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Importance of growth stage and weather conditions for the winter hardiness of autumn sown sugar beet

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ABSTRACT

The cultivation of sugar beet as a winter crop harvested in autumn of the next year is expected to contribute to a marked yield increase. Sown in autumn the plants have to survive frost during the winter. The study thus aimed to characterize the optimal growth stage, in which maximum winter hardiness is reached, and to determine the lowest temperature sugar beet plants can survive in this optimal growth stage. Furthermore, the importance of weather conditions (temperature, snow) in relation to the growth stage of the plants was assessed with a PCA (principle component analysis).

From 2009 to 2012 field trials with 5 genotypes at 3 locations in Germany were conducted, which were accompanied by greenhouse experiments with controlled frost experiments. The survival rate after winter was mainly affected by the environment (year × location, 93%), while the genotype effect (1%) was rather low. An optimal growth stage for maximum survival was determined at a thermal time after sowing of 600–900 °Cd (base temperature 3 °C). The greenhouse experiments revealed that in this optimal growth stage the plants survived a minimum temperature of −7 °C (−6 °C to −8 °C). In the field trials, the impact of the growth stage reached before frost (46%) on the survival rate after winter was considerably higher than the actual weather conditions during winter (17%). In particular too much advanced growth (dry matter yield of root and leaves, root diameter) resulted in a high susceptibility for frost damage. Regarding the weather conditions, the number of frost days with snow and the minimum temperature during winter without snow had the highest importance for survival.

The knowledge of the required thermal time to reach maximum winter hardiness can be used to optimize the sowing date of autumn sown beets in different environments. However, a conflict may occur between the aim to obtain optimal winter hardiness and to reach maximum yield in the next year.

1. Introduction

Cultivating autumn sown sugar beet as a winter crop (winter sugar beet) is discussed to increase the productivity of the whole chain of sugar production (Hoffmann and Kluge-Severin, 2010). Theoretic yield increases of 26–34% have been calculated for winter beet harvested in autumn of the next year (Jaggard and Werker, 1999; Hoffmann and Kluge-Severin, 2010). To realize this yield gain in commercial farms, a sufficient winter hardiness, which allows the plants to survive the winter without damage, is required for sugar beet cultivation.

Hoffmann and Kluge-Severin (2011) showed that a winter beet crop can easily be established in autumn. In their field trials from 2005 to 2007 the plants survived the winter under the temperate climatic conditions of Germany quite well. However, sometimes the survival of the beet crop seems to be difficult. In 9 field trials in Germany and Belarus, Kirchhoff et al. (2012) showed that the survival rates of autumn sown sugar beet after winter differed largely in the environments. For 4 regions of sugar beet cultivation in Germany, representing different climatic conditions in Central Europe, Reinsdorf and Koch (2013) calculated a probability of frost killing of 10–35% of the crop in a worst case scenario. Also for autumn sown sugar beet for seed production, Senff (1958) and Kockelmann and Meyer (2006) reported several problems concerning the survival of the young sugar beet plants during frost periods. Therefore, one of the most essential issues for the performance of the winter beet crop seems to be the survival of frost incidences during winter.

The weather conditions during winter are definitely important for the survival of the sugar beet plants. It is well known that a snow cover can contribute to a frost protection of the plants due to its thermo-insulating effects (Goodrich, 1982; Sokratov and Barry,

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2002). But the minimum temperature during winter is probably the most important factor which may affect the survival rate.

Spring sown sugar beet can only survive short periods with air temperatures down to −10 °C in autumn without any damage (Bürcky, 1981). The freezing point of the root tissue of fully developed sugar beet was between −2 and −4 °C in lab experiments (Chelemski, 1967). For autumn sown sugar beet, Kirchhoff et al. (2012) showed that they can survive air temperatures down to −23 °C under field conditions, provided that protection by snow cover was given (Kirchhoff, 2013a). Senff (1961) reported that soil temperatures were lethal for autumn sown beets at −10 °C, while Reinsdorf and Koch (2013) calculated a lethal temperature for the root tissue of −6 °C based on field trials. But so far, no experimental data are available concerning the minimum temperature for autumn sown sugar beet plants without snow cover which can serve as a data base to estimate the possibility for survival.

Besides the weather conditions, the growth stage of plants may also influence the ability to survive frost. For oil seed rape it has been found that plant development and growth stage, affected by sowing date and plant density, had a marked impact on the winter hardiness (Velicka et al., 2005, 2006; Velicka et al., 2011; Honermeier, 2006). It has also been reported that sugar beet plants with a root diameter between 5 and 25 mm can survive low temperatures better than bigger or smaller plants (Senff, 1958; Kockelmann and Meyer, 2006; Reinsdorf et al., 2013). But it has not yet been analyzed how the optimal growth stage of sugar beet plants for maximum winter hardiness can be characterized. Often the growth stage of crops, cultivated under different environmental conditions, is characterized with thermal time, in particular, if temperature is the limiting growth factor.

Kirchhoff et al. (2012) found a highly significant genotype by environment interaction for the survival of 396 *Beta* accessions, including also commercial sugar beet hybrids, after winter which they explained with differences in growth and vitality of the genotypes before winter. Weather conditions in autumn and different requirements for growing can result in differences of the growth stage of genotypes when the first frost occurs. But there is a lack of knowledge regarding the effect of weather conditions in autumn, before the first frost occurs, on growth and moreover, the survival rate of sugar beet genotypes. Furthermore, it is not clear which is the minimum temperature for young sugar beet plants in a growth stage which is optimal for maximum winter hardiness.

Our study thus aimed (i) to analyze the effect of the growth stage of autumn sown sugar beet on winter hardiness, (ii) to determine the minimum temperature for young sugar beet plants within the optimal growth stage for survival under controlled greenhouse and under field conditions and, (iii) to assess the importance of different weather conditions and parameters describing the growth stage on the survival rate of autumn sown sugar beet.

2. Materials and methods

2.1. Field trials

Field trials with 5 sugar beet hybrids in 4 replications were conducted as randomized block design near Göttingen, near the Harz Mountains and near Kiel for 4 years (2009/10, 2010/11, 2011/12, 2012/13) (Table 1). In 2010/11 no field trial had been carried out near the Harz Mountains, so altogether only 11 environments were considered. Sugar beet hybrids were provided by Strube Research (breeding company) which were chosen with regard to different winter hardiness. The pelleted seeds were sown in 6 row plots of 8 m length, 8 cm apart in the row and 45 cm row distance in August. Singling was done manually to a population density of 96,000 plants ha^{-1} in the 4–6 leaf stage. In October and December

Table 1
Characterization and meteorological data of the field trials 2009–2013.

Year	Location (GPS data)	Sowing date	Thermal time (°Cd)[a] and (days after sowing)			T_{min}[b]	Snow height at T_{min}	Cold sum[c]	Frost days with T_{min} < 0 °C (days with snow)	Critical days with T_{min} < −7 °C (days with snow)	Critical T_{min} without snow
			To 1st harvest[d]	To 2nd harvest[d]	To −7 °C	°C	cm	°Cd	n (%)	n (%)	°C
2009/10	Göttingen (51°28′N, 9°55′E)	04.08.2009	917 (86)	1081 (120)	1102	−19.3	13	−254	57 (88)	24 (92)	−7.2
	Harz (52°11′N, 10°54′E)	11.08.2009	875 (86)	1018 (112)	1036	−20.5	18	−309	65 (86)	24 (100)	−5.5
	Kiel (54°19′N, 9°58′E)	14.08.2009	763 (87)	875 (116)	880	−11.8	9	−250	72 (90)	22 (100)	−4.4
2010/11	Göttingen (51°29′N, 9°53′E)	09.08.2010	759 (80)	878 (126)	877	−17.4	20	−207	57 (65)	20 (85)	−11.3
	Kiel (54°19′N, 9°58′E)	11.08.2010	734 (82)	798 (125)	797	−12.4	19	−258	74 (68)	24 (96)	−7.3
2011/12	Göttingen (51°28′N, 9°55′E)	10.08.2011	909 (84)	954 (111)	1060	−19.0	1	−141	21 (52)	13 (77)	−14.3
	Harz (52°16′N, 10°56′E)	01.08.2011	1134 (100)	1178 (126)	1280	−19.9	2	−151	21 (81)	11 (100)	−5.3
	Kiel (54°19′N, 9°59′E)	04.09.2011	535 (64)	580 (94)	634	−16.4	8	−107	21 (86)	7 (100)	−3.9
2012/13	Göttingen (51°34′N, 9°53′E)	08.08.2012	863 (77)	957 (111)	1038	−11.8	3	−155	56 (73)	17 (94)	−8.5
	Harz (52°15′N, 10°58′E)	20.08.2012	732 (70)	822 (105)	823	−15.0	7	−173	62 (90)	13 (100)	−4.3
	Kiel (54°19′N, 9°59′E)	15.08.2012	714 (79)	785 (111)	785	−13.5	17	−198	73 (75)	14 (100)	−5.1

[a] Cumulated daily mean air temperature in 2 m height after sowing, base temperature 3 °C, values below 3 °C were set to zero.
[b] Minimum temperature during winter.
[c] Cumulated daily mean air temperatures in 2 m height below 0 °C during winter.
[d] 1st harvest in October, 2nd harvest in December.