EFFECT OF LOW TEMPERATURE ON BORON NUTRITION OF OILSEED RAPE AND SUNFLOWER

This thesis is submitted for the degree of Doctor of Philosophy

Submitted by

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DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary educational institution.

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ABSTRACT

Several reports appear in the literature linking low temperature damage in plants with boron (B) deficiency and alleviation of low temperature injury with B application has been reported in some crops and trees. These results imply that low temperature might increase plant B requirements, beside the reduction of B uptake by plant roots, or that low B tissues might be more sensitive to cold temperature damage than B adequate tissues. In controlled experiments, it has been shown that low root zone temperature (RZT) induces B deficiency in cassava, a tropical root crop. Apart from this, there are few definitive detailed investigations on low temperature effects on B nutrition of plants, including temperate species which are more tolerant of low temperature.

Winter oilseed rape (*Brassica napus* L.), a crop sensitive to low B supply, is a major crop in the middle and lower Yangtse river basin, China, where low B soils are widespread. Appearance of B deficiency in oilseed rape often coincides with cold weather during its winter and spring growth. However, the incidence and severity of B deficiency of oilseed rape plants and the efficacy of B fertilization varies from year to year and location to location in ways that are not explained simply by differences in cultivar, agronomy or soil B levels. Low temperature is probably one of the important environmental factors influencing growth and yield of oilseed rape in relation to B nutrition.

Therefore, the objective of the studies in this thesis was to investigate mechanisms of low temperature effects on B nutrition of plants with emphasis on oilseed rape. Field and glasshouse experiments were carried out and the physiological basis of plant response to B at different air and root temperatures is discussed.

A field experiment with oilseed rape cv. Zheyouyou 2 was carried out on a red soil (Hapludult, US Soil Taxonomy) with low B availability in Zhejiang province, China. Canopy covers made from transparent plastic sheets, which increased night temperatures by up to 1.5 ^{o}C around shoots for 15 days in early February, strongly increased shoot dry weight at all levels of B supply. Furthermore, covering plants increased shoot dry weight of B deficient plants without increasing their leaf B concentration. This suggests that internal B requirements were decreased by canopy covering, possibly due to higher temperatures within the canopy.

Experiments conducted to investigate the effect of RZT (10 and 20 ^{o}C) on oilseed rape cv. Hyola 42 response to B in solution culture, in summer and winter, showed that regardless of canopy conditions, low RZT (10 ^{o}C) promoted the distribution of shoot B towards the actively growing leaves, especially when B supply was low. At low B supply, B deficiency symptoms appeared later at 10 ^{o}C than 20 ^{o}C RZT and B concentrations in the youngest fully opened leaves (YOL) were higher in plants grown at RZT of 10 ^{o}C than that at 20 ^{o}C. Growth of plant dry weight (DW) was not affected by RZT in the summer but was greatly reduced at 10 ^{o}C than 20 ^{o}C in winter. In B adequate plants, shoot to root ratio (S/R ratio) was not affected by RZT regardless of canopy conditions. By contrast, S/R ratio was smaller in low B plants at 10 ^{o}C than 20 ^{o}C. In addition, low RZT delayed occurrence of plant B deficiency symptoms regardless of plants' pre-treatment RZT (either 10 or 20 ^{o}C). These results appeared to contradict the response to low RZT found in previous studies with cassava.

In a subsequent experiment, low RZT of 5 ^{o}C not only greatly reduced plant DW production of oilseed rape, but also accentuated plant B deficiency. Partitioning of B into the young growing shoots was also depressed and a significant decrease of B concentration in the youngest shoot parts was caused by 5 ^{o}C RZT in comparison with that at the control RZT (10 ^{o}C). Similar results were also observed in sunflower (*Helianthus annuus* L. cv. Hysun 25). But B deficiency symptoms in sunflower were induced by RZT as high as 12 ^{o}C, when plants were supplied with 0.25 μM B, whilst these plants were free from B deficiency at warmer RZT (17 - 27 ^{o}C). Higher external B concentrations were required at such RZT (Chilling temperature) for plant growth free from B deficiency. Therefore, there is a RZT threshold below which an increased response to B is expected in plants of oilseed rape and sunflower. And in the range of chilling RZT, the external B requirement for shoot growth increased with lower RZT. The threshold RZT was considerably higher in the chilling-sensitive plant species, sunflower, than in oilseed rape, a chilling-resistant plant species.

At chilling RZT, leaf functioning was impaired by low B supply as measured by potassium (K) leakage from the youngest mature leaf blade (YML) of sunflower, whereas it was much less directly affected by RZT, and there was no effect of RZT on B- adequate plants. By contrast to leaves, root function was impaired more by chilling RZT than low B.

Despite their different threshold RZT, in both oilseed rape and sunflower, the rates of B uptake (BUR) and B translocation from root to shoot (BTR) were dramatically depressed by chilling RZT especially at low B supply (0.2 μM B): being only 30% of those at the control (5 ^{o}C vs 10 ^{o}C RZT) in oilseed rape and 33% (10 ^{o}C vs 20 ^{o}C RZT) in sunflower, respectively. By contrast, there was little or no difference over a range of warmer RZT (10 - 20 ^{o}C for oilseed rape, and 20 – 27 ^{o}C for sunflower). It is predicted that higher rates of B application will be required for plant growth when soil temperature is below a critical threshold, which is between 5 and 10 ^{o}C for oilseed rape, and about 17 ^{o}C for sunflower, respectively. Below the threshold RZT plant B deficiency was induced and accentuated due to impairment of B translocation into growing shoot parts besides the decrease of B uptake rate and B transport rate and greater shoot to root ratio.

In comparison with RZT, little is known about causal mechanisms linking cold air temperature and B nutrition. Experiments in this thesis showed not only B transport to the shoot was strongly reduced by low night air temperature during a 6 day period (11.7

– 19.4 vs 15.5 – 23.5 ^{o}C), but also that an overnight chilling (at 0 ^{o}C) could cause more severe injury to low B than adequate B leaves of oilseed rape plants, expressed by higher solute leakage, in comparison with control (at 10 ^{o}C). Moreover, after chilling treatment, solute leakage from low B leaves was increased by exposure to light, which suggests that low temperature injury to leaves in low B plants after a freezing night in the field is at least partly a consequence of light induced damage of leaves.

In summary, at chilling temperature, B uptake, transport and partitioning into growing shoots are strongly impaired, and B use efficiency in the growing tissues might be reduced as well. Low temperature contributes to plant B deficiency also by increasing S/R ratio, so that shoot B demand is not satisfied by available B. Furthermore, low air temperature might increase the internal B requirement for shoot growth. To further understand mechanisms of low temperature, especially the air temperature, effects on plant responses to B, more research is needed, such as the relationship between low temperature and B incorporation into cell walls which may play an important role in leaf tolerance to chilling temperature.

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PUBLICATIONS

The publications listed below originated from the research contained in this thesis:

Ye ZQ, Huang LB, Bell RW and Dell B 2003 Low root zone temperature favours shoot B partitioning into young leaves of oilseed rape (*Brassica napus*). Physiol. Plant. 118: 213-220.

Ye ZQ, Bell RW, Dell B and Huang LB 2000 Response of sunflower to boron supply at low root zone temperature. Commun. Soil Sci. Plant Analy. 31: 2379-2392.

Ye ZQ, Bell RW, Huang LB, Yang Y and Dell B 1997 Covering plants at night in the winter increased seed yield of transplanted oilseed rape (*Brassica napus* L. cv. Zheyouyou 2) on a low boron soil. *In* Boron in soils and plants. Eds. R W Bell and B Rerkasem, pp. 29-34. Kluwer Acad. Publishers, Dordrecht.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF PLATES

Page

List of Plant Species Names

Species	Plant
Antirrhinum majus	Snapdragon
Apium graveolens	Celery
Arabidopsis thaliana	
Arachis hypogaea	Peanut
Asparagus officinalis	Asparagus
Avena sativa	Oats
Beta vulgaris	Sugar beet
Brassica napus	Oilseed rape
Brassica oleracea	Broccoli
Citrullus vulgaris	Watermelon
Cucumis melo	Muskmelon
Cucumis sativus	Cucumber
Cucurbita pepo	Squash
Helianthus annuus	Sunflower
Hordeum vulgare	Barley
Lilium longiflorum	Lily
Lycopersicon esculentum	Tomato
Malus domestica	Apple
Manihot esculenta	Cassava
Nicotiana tobacum	Tobacco
Oryza sativa	Rice
Triticum aestivum	Wheat
Vigna mungo	Black gram
Vigna radiata	Green gram
Xenopus laevis	
Zea mays	Corn, maize