Field Crops Research 149 (2013) 262–268

Contents lists available at SciVerse ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Genetic progress in Dutch crop yields

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ARTICLE INFO

Article history:
Received 8 February 2013
Received in revised form 8 May 2013
Accepted 14 May 2013

Keywords:
Winter wheat
Spring barley
Potato
Sugar beet
Crop yield
Genetic improvement

ABSTRACT

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. In this paper we study the progress in yields of newly released varieties in official Dutch variety trials as a proxy for the progress in genetic yield potential, i.e., yield under absence of water and nitrogen limitation and pests and diseases. The use of yields from variety trials as a proxy for genetic yield potential is justified as these are well managed and because water is hardly limiting under Dutch climate–soil conditions. We compared the genetic yield progress of winter wheat (*Triticum aestivum* L.), spring barley (*Hordeum vulgare* L.), ware and starch potato (*Solanum tuberosum* L.) and sugar beet (*Beta vulgaris* L.) over the past ca. 30 years (ca. 1980–2010) with the developments in on-farm yields over the same period. GenStat 14th edition was used to perform modified joint regression analyses (mjra) and residual (or restricted) maximum likelihood (reml) analyses of yields in order to separate year (i.e., climate and/or management) effects from variety effects. Genetic progress in yield has been linear with ca. 100 and 60 kg ha^{-1} year^{-1} (15% moisture), respectively, for winter wheat and spring barley, 580 kg ha^{-1} year^{-1} payment weight for starch potato, and, partly non-linear for sugar beet, i.e., 80–170 kg sugar ha^{-1} year^{-1} depending on resistance type of the varieties. We also analyzed significant year effects (corrected for genetic progress) for most crops in the variety trials, which point at an effect of climate (environment) and/or management in addition to the genetic effect. Farm yields of winter wheat, spring barley and starch potato have increased linearly over the last decades, with ca. 90, 70 and 320 kg ha^{-1} year^{-1} (in the same units as above). Increase in sugar yields on farms was concave (20–230 kg ha^{-1} year^{-1}) and spectacular over the last 10 years. For ware potatoes the genetic yield increase was only 20 kg dry matter ha^{-1} year^{-1} and reliable farm statistics for dry matter yields are lacking. We conclude that for the main crops in the Netherlands genetic progress in yield potential of varieties newly released over the past three decades has been substantial and largely linear. Farm yields for these crops also continued to increase, at approximately the same rates, but could not always keep pace with the combined genetic and year effects (G × E × M) in variety trials, suggesting a widening yield gap.

1. Introduction

A proposed key solution for the challenge of feeding nine billion people in 2050 is a sustainable intensification of agriculture to increase yields per unit of land and other natural or human resources. Following the concepts of production ecology (Van Ittersum and Rabbinge, 1997) several ways can be distinguished to increase crop yields. Basically, crop yields are a result of interactions between genetic features, the environment (climate and soils) and management, i.e., G × E × M interactions (Hammer and Jordan, 2007). Under given climatic conditions and assuming optimum management, the so-called potential yield level is the highest yield level that can be achieved. In practice yields will be lower due to a combination of water and nutrient limitation and pests and diseases, resulting in so-called yield gaps (Van Ittersum and Rabbinge, 1997; Lobell et al., 2009). Crop production can be increased through closing yield gaps and through increasing the potential yield level. To achieve higher yields in a high-yielding country such as the Netherlands, where yield gaps are small, an increase in potential yield through breeding is a main prerequisite to sustain progress in farmers' yields. The increase of potential yields of newly released varieties over the past decades is studied in this paper. Our aim is to depict the contribution of breeding in the progress of food crop yields in the Netherlands during the past ca. 30 years for winter wheat (*Triticum aestivum* L.), spring barley (*Hordeum vulgare* L.), potato (*Solanum tuberosum* L.) and sugar beet (*Beta vulgaris* L.). The influence of climate change and crop management improvement is only considered in the discussion, but not analyzed in detail.

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0378-4290/$ – see front matter
http://dx.doi.org/10.1016/j.fcr.2013.05.008

Since the year 2000 several studies on the contribution of breeding to yield improvement in the temperate climate area of north-western Europe have been published. Analyses on winter wheat yields for the last 25–35 years in the United Kingdom (UK) and France show an annual increase of 74–128 kg ha^{-1} $year^{-1}$ (Sylvester-Bradley, 2002; Foulkes et al., 2007; Brisson et al., 2010; Mackay et al., 2011). Fischer and Edmeades (2010) show an increase of 61 kg ha^{-1} $year^{-1}$ between 1990 and 2009 in the UK. Peltonen-Sainio et al. (2009) found a progress of 29 kg ha^{-1} $year^{-1}$ between 1970 and 2005 in Finland.

For spring barley few results are available. A yield improvement of 21 kg ha^{-1} $year^{-1}$ was found in Norway (Lillemo et al., 2010), whereas for the UK Mackay (2011) calculated an increase of 60 kg ha^{-1} $year^{-1}$ between 1982 and 2007.

For potato the only reference we found was Simmonds (1981 in Bradshaw, 2009) who estimated:"... that of the 8.9 Mg/ha increase in [fresh] yield from 1964 to 1976, 4.0 Mg/ha was environmental (better husbandry and management), 5.5 Mg/ha was due to the near replacement of cvs King Edward and Majestic with three modern varieties Pentland Crown (from SPBS), Maris Piper and Désirée...".

According to Mackay (2011) sugar yield of sugar beet in the UK increased by breeding with 0.105 Mg of sugar ha^{-1} $year^{-1}$ between 1982 and 2007 and according to Loel et al. (2011) in Germany the sugar yield increase was 0.9% $year^{-1}$ from 1964 to 2003.

Previous publications focused only on one or a few major crops and comparisons of genetic progress in yields with average farm fields were not always performed. In this study we estimated genetic progress in yield of five major arable crops grown in the Netherlands. We also analyzed the average progress in variety trials and of farm yields. We differentiated yield progress in varieties without and with resistance against some important pests and diseases of the crops sugar beet and starch potato, which are very important for the economic result of Dutch arable farmers. Due to narrow crop rotations relatively many soils in the Netherlands are infected with soil-borne pests and diseases that, in the absence of soil fumigation, prevent farmers from realizing yield potential despite optimum management.

2. Materials and methods

2.1. Data

For the analysis of the contribution of breeding in yield improvement in winter wheat, spring barley, ware potato, starch potato and sugar beet, data were collected from variety trials in the Netherlands from the late 1970s until 2010. The official variety trials were conducted by Applied Plant Research (PPO) and the Institute of Sugar beet Research (IRS). Data for ware potatoes were obtained from Plant Research International (PRI); yields were only determined in the official variety trials until 2004. Farm yields were obtained from the official Dutch census data. Good statistics of farm yields for ware potato are not available because fresh yields on clay soils in the statistics are a combination of ware potato and seed potato yields, with the latter yields being much lower because of immature harvest; also accurate data on dry matter content are not available.

Variety trials in the Netherlands are assumed to take place under optimum nutrient and crop protection management. They are generally not irrigated (see Table 1), but the relatively even and high precipitation and often high 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.

For winter wheat and spring barley the grain yield was expressed in 85% dry matter, for ware potato dry matter yield was used; starch potato yields were expressed in payment weight (a

Table 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	Average number of varieties tested per year (spread)	Soil type and region in the Netherlands[f]	Net plot size in metre (length × width)	Number of replicates	Irrigation	Source farm yield data
Winter wheat	PPO	1978–2010	1968–2008[a]	65	12.6 (7–19)	Marine clay in SW, centre, N	9 × 1.5 or 2.5	2 or 3	No	CBS[d]
Spring barley	PPO	1978–2010	1970–2007[a]	52	10.1 (2–14)	Idem	9 × 1.5 or 2.5	2 or 3	No	Eurostat
Ware potato	PRI	1977–2004	1945–1995[b]	69	29.6 (6–61)	Idem	Minimum 16 plants	1 or more	Seldom	Not available
Starch potato	PPO	1984–2010	1964–2010[b]	68	20.5 (9–33)	Sand and cleared peat in NE	4.95 × 1.5 (32 plants)	3	Yes	LEI/Avebe[e]
Sugar beet	IRS	1980–2010	1970–2008[a]	144	17.1 (8–26)[g] 22.8 (4–35)[g]	All soils and regions	14.5 × 3	3–6[c]	Yes	IRS

[a] First year of official testing.
[b] Registration year or entry on the national variety list.
[c] Six replicates in case of *Rhizoctonia* resistance variety trial.
[d] CBS – Statline: after 1991 the division of the respective marine clay areas was slightly changed.
[e] Avebe is the Dutch starch potato processing industry.
[f] N = north, E = east, S = south, W = west.
[g] Non-resistant and resistant variety trials respectively.