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Manganese application increases winter hardiness in barley

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ABSTRACT

Manganese (Mn) deficiency is commonly connected with soil properties, and application of Mn is frequently performed to winter barley (*Hordeum vulgare* L.) in fields with a history of deficiency. Since the availability of Mn also is affected by seasonal variations, there is a risk of excessive application in some seasons while the application is not sufficient in other seasons in such fields. The objective of this study was to investigate the effect of foliar application of Mn in autumn and early spring on barley winter hardiness, in combination with or without N application in autumn. We also evaluated a commercially available Mn-scanner as a tool to identify the need for Mn application. Two field experiments per growing season were performed in south Sweden in 2010–2011 and 2011–2012 in fields where Mn deficiency often occurs. Foliar applications of various Mn products were made once (in October) or twice (in October and in March the following year). A single dose of 0 or 30 kg ha^{-1} N was applied, as N—NO_3, in October. Barley leaves were collected and Mn status determined with the NN-Easy55 Mn-scanner. Yield was determined in the field experiments in 2011–2012. Our results showed that the requirement of Mn application varied between sites and seasons and was affected by N supply. Mn application increased the winter survival by 33% and the grain yield by 36% in the barley plants with the lowest Mn status in autumn. The risk of Mn deficiency increased when N (NO_3—N) was applied in autumn. In one of the harvested field experiments, yield was suppressed by N application in autumn and was recovered by Mn application. Repeated Mn applications might be required to increase winter survival and grain yield, especially when N has been applied in the autumn. To reach an optimal Mn application, tools such as the NN-Easy55 Mn-scanner can be used to monitor the Mn status of the plants. Thereby unnecessary application of Mn is prevented and sufficient amounts are applied during deficiency.

1. Introduction

Manganese (Mn) is an essential micronutrient for plant growth, as it is required in many processes e.g. photosynthesis. It is also involved in defence mechanisms, where Mn acts as a cofactor in many enzymes, such as superoxide dismutase, defending the plant against free radicals, and in enzymes involved in the biosynthesis of lignin and flavonoids (Marschner, 1995). Manganese deficiency in crops is prevalent in many areas of the world and is often due to unfavourable soil properties, e.g. high pH or well-drained loose soils that favour oxidation of Mn^{2+} to the plant-unavailable form MnO_2 (Page, 1962). There are particular problems with Mn deficiency in winter barley (*Hordeum vulgare* L.) (Reuter et al., 1988). Adequate Mn status of barley seeds and plants can increase plant survival, tiller development, plant size and grain yield (Longnecker et al., 1991; Longnecker and Graham Card, 1993; Hebbern et al., 2005; Birkelund Schmidt et al., 2013). Furthermore, Mn deficiency increases the risk of drought stress in barley due to reduced epicuticular wax layer and as a consequence, increased transpiration (Hebbern et al., 2009).

In Sweden, Mn deficiency often occurs in fields with sandy soil and high pH. Since the oxidation of Mn depends of climatic conditions the variation between seasons may be significant. Foliar application of Mn in autumn is commonly practised by farmers to increase winter hardiness in areas where deficiency is common. Application of Mn in early spring is also frequently performed and is believed to aid the recovery of weak plants. Thereby, there is a risk of an excessive application of Mn in some seasons while the application is not sufficient in others. Nitrogen (N) may also be applied in autumn to increase the growth of the crop before winter. However, increased growth through N fertilisation can reduce the Mn status of the plants by dilution effects and thereby affect winter survival. It has been

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shown that application of N generally increases the production of tillers (Alzueta et al., 2012), which may increase the tiller mortality due to increased competition for resources (del Moral and del Moral, 1995).

Manganese deficiency in plants may occur latently, long before any symptoms are visible. Thus, the total impact of manganese deficiency on the crop is unknown. Various methods for determining the Mn status of plants have been developed, many of which are based on measuring fluorescence (Adams et al., 1993; Val et al., 1995; Birkelund Schmidt et al., 2013). One such Mn-scanner, the NN-Easy55 Plant Efficiency Analysing System (NutriNostica, Denmark) is reported to be accurate in determining the Mn status of the plant (Husted, 2007).

The main objective of the present study was to investigate the effect of foliar application of Mn in autumn (October) and early spring (March), with or without N applied in autumn, on the winter hardiness of barley. A secondary objective was to evaluate the NN-Easy55 Mn-scanner as a tool to monitor plants and identify the need for Mn application.

Our starting hypotheses were that (i) Mn status and winter hardiness are improved by foliar application of Mn; (ii) application of N in autumn reduces winter hardiness, and (iii) the NNEasy-55 Mn-scanner can be used as a tool to identify the need for Mn application to increase winter hardiness.

2. Materials and methods

2.1. Field experiments

Two field experiments, on-farm trials at Kristianstad and Tollarp, were performed per season in 2010–2011 and in 2011–2012 by the Field Research Unit at the Rural Economy and Agricultural Societies (Hushållningssällskapet, Kristianstad, Sweden). Fields with high risk of Mn deficiency and where the farmers frequently use foliar application of Mn to winter barley were selected. The experiments were set up in parts of the fields with an even establishment of winter barley cv. 'Apropos'. Sites, dates of Mn treatments and the properties of composite soil samples from the four field experiments are shown in Table 1. Mean temperatures in October–April at the field experimental sites during 2010–2012 are shown in Fig. 1.

The experiments had a split-plot design with N treatments in main plots (36 m × 12 m) and Mn treatments in subplots (4 m × 12 m). All treatments had three replicates. The two N treatments used were 0 and 30 kg N ha^{-1} as NO_3—N (YaraLiva®, Kalksalpeter, Yara), applied in early October. The recommended rates of two Mn foliar products used in 2010–2012 were: $MnSO_4$ (3 kg ha^{-1} = 1 kg Mn ha^{-1}) and Mantrac Optiflo (Yara) (1 L ha^{-1} = 0.5 kg Mn ha^{-1}). In 2011–2012, an additional treatment of NoroTech™ Mangan (1 L ha^{-1} = 0.15 kg Mn ha^{-1}) was included in the experiments. The Mn products were applied once, in October (DC 21; Zadoks et al., 1974) or twice, in October and

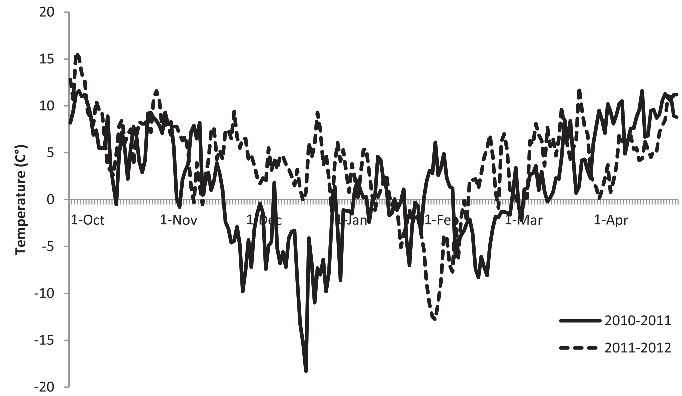

Fig. 1. Mean temperatures at the field experimental sites October–April in 2010–2011 and 2011–2012.

March (Table 1). Therefore, in 2010–2011 there were four Mn treatments and a control treatment without Mn, while in 2011–2012 there were six Mn treatments and a control. On each application occasion the recommended rate was applied, so the treatments with applications in October and March received twice as much Mn as the treatment with one application in October. A dose of 50 kg ha^{-1} kieserite ($MgSO_4 \times H_2O$) was applied to all plots in the field experiments to overlap any effect of sulphur in $MnSO_4$.

2.2. Determination of plant Mn status and winter survival

Four young leaves without any visual sign of stress were collected from each plot about two weeks after Mn foliar application i.e. beginning of November and April. The leaves were stored at 8 °C for a maximum of 48 h and the Mn status of each leaf was determined with the NN-Easy55 scanner (NutriNostica Aps, Denmark). The mean PEU values of the four leaves were used in the statistical analyses. The leaves were adapted to darkness for 25 min with clips supplied with the Mn-scanner before scanning. The Mn-scanner delivers a PEU (Plant Efficiency Unit) value giving the Mn status of the plants. PEU values >95 show no deficiency, 90–94 no or slight deficiency, 75–89 deficiency; 60–74 strong deficiency; and <60 very strong deficiency (NutriNostica, 2007).

In a 1 m pegged out section of two seed rows per plot, the number of plants m^{-2} was determined in mid October and in April in connection with the leaf sampling for PEU measurement. The percentage of plant survival was then calculated.

2.3. Yield

Two trials in 2012 were harvested (23–27 July) with a plot combine SAMPO 2010 (SAMPO-ROSENLEW, Finland) equipped

Table 1
Sites of field experiments, dates of Mn application and soil properties.

Year	Latitude, longitude	Date Mn applied		Soil properties					
Field experiment		Autumn	Spring	pH	OM (%)	Clay (%)	Sand (%)	P–AL (mg kg^{-1})	K–AL (mg kg^{-1})
2010–2011									
Kristianstad 1	56°0.07′N, 14°4.4 ′E	26 October 2010	30 March 2011	7.7	4.9	7	73	230	50
Tollarp 1	55°56′N, 14°0.3′E	26 October 2010	30 March 2011	6.9	4.6	6	71	80	110
2011–2012									
Kristianstad 2	56°0.12′N, 14°6.28′E	3 October 2011	23 March 2012	6.6	1.8	5	85	180	190
Tollarp 2	55°56.9′N, 13°56.1′E	21 October 2011	22 March 2012	6.9	3.9	6	72	330	210