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Crop rotation effects on yield, technological quality and yield stability of sugar beet after 45 trial years

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ABSTRACT

Long-term field trials constitute an essential basis for research into the effects of agricultural management practices on yield and soil properties. The long-term field trial Etzdorf (Germany) was set up in 1970 and uses various crop rotations with sugar beets (*Beta vulgaris* L., SB) to investigate the influence of increasing cropping concentrations (20 %–100 %) and decreasing cropping intervals (0–4 years) on the yield and quality parameters of SB. However, evaluation of the yield stability of SB in diverse crop rotations has not been conducted in this context so far. For this reason, the yield for the last 13 years of the trial (2002 until 2014) was subjected to such an evaluation. Besides cropping interval and cropping concentration, the crop rotations investigated also differed in terms of the complementary crops cultivated (winter wheat, *Triticum aestivum* L.; alfalfa, *Medicago* ssp.; potato, *Solanum tuberosum* L. and grain maize, *Zea mays* L.). Both SB root yield and white sugar yield increased with an increasing cropping interval or decreasing cropping concentration of SB in the crop rotation. In addition, a positive effect on root yield and white sugar yield was seen when integrating alfalfa, while cultivating SB after SB displayed the lowest root yield and white sugar yield. Sugar content was lowest in SB monoculture. In order to assess stability of white sugar yield, the coefficient of variation and ecovalence were calculated, and a linear regression analysis of the individual crop rotations' annual yield was performed for the annual average of all crop rotations. When considering these three parameters, the crop rotations with a cropping interval of at least 2 years displayed higher yield stability, with simultaneously higher white sugar yield, than the crop rotations with a cropping interval of 0 and 1 year. By integrating alfalfa into the crop rotation, it was also possible to achieve above-average white sugar yield with high yield stability for a cropping interval of 1 year.

1. Introduction

In the context of crop rotation, sugar beet (SB, *Beta vulgaris* L.) is characterised by a marked yield loss if cultivated in narrow crop rotation or continuously (monoculture). This is caused mainly by infestation with the beet cyst nematode *Heterodera schachtii* Schmidt (Liste et al., 1992) or soil-borne diseases such as black root (*Aphanomyces cochlioides* Drechsler, Schäufele and Winner, 1989). Increasing proportions of SB in the crop rotation up to monoculture therefore usually lead to significant yield losses (Deumelandt et al., 2010; Hlisnikovsky et al., 2014). Whereas, also steady SB yield in monoculture compared to crop rotations was reported by Draycott et al. (1978). On farms growing SB, approximately 10 %–25 % of arable land is therefore cultivated with SB (Stockfisch et al., 2008). But this does not allow any precise conclusions to be drawn about cropping concentrations within crop rotations. Following Märländer et al. (2003), SB is included in the crop rotation every 3–4 years. For the southern German cultivation area, Graber and Risser (2013) report that 33 % of SB is cultivated with a cropping interval of 2 years, 26 % with 3 years and 40 % with 4 or more years. Cropping intervals of less than 2 years are therefore uncommon for SB. The primary preceding crops grown before SB are winter wheat

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(WW, *Triticum aestivum* L.) and winter barley (*Hordeum vulgare* L.) (Buhre et al., 2014). In some regions, potatoes (*Solanum tuberosum* L.) and maize (*Zea mays* L.) are also increasingly being included as part of crop rotations (Buhre et al., 2014; Märländer et al., 2003). At present, also energy crop rotations with a high proportion of SB and maize for biomass production are discussed (Brauer-Siebrecht et al., 2016; Jacobs et al., 2014).

In the future, however, an increase in cropping concentrations of SB in crop rotations, or the increased cultivation of SB in short, 3–4-year crop rotations (cropping interval of 2 or 3 years) is likely. The abolition of the European quota system for sugar in 2017 (European Parliament, 2013) should see an overall rise in SB and sugar production across the EU member states of around 4 %, with the largest increases in Denmark, Germany, the United Kingdom and Romania (Burrell et al., 2014). Actually, the contract offers of sugar industry for the cultivation area may result in an increase of even more than one third in classical growing areas near sugar factories (Anonymus, 2016). An increased demand for SB will be covered by extending acreage in existing SB cultivation areas (Gocht et al., 2012), and SB production will continue to be concentrated near sugar factories in order to minimise transportation costs (Isermeyer et al., 2005). This could lead to a specialisation of farms growing SB, and as such a higher SB cropping concentration may also be economically advantageous even if yield is lower. However, one prerequisite for this is that yield remains stable when cropping concentration increases. So far yield stability analysis for SB has been limited to comparing varieties under differentiated environmental conditions (Hoffmann et al., 2009; Liovic and Kristek, 2000). Only a few studies have been performed with regard to agricultural management practices such as tillage or crop rotation variants (e.g. SB-WW-WW, catch crop_SB-WW-catch crop_WW, Heyland and Hambüchen, 1990).

The question therefore arises of how increased cropping concentrations of SB in the crop rotation, or reduced cropping intervals for SB, influence yield stability. In order to be able to map the impact of agricultural management practices on yield level, long-term field trials are necessary (Körschens, 2006, 2010). Furthermore, long-term field trials are a core element of basic agricultural research, and thus are necessary to investigate site-adapted management methods (Stützel et al., 2014). However, the number of long-term field trials in Europe has decreased during the last decades. The long-term field trial in Etzdorf was set up in 1970 in a traditional SB cultivation area in Germany and contains various crop rotations with increasing SB cropping concentrations. Despite its unique conception, the trial had to be stopped in 2015 because of technical and financial reasons. SB yield has been evaluated on a regular basis over the trial period (Deumelandt et al., 2010; Fischer and Liste, 1979; Liste et al., 1992), whereas the impact of crop rotations on the yield stability of SB has yet to be examined in detail. In the context of yield evaluations from the last 13 years, this paper therefore aims to demonstrate the yield stability of SB in crop rotations with different cropping concentrations and cropping intervals.

2. Material and methods

2.1. Field site and experimental design

The investigations were performed at a long-term field trial in Etzdorf (Saxony-Anhalt, Germany, 51°43′ N; 11°76′ E, altitude 134 m), which was started in 1970 and is run by the Martin Luther University Halle-Wittenberg. The soil type is classified as a Haplic Chernozem (FAO, 2006). The soil texture in the tilled soil (0–30 cm) was that of a silt loam (250 g kg^{-1} clay, 50 g kg^{-1} sand), while the pH value was 6.9. The long-term (1970–2001) mean annual precipitation rate was 453 mm, and mean annual temperature was 9.0 °C. For

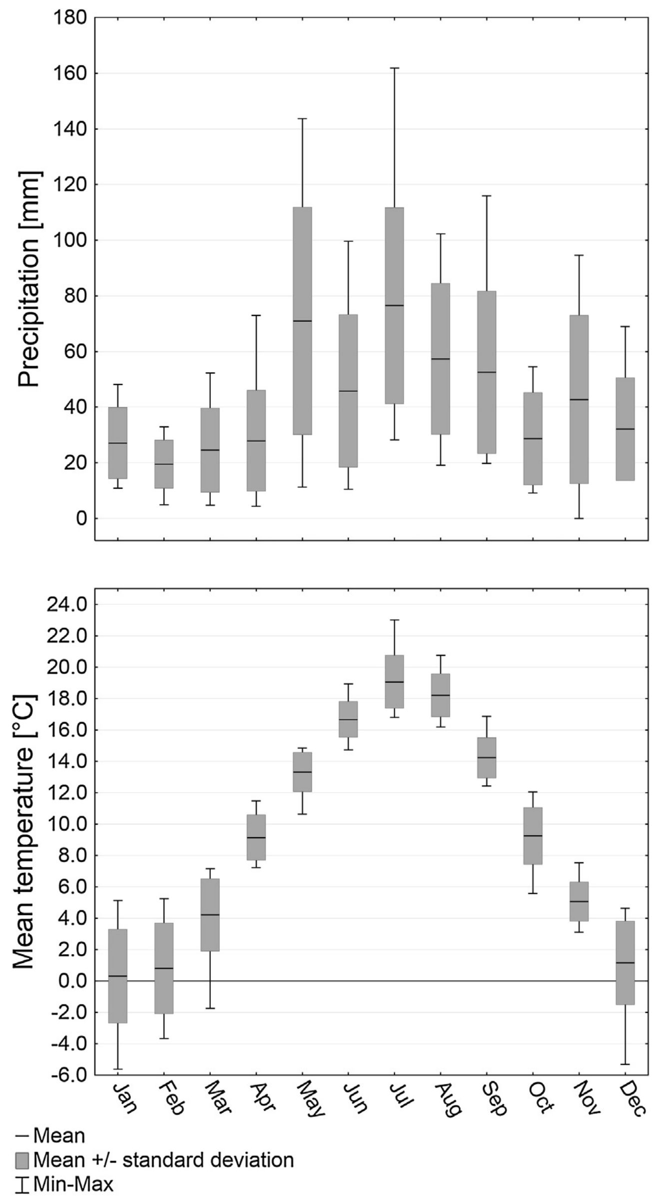

Fig. 1. Mean precipitation rate and mean temperature by month for the period 2002–2014 at the long-term field trial Etzdorf.

the reference period (2002–2014), the mean annual precipitation amounted to 506 mm (min. 350 mm, max. 663 mm), and the mean annual temperature was 9.3 °C (min. 7.6 °C, max. 10.4 °C) (Fig. 1).

Eight crop rotations were cultivated at the long-term field trial Etzdorf (Table 1). The crop rotations differed with regard to the cropping concentration of SB, the cropping interval for SB and the integration of winter wheat (WW, *Triticum aestivum* L.), grain maize (GM, *Zea mays* L.), potato (Pot, *Solanum tuberosum* L.) and alfalfa (Alf, *Medicago* ssp.). Each crop rotation field was cultivated every year. For the crop rotations consisting of two or three crop rotation fields with SB (crop rotation 2, 5 and 6, Table 1), all crop rotation fields with SB were analysed separately, meaning twelve crop rotation fields were compared.

The field trial had a block design with two replications (plot size 26.4 m^2, 8.8 m × 3.0 m). Resulting crop residues (SB and Pot leaves, WW and GM straw) were removed from the plots. Alf was cultivated as a forage crop and was usually harvested three times a year. Primary soil tillage was performed for the whole field trial in the autumn using a mouldboard plough at a soil depth of 30 cm. Mineral