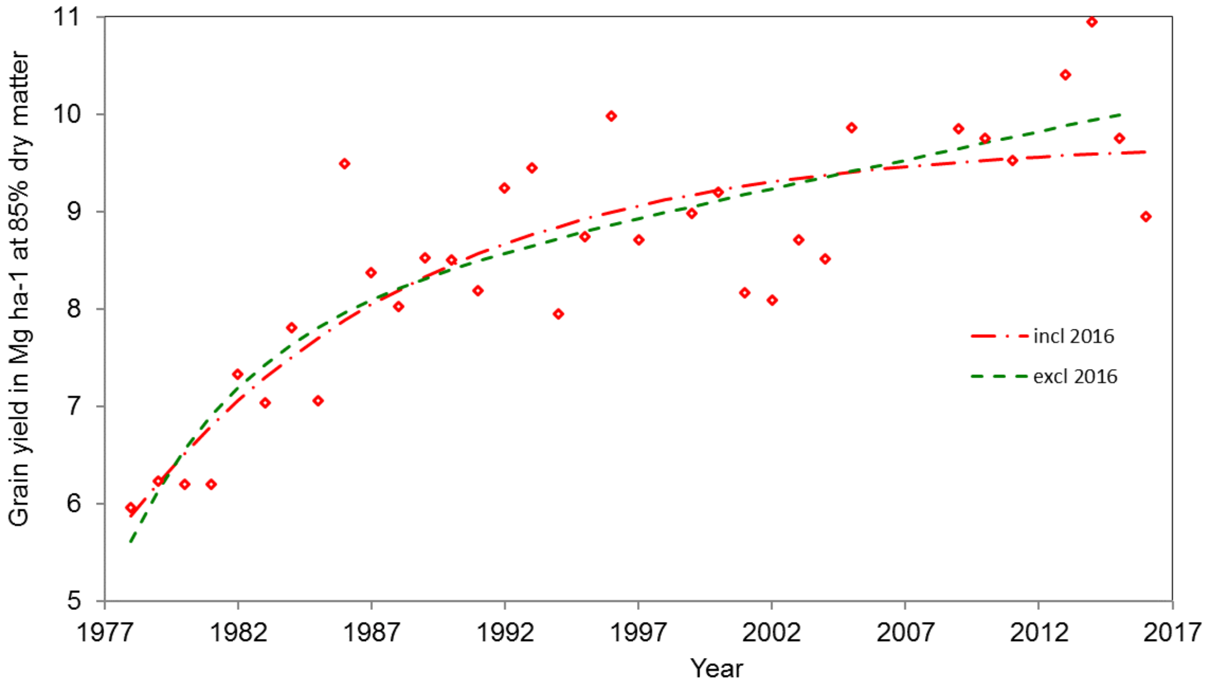


Fig. 4.2.2. The highest yielding variety in each year is depicted with ⬦. The green dashed line excludes 2016 and the red intermittent dot-dash line includes 2016

4.3 Starch potato

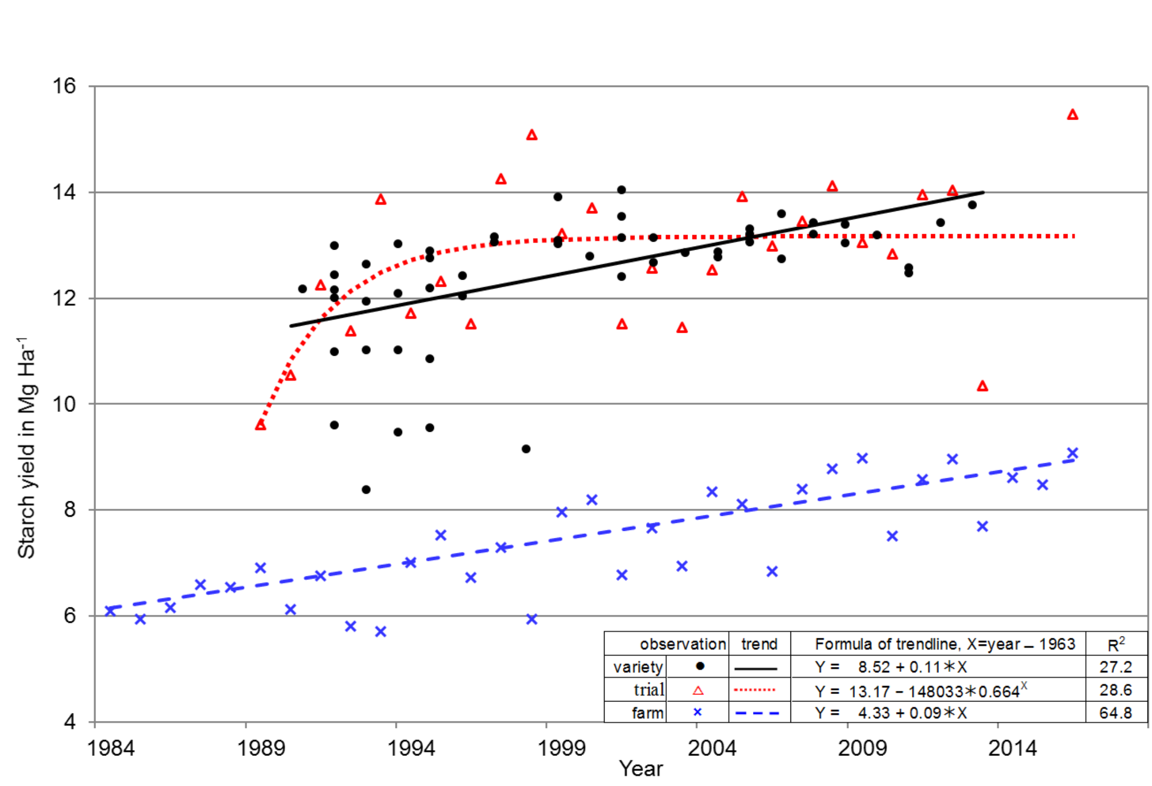


Fig. 4.3.1 Starch yields in Mg ha^{-1} of varieties from trial fields carried out on sand and reclaimed peat soils in the north-eastern region of the Netherlands from 1984 till 2016. The blue dashed line (x observations) shows the progress in average farm yields based on statistics. The red dotted line (△ observations) shows the progress in average trial field yields. The solid black line shows the progress in mjra corrected yields of varieties released in a particular year (• for year corrected yields for newly released varieties).

The present analysis for starch potatoes is based on starch yield. The previous analysis from 1990 until 2010 was performed on the basis of payment weight. This difference in yield indicator must be considered when comparing results between both analyses. Since starch yield and payment weight are both linearly related with under water weight and thus starch content, we do not anticipate any effect of this difference for our analysis of genetic yield progress.

As in the previous analysis only varieties introduced after 1990 were considered, because in the years before hardly any progress was observed opposed to later years. The spread of the individual varieties around the black variety line is rather large and so the R^2 is low (i.e. 27.2%). Nevertheless, the average progress during the period 1990-2015 was linear with a yearly increase of 110 kg starch per ha per year, and larger than the progress for the period 1990-2010 (87 kg starch per ha per year) The year effect of climate and crop management was not significant. The maximum yielding variety in each year did not show a clear course (data not shown).

The red dotted trial line became almost horizontal after the mid-1990s, which may be attributed to the low starch yield in 2013 and the absence of variety trials in 2014 and 2015, when farm yields recovered to an average level (see blue symbols in Fig. 4.3.1). Leaving out 2013 from the trial year average led to a linearly increasing course of this line from the early 90's onwards, varying from 80 to 114 kg per ha per year starch yield increase concluded from respectively an expo-linear and a linear fitted line (respectively with an R^2 of 35.4 and 43.3. Data not shown)

Farm yields showed a linear progress similar to the 1990-2010 trajectory. For both studied time spans farm yields increased slightly less than the genetic improvement, which implies a slowly growing yield gap between farm and genetic potential starch yield.

4.4 Sugar beet

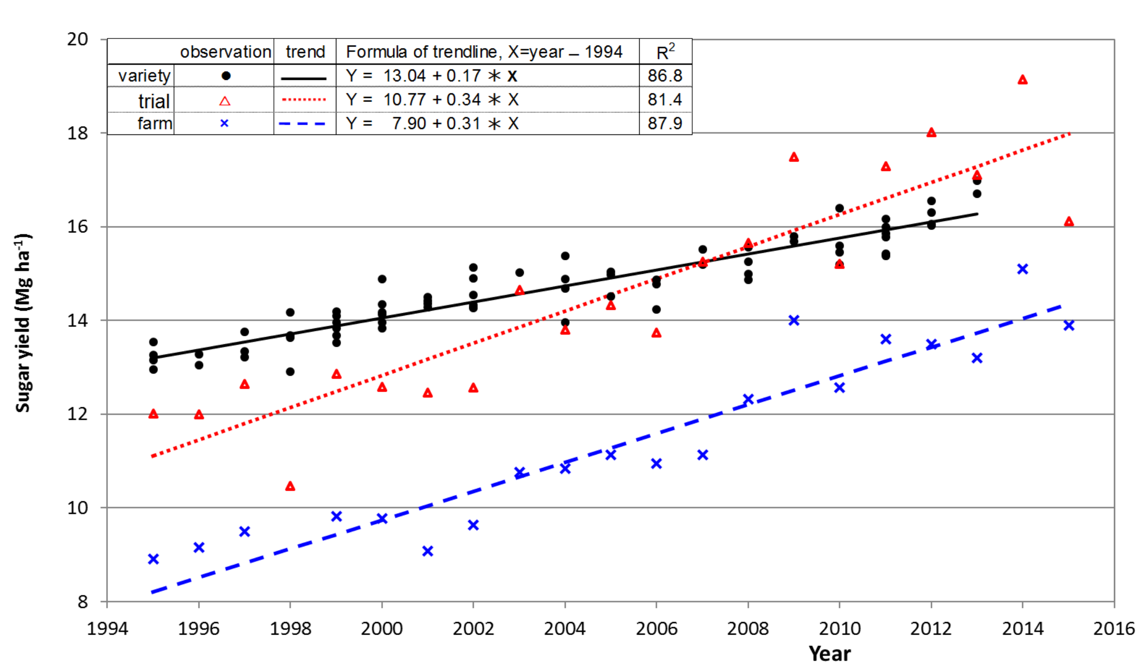


Fig. 4.4.1 Sugar yields in Mg ha^{-1} of *Rhizomania* resistant varieties from trial fields carried out on *Rhizomania* infected soils in The Netherlands. The blue dashed line (x observations) shows the progress in average farm yields. The red dotted line (▲ observations) shows the progress in average trial field yields. The solid black line shows the progress in reml corrected yields of varieties released in a particular year (• for year corrected yields for newly released varieties with resistance against *Rhizomania*).

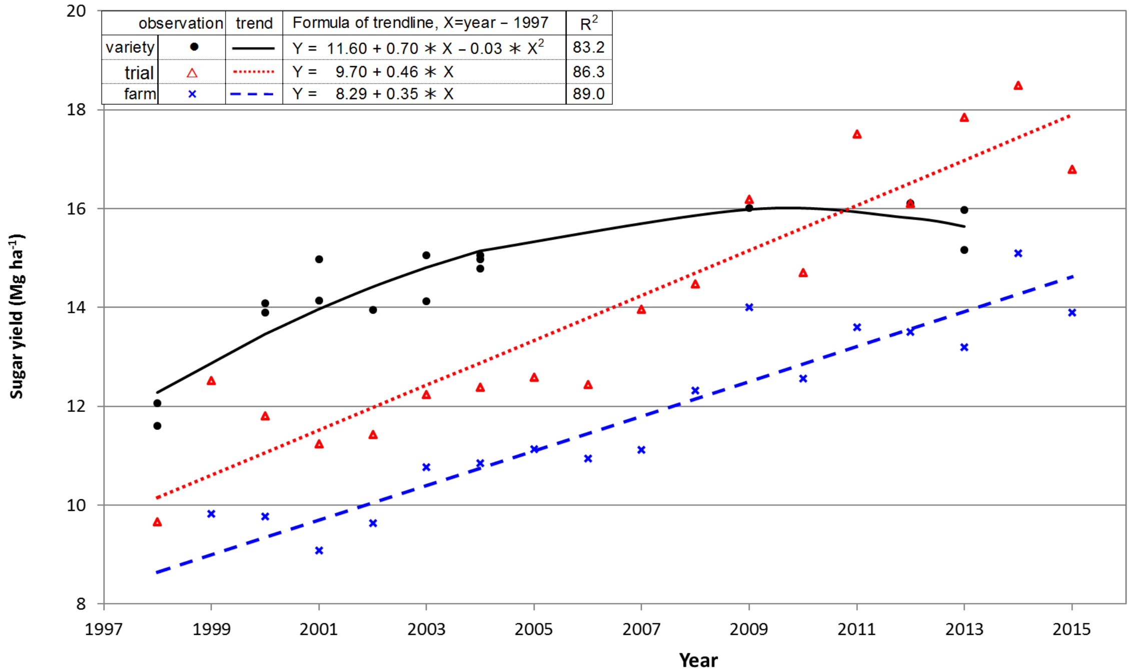


Fig 4.4.2. Sugar yields in Mg ha^{-1} of *Rhizoctonia* resistant varieties from trial fields carried out on *Rhizoctonia* infected soils in The Netherlands. The blue dashed line (x observations) shows the progress in average farm yields based on the same statistics as in Fig. 4.4.1. The red dotted line (▲ observations) shows the progress in average trial field yields. The solid black line shows the progress in reml corrected yields of varieties released in a particular year (• for year corrected yields for newly released varieties with resistance against *Rhizoctonia*).

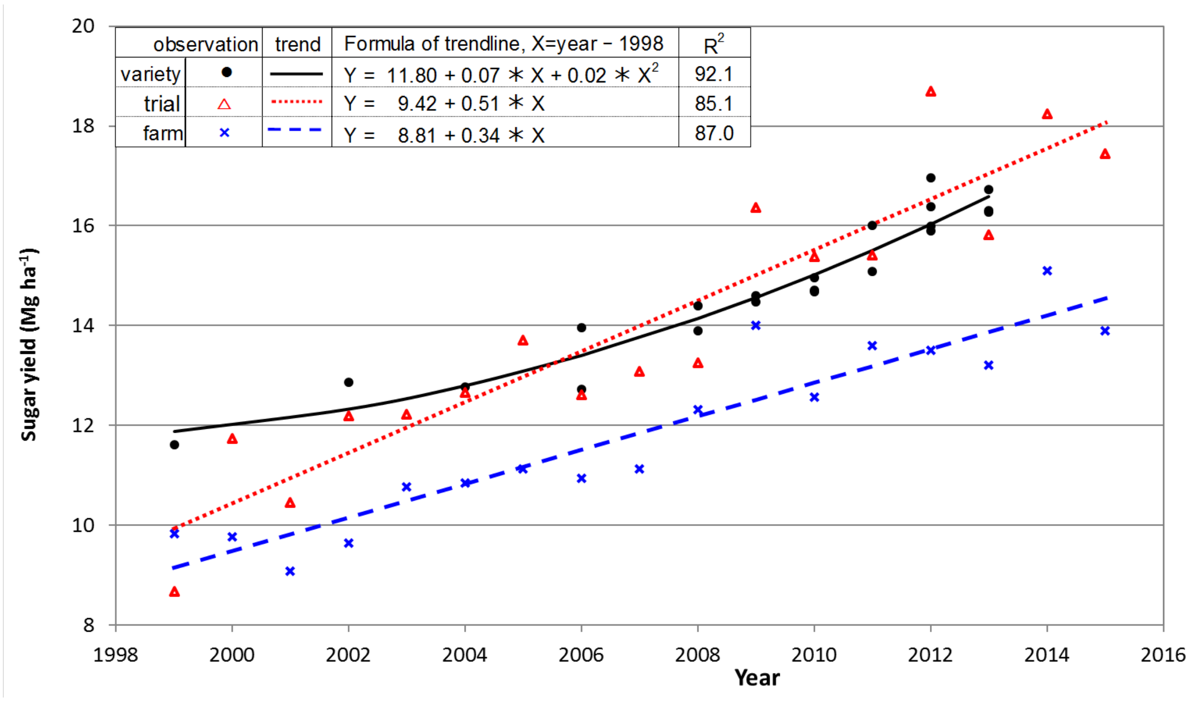


Fig 4.4.3. Sugar yields in Mg ha^{-1} of nematode (*Heterodora schachtii*) resistant varieties from trial fields carried out on nematode infected soils in The Netherlands. The blue dashed line (**x** observations) shows the progress in average farm yields based on the same statistics as in Fig. 4.4.1. The red dotted line (▲ observations) shows the progress in average trial field yields. The solid black line shows the progress in reml corrected yields of varieties released in a particular year (• for year corrected yields for newly released varieties with resistance against nematode).

When interpreting Figures 4.4.1 - 4.4.3 it should be noted that on average variety trials are harvested earlier than farmers' fields, and trials are carried out on the best (parts of) fields, excluding spray tracks and head lands. After harvest the trials are processed almost immediately, whereas farmers' harvest may be stored for some time and therefore suffer losses.
The genetic progress is different for each of the resistance groups; linear, convex and concave, respectively, for *Rhizomania, Rhizoctonia* and nematode resistant varieties. The convex shape of the *Rhizoctonia* resistant varieties is mainly caused by the two varieties first tested in 2013, having a yield which does not exceed the previous varieties in this category. Both varieties were registered on the recommended variety list as a B-variety, because, despite their moderate yield, one variety had a higher level of *Rhizoctonia* resistance and the other had a supplementary *Rhizomania* resistance. Besides, between 2004 and 2012 only one variety was registered on the Dutch recommended variety list. In 2016 two higher yielding varieties were included in the recommended list (written communication, Levine de Zinger, IRS). New nematode resistant varieties clearly showed an increasing yield progress, as a result of an efficient incorporation of nematode resistance by breeding companies.

Compared to the analysis until 2010 (Appendix 5), the genetic progress, year effect, trial and farm yields of the *Rhizomania* and *Rhizoctonia* resistance groups now showed a larger yearly increase than until 2010, implying that new varieties, climate and/or crop management all seem to have contributed to a higher sugar yield. The genetic contribution of new *Rhizomania* resistant varieties was estimated at 170 kg sugar yield per ha per year, for nematode resistant varieties this contribution was almost 300 kg. The maximum yielding variety in each year does not show a clear course (data not shown). The yearly increase of the farm yields, which could not be attributed to the different resistance groups, was over 300 kg sugar yield per ha, which is tremendous.

For all three categories of sugar beet varieties both farm and trial field yields showed a linear progress, with a somewhat widening gap between farm and trials yields. The yield gap increase in the *Rhizoctonia* and nematode resistance trials was larger than in the *Rhizomania* resistance trials. The relatively small yield gap increase between trial and farm yield in the *Rhizomania* resistant group might be attributed to the development of a new *Rhizomania* variant, against which not all varieties are resistant yet.

5. References

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Appendix-1 Overview of crops, information sources, time span, number of varieties and plot sizes

Crop	Data source	Time span yield data	Oldest and youngest variety	Number of varieties included	Soil type and region in the Netherlands [6]	Net plot size in meter (length x width)	Number of replicates	Irrigation	Source farm yield data
Winter wheat	PPO	1978-2016	1968-2014 [1]	79	Marine clay in SW, centre, N	9 x 1.5 or 2.5	2 or 3	No	CBS [4]
Spring barley	PPO	1978-2016	1970-2014 [1]	54	Idem except N	9 x 1.5 or 2.5	2 or 3	No	Eurostat
Starch potato	PPO	1984-2016	1973-2011 [2]	52	Sand and cleared peat in NE	4.95 x 1.5 (32 plants)	3	Yes	LEI/ Avebe [5]
Sugar beet	IRS	1995-2015	1970-2013 [1]	107	All soils and regions	14.5 x 3	3 to 6 [3]	Yes	IRS

[1] First year of official testing
[2] Registration year or entry on the national variety list
[3] Six replicates in case of *Rhizoctonia* resistance variety trial
[4] Avebe is the Dutch starch potato processing industry
[5] CBS- Statline: after 1991 the division of the respective marine clay areas was slightly changed
[6] N=north, E=east, S=south, W=west

Appendix-2 Winter wheat

Summary of the genetic progress in Dutch winter wheat yield. Comparison between the situation until 2010 and until 2016

			Genetic progress (corrected for year effects)		Year effect (genetic progress excluded)		Progress in farm yields	
Crop	Region and soil type	Period	Mg ha^{-1} $year^{-1}$	increase	Mg ha^{-1} $year^{-1}$	increase	Mg ha^{-1} $year^{-1}$	increase
Winter wheat (85% dm[b])	Marine clay (average of North, Central and South-west)	1978-2010	0.09	linear	0.04	linear	0.09	linear
Winter wheat (85% dm[b])	Marine clay (average of North, Central and South-west)	1978-2016	0.09	linear	0.10→ − 0.05	declining[a]	0.12→0.00	declining[a]

[a] average of the first, respectively, last decade of the analysed time span
[b] dm = dry matter

Appendix-3 Spring barley

Summary of the genetic progress in Dutch spring barley yield. Comparison between the situation until 2010 and until 2016

			Genetic progress (corrected for year effects)		Year effect (genetic progress excluded)		Progress in farm yields	
Crop	Region and soil type	Period	Mg ha^{-1} $year^{-1}$	increase	Mg ha^{-1} $year^{-1}$	increase	Mg ha^{-1} $year^{-1}$	increase
Spring barley (85% dm[b])	Whole country, clay	1978-2010	0.06	linear	0.03	linear	0.07	linear
Spring barley (85% dm[b])	Whole country, clay except northern region	1978-2016	0.03 → 0.09	inclining[a]	0.09 → − 0.07	declining[a]	0.0	linear

[a] average of the first, respectively, last decade of the analysed time span
[b] dm = dry matter

Appendix-4 Starch potato

Summary of the genetic progress in Dutch potato starch yield. Comparison between the situation until 2010 and until 2016

			Genetic progress (corrected for year effects)		Year effect (genetic progress excluded)		Progress in farm yields	
Crop	Region and soil type	Period	Mg starch ha^{-1} $year^{-1}$	increase	Mg ha^{-1} $year^{-1}$	increase	Mg ha^{-1} $year^{-1}$	increase
Starch potato	North-east, cleared peat and sand	1990-2008	0.09	linear	not significant		0.1	linear
Starch potato	North-east, cleared peat and sand	1990-2016	0.11	linear	not significant		0.09	linear

[a] average of the first, respectively, last decade of the analysed time span

Appendix-5 Sugar beet

Summary of the genetic progress in Dutch sugar beet yield. Comparison between the situation until 2010 and until 2015

Sugar yield				Genetic progress (corrected for year effects)		Year effect (genetic progress excluded)		Progress in trial yields		Progress in farm yields	
Crop	Region and soil type		Period	Mg ha^{-1} year^{-1}	increase	Mg ha^{-1} year^{-1}	increase	Mg ha^{-1} year^{-1}	increase	Mg ha^{-1} year^{-1}	increase
Sugar beet not-resistant (sugar)	Whole country, all soil types		1981-1990	0.08	quadratic (concave, increase)	not significant		0.08	linear	0.02	quadratic (concave, increase)
			1993-2002	0.14						0.12	
Sugar beet resistant (sugar)	Whole country all soil types	*Rhizomania* resistant	1995-2008	0.16	convex	0.16	linear (1995-2008)	0.28	linear	0.23	quadratic (concave, increase)
		Rhizomania resistant	1995-2015	0.17	linear	0.19	linear	0.34	linear	0.31	linear
Sugar beet resistant (sugar)	Whole country all soil types	*Rhizomania* + *Rhizoctonia* resistant	1998-2004	0.17	linear	0.16	linear (1995-2008)	0.28	linear	0.19	quadratic (concave, increase)
		Rhizomania + *Rhizoctonia* resistant	1998-2015	0.22	convex	0.32	linear	0.46	linear	0.35	linear
		Nematode resistant	1999-2015	0.34	quadratic (concave, increase)	0.23	linear	0.51	linear	0.34	linear

[a] average of the first, respectively, last decade of the analysed time span
[b] dm = dry matter