Waterlogging and canola

By Murray Hartman

1. As root oxygen levels decline, energy generation from root stored sugars switches from aerobic respiration to less efficient anaerobic processes (glycolysis and fermentation pathways). The cytoplasm of root cells becomes acidic which then causes cell death. In addition, cell damage occurs after reintroduction of oxygen to the root system because the systems that deal with oxygen radicals have been affected.
2. As root energy generation declines and root cells die, the active transport of nutrients to shoots declines (most notably the macronutrients). The oxygen depleted wet soil causes soil microbes to switch to anaerobic metabolism which not only promotes denitrification (and thus available N loss) but also chemical reduction of iron (i.e. Fe^{+3} is reduced to Fe^{+2}), manganese and sulphate (and thus available S loss). Iron, manganese and sulphide toxicity can then occur, but this is likely of secondary importance compared to macronutrient deficiency.
3. Warm flooded soil may show symptoms earlier than cold waterlogged soil since soil microbes are more active and deplete oxygen levels more quickly, and possibly produce toxic levels of Fe^{+2} and Mn^{+2} more quickly. Plants flooded under cold conditions may end up with higher damage since plant response mechanisms may be reduced. There is some evidence that plants exposed to moderately saturated soils can become somewhat acclimatized and show better tolerance to subsequent oxygen depleted soil.

4. Flooded soil abiotically emits ethylene which is a plant hormone with many different effects on plant physiology. Submerged roots also produce more ethylene precursors (ACC) that are transported via xylem to above ground parts. There is a concert of hormonal changes involving other hormones than ethylene. After flooding and one photoperiod (~12 hours), synthesis of ethylene precursors are accelerated and the ACC oxidase / receptor sites in above ground parts are also up-regulated. Under waterlogged situations, ethylene promotes stem elongation (premature bolting) which may be a survival mechanism to allow some seed production, or to increase plant height above water and thus increase flow of oxygen down to roots. However, canola does not seem to have specialized channels of cells (aerenchyma) that can conduct oxygen more readily. Research has shown that external ethylene application strongly mimics the symptoms of waterlogging.
5. Mature plants have been described as more tolerant of waterlogging than seedlings. Canadian studies with cereals and flax has found that young seedlings (2 day) were more sensitive than older seedlings. Chinese research indicates the seedling stage is most susceptible, followed by stem elongation and pod formation, whereas the least vulnerable was the flowering stage. However, one European study reported greater biomass reductions with waterlogged 11 day old *B. napus* seedlings than 5 day old.
6. Data on canola yield loss due to waterlogging is sparse, and the Canola Growers Manual describes one pot report from Argentina. There was a yield loss reported with the shortest waterlogging period of 3 days, so there may be yield loss with even shorter periods of waterlogging. But the seedling stage (4 leaf) was conducted in their winter period with temperatures of 6 – 7 C. Canadian studies on 2 leaf cereal crops found that 1, 3 and 7 day flooding caused 0, up to 9% and 40-60% yield losses respectively. Another Canadian greenhouse trial found yield reductions from 7 day flooding at the 2 leaf stage of flax, oats, barley and spring wheat to be 24, 39, 57 and 42% respectively.

7. There has been some research that found differences in waterlogging tolerance between mustard / rapeseed species (*B. juncea* best, *B. napus* worst) or germplasm (*B. rapa* waterlogging tolerance could be achieved through recurrent selection). Waterlogging tolerance was partly related to development of adventitious roots. Chinese research has found varietal differences in waterlogging tolerance of germinating *B. napus* seeds, and in their trials *B. juncea* had less tolerance than *napus or rapa.*
8. Chinese research has reported some alleviation of waterlogging stress in canola by application of fertilizer (mainly N, but also P and K), and / or growth regulators.

A concise summary of waterlogging effects on plant growth from a section of a recent paper; excerpted from Bedard-Haughn (Can. J. Soil Sci., 2009)

Effects on Plant Growth

Even when the field is trafficable at the surface, and the crop is seeded in a timely fashion, the producer may encounter issues associated with excess water due to the presence of a shallow water table. In examining the root system of a winter wheat (Triticum aestivum) crop, Brisson et al. (2002) identified the proportion of roots in the water table as the most significant stress variable explaining plant response to excess water. Where the water table is less than 1 m from the soil surface, it may influence soil aeration, nutrient availability, and plant available moisture, but the net effect on plant growth will vary widely with crop type (Evans and Fausey 1999). However, the significance of the water table depth will also vary dramatically according to soil texture. Assuming comparable climate and crop type, the optimum water table depth for plant growth will be shallower for sandy soils and deeper for clay soils because sandy soils have thinner capillary fringes (Warrick 2000).

The impacts of excess water conditions on plant growth and metabolism have been studied extensively and are summarized in the works of Drew (1992, 1997), Jackson and Drew (1984), Gibbs and Greenway (2003), and Greenway and Gibbs (2003). The reader interested in details on plant physiological responses and adaptations to waterlogged or anoxic conditions should refer to these comprehensive reviews. Some of the dominant effects on plant growth and related plant response to crop yield are summarized below.

Although some plants are able to withstand hypoxic conditions, for most, O_2 shortage is the first and primary factor influencing root response to excess water (Drew 1997). Low O_2 concentrations limit root respiration and drastically reduce the energy available from the oxidation of glucose, with up to 95% reductions in ATP production (Barrett-Lennard 2003). Accumulations of ethylene and CO_2 further suppress or alter root growth and development. When saturation persists, anaerobic respiration occurs, and nitrite and the reduced forms of iron (Fe^{+2}) and manganese (Mn^{+2}) may accumulate to injurious levels. Eventually, hydrogen sulfide (H_2S) may also accumulate, killing plant roots (Evans and Fausey 1999; Jackson and Drew 1984). Given these effects on plant root metabolism, plants tend to develop a smaller, more superficial rooting pattern when a high water table is present (Zhang et al. 2004), which in turn has implications for nutrient demand and the plant's response to drought and/or temperature fluctuations if the water table recedes later in the growing season (Jackson and Drew 1984). For many species, there is an interacting effect between the timing of excess water and plant growth stage, with young, actively growing seedlings generally being most vulnerable to damage and dormant plants, with their much lower respiration rates, being least vulnerable (Huang 2000).

Excess water conditions may also impact the ability of a plant to take up inorganic nutrients due to the effects on processes associated with solute movement across membranes (Barrett-Lennard 2003). Uptake of essential nutrients such as N, P, and K takes place against gradients of chemical and electrical potential, which requires energy inputs from aerobic respiration; respiration is inhibited under anaerobic conditions making nutrient uptake energetically unfavorable (Greenway and Gibbs 2003). For example, Huang et al. (1995) reported reduced concentrations of N, P, K,Mg, and Zn in wheat shoots under waterlogged conditions (and an increased concentration of these same elements in the wheat roots). Plant nutritional value or crop quality can be affected by the amount and timing of nutrient availability. Insufficient N availability during the grain fill period results in low grain protein (Miller et al. 2002), where grain protein is a quality index for cereal crops.

The inhibition of root growth can also decrease the hydraulic conductivity of the root system, stimulating stomatal closure, reducing transpiration and water uptake, and leading to wilting (Jackson 1979). Photosynthesis in water-sensitive plants also decreases rapidly under excess water in the soil (Evans and Fausey 1999; Huang 2000). Other reported shoot responses to excess water include elevated plant temperature, changes in growth patterns (such as epinastic growth, hypertrophic swelling and stem elongation), slowed growth and dry matter accumulation, premature senescence, and sometimes death [summarized in Evans and Fausey (1999)].

The general inhibitions of shoot growth and leaf senescence have been attributed to decreased synthesis of auxins, gibberellins, and cytokinin (three of the five major plant growth hormones) and increased synthesis of abscisic acid (ABA) and ethylene (the other two major plant hormones) and their translocation from plant roots to shoots (Huang 2000).

Weed and Disease Pressures

Where flooding and excess water lead to late planting or to no crop being seeded at all, weeds have a competitive advantage and can become increasingly problematic for several years if allowed to go to seed. Floodwaters from over-banking streams may also introduce new weed species into affected areas. Unfortunately, an additional consequence of flooding and excess water is slowed microbial degradation of herbicide and hence an increased risk of carryover from year to year, increasing the potential for damaging annual crops in the year following application (McGillberry 1998).

Many of the aforementioned excess-water stresses on root physiology make plant roots more susceptible to soil-borne pathogens, including fungi, bacteria, nematodes, and viruses (Rao and Li 2003; Stolzy and Sojka 1984). Pathogen-dominant fungi such as Rhizoctonia, Pythium and Phytophthora are commonly associated with excess water conditions (Duniway 1979; Huang 2000). Fungi species can have resting oospores that remain dormant for extended periods and only become active and of concern to agriculture under optimum conditions (Stolzy and Sojka 1984). Many fungal pathogens may be managed by fungicide application, but the timing of the application can be critical to minimize risk of seedling damage.

Other Abstracts with some relevance for canola:

Structural changes in rapid-cycling *Brassica rapa* selected for differential waterlogging tolerance

Christine J. Daugherty, Sharon W. Matthews, Mary E. Musgrave

Canadian Journal of Botany, 1994, 72:1322-1328, 10.1139/b94-162

Abstract

Two populations of rapid-cycling *Brassica rapa* L. selected for differential waterlogging tolerance and a commercially available standard population were compared in their structural responses to waterlogging. Rates of dry matter accrual were similar under drained conditions but were lower after 6 days of waterlogging, especially in the sensitive population. Chlorophyll content of leaves from the sensitive population was significantly lower than the tolerant population. Examination of the foliage by TEM after 4 days of waterlogging revealed large starch grains that apparently disrupted the grana stacks in the sensitive population. Root morphology also distinguished the populations. After 8 days of waterlogging, numerous adventitious roots were visible in the standard and tolerant populations but not in the sensitive population. No aerenchyma was detected by examination of root cross sections. Mitochondrial morphology was affected by waterlogging, resulting in elongate, branched organelles. Isozyme analysis of malic enzyme, malate dehydrogenase, glucose-6-phosphate dehydrogenase, and pyruvate decarboxylase revealed no differences due to population, treatment, or duration. Isozymes of alcohol dehydrogenase varied with duration of waterlogging, and isozyme forms of phosphoglucomutase were distinct depending on the population. The appearance of stress-specific structural features in populations of *B. rapa* is discussed in relation to differences in waterlogging tolerance.

Characterization of populations of rapid-cycling *Brassica rapa* L. selected for differential waterlogging tolerance

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Journal of Experimental Botany, 1994 Volume45, Issue3 Pp. 385-392

Abstract

By challenging a heterogenous population of plants (rapid-cycling *Brassica rapa* L.) with waterlogging stress, we selected plants which differed in their response to root zone hypoxia. These individuals were placed into 'tolerant' and 'sensitive' populations based on foliage colour after waterlogging and were then mass-pollinated and re-selected over seven generations to produce the stable populations described. To assess responses to root zone hypoxia in the selected populations, plants were grown for 1 week after germination under normal watering conditions and then subjected to waterlogging stress for up to 8 d. Under control conditions, no differences were found between the tolerant and sensitive populations in any of the parameters studied. Chlorophyll concentrations in the tolerant population were significantly greater than the concentrations in the sensitive population when plants had been waterlogged. A similar stress-specific difference was found in root and shoot dry matter accrual. As soil redox values (and hence, available oxygen) decreased, an increase in soluble carbohydrates and starch occurred in the leaves of waterlogged plants. Changes in soluble carbohydrates were noted as early as 12 h after waterlogging in the sensitive plants, and starch concentrations were significantly higher for this population 24 h after waterlogging. Under waterlogged conditions, activities of alcohol dehydrogenase (ADH) and pyruvate decarboxylase (PDC) increased, phosphoglucomutase and malate dehydrogenase decreased, and malic enzyme and glucose 6-phosphate dehydrogenase did not change. The sensitive population exceeded the tolerant population in activities of ADH and PDC after 18 and 48 h of waterlogging, respectively. The results demonstrate that stress-specific differences in population responses to waterlogging can be achieved through recurrent selection.

Effects of waterlogging on growth and some physiological parameters of four *Brassica* species

M. Ashraf and S. Mehmood

Plant and Soil Volume 121, Number 2, 203-209, DOI: 10.1007/BF00012313

Abstract

Waterlogging tolerance of four *Brassica* species, *Brassica campestris* L., *B. carinata* A. Br., *B. juncea* (L.) Czern and Coss., and *B. napus* L. was assessed after 4 weeks growth in greenhouse at two waterlogging treatments, unflooded control soil, and fully waterlogged soil.

Shoot fresh and dry biomass, in both mean and relative terms, was highest in *B. juncea* and lowest in *B. napus* at waterlogging treatment. *B. carinata* was as good as *B. juncea* in mean shoot fresh and dry matter but it had almost same relative shoot fresh matter as that in *B. campestris*, but was second highest in relative shoot dry weight.

Waterlogging treatment caused a marked reduction in chlorophyll content in all four species but the species difference was not evident. However, *B. juncea* and *B. napus* had lower relative total chlorophyll than the other species.

A marked increase in soluble protein content of *B. juncea* and a significant increase in total amino acids in *B. carinata* was observed under waterlogged conditions as compared to the other species.

At the waterlogging regime, an increase in iron content in both shoots and roots was observed in all four species. *B. juncea* accumulated lower amount of iron in both shoots and roots as compared to the other species, whereas *B. carinata* had also lower iron in the roots. The species did not differ for shoot manganese content but *B. carinata* had significantly higher manganese in the roots as compared to the other species.

Root Temperature and Aeration Effects on the Protein Profile of Canola Leaves

Jennifer A. Franklin,* Nat N. V. Kav, William Yajima, and David M. Reid
CROP SCIENCE, v.45(4):1379-1386, 2005.

Abstract : Canola (Brassica napus L.) is planted in early spring and must survive both low soil temperatures and periods of wet weather. Shoot effects result from both low root temperature and low aeration, but little is known about the interaction between these two environmental factors, particularly with respect to changes in gene products. In this study, canola plants ('46A65') were treated in solution culture. Shoot temperatures were maintained at day/night temperatures of 24/18 degrees C, while roots were maintained at an ambient temperature of 24/18 degrees C, or cooled to 10 degrees C. Roots were either aerated, or not aerated to create hypoxic treatments. Plants with roots in cold and hypoxic solution accumulated starch in the root, and had greater reductions in fresh weight and leaf area than those in either cold or hypoxic treatments alone. Twenty-one changes in protein expression were also found in the cold hypoxic treatment, 17 of which were not found in either cold or hypoxic treatments alone. Gene products up-regulated in leaves included cytochrome oxidase Subunit I (COX1) in response to hypoxia, elongation factor eEF1 gamma chain in plants with cooled roots, and chaperonin 10 when roots were cooled without aeration. Results demonstrate the interaction between multiple stresses on a molecular level, and suggest that flooding under cool soil temperatures will be more detrimental to canola than that which occurs at warmer temperatures.

Note on the effects of winter and spring waterlogging on growth, chemical composition and yield of rapeseed

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Field Crops Research
Volume 47, Issues 2-3, August 1996, Pages 175-179

Abstract

In regions where climatic conditions are adequate for rapeseed production soils may suffer waterlogging of varying duration. A pot trial was conducted to determine the effects of waterlogging on the growth, nutrient absorption and yield of rapeseed. As the effect of anoxia is known to depend on temperature the study was carried with winter or spring floods of 3, 7 or 14 days duration compared with a control without flooding. Seed yield was affected by 3 or more days of waterlogging. Winter waterlogging decreased the number of seed per plant, due to fewer branches, siliques and seeds per silique. Spring waterlogging, by contrast, reduced individual seed weight and seed oil content. The uptake of N, P, K and Ca decreased significantly with flooding but that of Na increased with spring waterlogging. Yield decline was greater with winter than with spring flooding. Temperature during the flooded period was not the only factor determining the effects of waterlogging: the stage of development, when waterlogging occurred, is also an important factor.

Effects of waterlogging at different growth stages on physiological characteristics and seed yield of winter rape (*Brassica napus* L.)

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Field Crops Research
Volume 44, Issues 2-3, December 1995, Pages 103-110

Abstract

A study on physiological and yield effects of waterlogging of rape plants at different stages of growth was conducted in specially designed experimental tanks. Waterlogging at seedling and floral bud appearance stages significantly decreased leaf chlorophyll content, superoxide dismutase and catalase activities, the accumulation of leaf malondialdehyde and ethylene production, and leaf photosynthetic rate and root oxidizability. The experiment confirmed that the physiological function of rape plants was retarded during the time of waterlogging, and its adverse effect remained afterwards. Also, plant height, stem width and the number of primary branches per plant were significantly decreased by waterlogging at seedling and floral bud appearance stages. Pods per plant and seeds per pod were also significantly reduced, giving 21.3% and 12.5% decrease of seed yield from the control for treatments at the seedling and floral bud appearance stages, respectively. No significant difference in yield components and seed yield was observed between the control and treatments applied at flowering and pod formation stages. The paper also analyses the relationships between the physiological reactions of waterlogging, morphological characteristics, and yield components and discusses ways to alleviate waterlogging damage in plants.

Effects of waterlogging at different stages of development on the growth and yield of winter oilseed rape (*Brassica napus* L.)

Robert Q. Cannell, Robert K. Belford

Journal of the Science of Food and Agriculture, 31: 963–965. doi: 10.1002/jsfa.2740310915

Volume 31, Issue 9, pages 963–965, September 1980

Abstract

Oilseed rape, growing in a sandy loam soil in lysimeters, was subjected to waterlogging to the soil surface at different stages of growth. Brief periods of waterlogging in December and January (10 days) or in May (10 days) resulted in slightly shorter plants but hardly affected yield. Waterlogging in December/January for 6 weeks in cold (1–2°C) weather, slightly restricted

leaf development and delayed flowering, but yield was unaffected. At the end of waterlogging for a similar duration between January and March (when the mean temperature was about 6°C), the height and leaf area of the plants was approximately halved, the number of senescent leaves was almost doubled and flowering was accelerated; at harvest in July these plants were 17% shorter and yields of seed, oil and straw were 14, 17 and 23% less, respectively, than for plants in freely-drained soil. During the prolonged waterloggings short fleshy white roots developed slightly below and on the soil surface.

A lack of aerenchyma and high rates of radial oxygen loss from the root base contribute to the waterlogging intolerance of *Brassica napus*

L.A.C.J. Voesenek, W. Armstrong, T.D. Colmer, G.M. Bögemann and M.P. McDonald

Australian Journal of Plant Physiology **26 (1) 87 - 93**

Abstract

The morphology and physiology of the response of two cultivars of *Brassica napus* to an anaerobic root medium was investigated. The cultivars Chikuzen and Topas showed a large reduction in growth rate when their roots were exposed to a de-oxygenated stagnant nutrient solution containing 0.1% w/v agar. Older seedlings (11 d old) were more sensitive to stagnant agar, expressed as biomass accumulation, than younger ones (5 d old). *Brassica napus* was characterized by a constitutively low root porosity (3–5%), typical for plant species with a low tolerance to waterlogging. A hypoxia pre- treatment (16 h; 2.25% O_2) before exposure to de-oxygenated stagnant agar had no effect on the final number or length of lateral roots and adventitious roots. *Brassica napus* cv. Chikuzen is characterized by radial oxygen loss being most at the basal portion of the root, when a strong oxygen sink surrounds the root. Oxygen profiles through laterals of *Brassica napus* cv. Chikuzen show a typical pattern with low oxygen concentrations in the stele and somewhat higher levels in the cortex. Despite the continuum of intercellular air spaces in the root cortical tissue the lack of aerenchyma and therefore low rates of

internal oxygen diffusion restricts root growth in anaerobic media and presumably contributes to the sensitivity of *Brassica napus* to waterlogging.

Yield of wheat and canola in the high rainfall zone of south-western Australia in years with and without a transient perched water table

Heping Zhang, Neil C. Turner and Michael L. Poole

Australian Journal of Agricultural Research 2004: 55 (4) 461 - 470

Abstract

The yields of wheat and canola in 2 successive years with and without the development of a perched watertable were compared in the high rainfall zone of south-western Australia. In 2001, no perched watertable was observed and wheat and canola yields were close to their estimated potentials. In 2002, a perched watertable developed at less than 30 cm below the soil surface for more than 8 days and at less than 50 cm below the soil surface for at least 30 days at the tillering stage of wheat and at the rosette stage of canola. The air-filled porosity of the soil fell below the critical value of 10% at 10 and 30 cm depth for about 40 days. This reduced the maximum leaf area index of canola by 46% and of wheat by 30%, and reduced the shoot dry matter of wheat at flowering by 27% and by 40% at podding in canola compared with those in 2001. The growth of the wheat roots was constrained at depths from 50-90 cm from the soil surface in 2002 compared with 2001. However, the roots of canola and wheat were able to grow to at least 1.4 m in both 2001 and 2002. In both years, a much higher proportion (>10%) of roots was present in the clay subsoil compared with previous reports in south-western Australia and enabled the crops to utilise a greater amount of water from the clay subsoil. The wheat yield in 2002 was 37% lower than in 2001 and well below the potential, largely as a result of a reduced tiller number per plant and ears per unit area. Despite the greater reduction in dry matter in canola than in wheat in 2002, the seed yield of canola was 17% higher in 2002 than in 2001. Canola, an indeterminate crop, was able to respond to the late rain that occurred in 2002 compared with 2001 and produced a significantly higher seed number per unit area. In 2002, grain size in wheat was 25%

larger than in 2001, but this increase was insufficient to compensate for the yield loss resulting from the fewer ears per unit area. It is concluded that early transient perched watertable induced subsurface waterlogging, and that the subsurface waterlogging can be a major constraint to crop growth in the high rainfall region of southwestern Australia, and that reducing waterlogging could be a key to achieving higher crop production.

Seed Film Coating with Uniconazole Improves Rape Seedling Growth in Relation to Physiological Changes Under Waterlogging Stress

Jun Qiu, Renmin Wang, Jizhi Yan and Jin Hu

Plant Growth Regulation , 2005

Volume 47, Number 1, 75-81, DOI: 10.1007/s10725-005-2451-z

Abstract

Waterlogging is an important constraint of global production of rape. The effects of seed film coating with 0.0075% uniconazole on the growth and physiology was investigated using seedlings from three varieties of rape (*Brassica napus* L.) subjected to waterlogging. While seed coating with uniconazole had no significant effect on germination percentage during waterlogging stress, it enhanced root vigour, increased root length, root volume and root dry weight. It also significantly enhanced leaf dry weight and ratio of root to shoot, but induced a significant decrease in shoot height and stem dry weight. Seed film coating with uniconazole also significantly increased the activities of the antioxidant enzymes, POD, CAT and SOD, and soluble sugar concentration during waterlogging. Thus, it suggests that seed film coating with uniconazole at a suitable concentration can improve rape seedling growth and increase seedling establishment during waterlogging.

Effects of waterlogging on nitrogen accumulation and alleviation of waterlogging damage by application of nitrogen fertilizer and mixtalol

in winter rape (Brassica napus L.)

Zhou, W | Zhao, D | Lin, X

Journal of Plant Growth Regulation

Vol. 16, no. 1, pp. 47-53. 1997.

A study on the physiological and yield effects of waterlogging and the alleviation of waterlogging damage by the application of nitrogen fertilizers and mixtalol in winter rape was conducted in experimental tanks especially designed for controlling soil moisture content. The results showed that waterlogging at the seedling and stem elongation stages causes a significant decrease in nitrogen content and rate of nitrogen accumulation. Leaf chlorophyll content, superoxide dismutase and catalase activities, and root oxidizability (capacity for root oxidation) and root exudate were also reduced by waterlogging. The experiments confirmed that the physiological function of rape plants was retarded during the time of waterlogging at the seedling stage, and its adverse effects remained. Plant height, stem width, and the number of primary branches per plant were decreased significantly by waterlogging at the seedling and stem elongation stages. Pods per plant and seeds per pod were also reduced significantly, giving a 21.3 and 12.5% decrease of seed yield from the control for treatments at the seedling and stem elongation stages, respectively. Foliar sprays of nitrogen fertilizers at the seedling stage or mixtalol at the flowering stage alleviated plant damage caused by waterlogging by retarding chlorophyll and nitrogen degradation, increasing superoxide dismutase and catalase activities and root oxidizability, and improving yield components and seed yield of waterlogged plants. Therefore, besides draining off water, alleviation of waterlogging damage may be controlled by applying nitrogen fertilizer and a suitable plant growth regulator at appropriate growth stages.

Alleviation of Waterlogging Damage in Winter Rape by Uniconazole Application: Effects on Enzyme Activity, Lipid Peroxidation, and Membrane Integrity.

Leul M, Zhou WJ.

J Plant Growth Regul. 1999 Aug;18(1):9-14

Abstract

Oilseed rape (Brassica napus L.) seedlings treated with uniconazole [(E)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-l-yl)-l-penten-3-ol] were transplanted at the five-leaf stage into specially designed experimental containers and then exposed to waterlogging for 3 weeks. After waterlogging stress, uniconazole-treated seedlings had significantly higher activities of superoxide dismutase, catalase, and peroxidase enzymes and endogenous free proline content at both the seedling and flowering stages. Uniconazole plus waterlogging-treated plants had a significantly higher content of unsaturated fatty acids than the waterlogged plants. There was a parallel increase in the lipid peroxidation level and electrolyte leakage rate from the leaves of waterlogged plants. Leaves from uniconazole plus waterlogging-treated plants had a significantly lower lipid peroxidation level and electrolyte leakage rate compared with waterlogged plants at both the seedling and flowering stages. Pretreatment of seedlings with uniconazole could effectively delay stress-induced degradation of chlorophyll and reduction of root oxidizability. Uniconazole did not alter the soluble sugar content of leaves and stems, after waterlogging of seedlings. Uniconazole improved waterlogged plant performance and increased seed yield, possibly because of improved antioxidation defense mechanisms, and it retarded lipid peroxidation and membrane deterioration of plants.

Alleviation of waterlogging damage in winter rape by application of uniconazole: Effects on morphological characteristics, hormones and photosynthesis

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Field Crops Research
Volume 59, Issue 2, 6 November 1998, Pages 121-127

Abstract

Oilseed rape seedlings (*Brassica napus* L.) treated with uniconazole were transplanted at the five-leaf stage into specially designed experimental containers, and then exposed to waterlogging for 3 weeks. Pre-treatment of rape seedlings with uniconazole significantly increased seedling height, shoot width, number of green leaves and leaf area per plant, and consequently the shoot, root, and total dry weight after waterlogging. Following waterlogging stress, the uniconazole treated plants had a significantly improved growth including plant height, length and width of leaves, number of green leaves, leaf area per plant, and canopy width at the stem elongation stage, and plant height, stem width, and root, shoot and total dry weight at the flowering stage. At harvest, uniconazole treatment increased the number of primary and secondary branches, seeds per pod, and number of effective pods in branches and in terminal raceme after waterlogging treatment. The uniconazole-induced increase in the number of pods per plant and number of seeds per pod were the two yield components responsible for the significantly greater seed and oil yields obtained from the uniconazole plus waterlogging treated plants, over either the control or waterlogged plants. Uniconazole also reduced waterlogging-induced rise in the erucic acid content of the seeds. The modification of GA_3, zeatin, ABA and ethylene levels due to pre-treatment of rape seedlings with uniconazole might have helped to delay the chlorosis and senescence induced by waterlogging. Uniconazole treatment also increased the leaf photosynthetic rates of waterlogged plants, in part, due to the changes in leaf conductance and hormone levels which ultimately affected various physiological processes.

Effect of application of nitrogen, phosphorus and potassium fertilizers on yield in rapeseed (*Brassica napus* L.) under the waterlogging stress

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[J] Acta Metallurgica Sinica, 2009,V15(5): 1122-1129

Two rapeseed (Brassica napus L.) varieties (Zhongshuang No.10 and

Zhongyouza No.5) were used to study the effects of application of nitrogen (N), phosphorus (P) and potassium (K) fertilizers on yield in rapeseed under the waterlogging stress. The plant was submerged at the seedling stage to mimic the condition of waterlogging. The experiment was replicated two times with “3414” design. The results showed that N, P and K fertilization significantly affected yield traits in rapeseed under the waterlogging stress. The grey relational analysis showed that N application rate was positively correlated with the number of seed per pod, siliques per plant, primary branches, secondary branches and the length of raceme. The P application rate was positive correlated with the number of siliques per plant and seed per pod. And K application rate was positive correlated with the number of seed per pod, 1000-seed weight and the length of raceme. The results indicated that the ensuring middle level of P and K fertilization, enhanced nitrogen fertilization can significantly increase the yield of rapeseed and the cost value ratio and economic benefits under waterlogging stress. By establishing the fertilizer response equations, the optimum fertilizer applicant of rapeseed under the waterlogging stress were as N 267 kg/ha, P_2O_5 120 kg/ha, K_2O 120 kg/ha.

Comprehensive Evaluation on Tolerance to Waterlogging Among Different Rapeseed Varieties

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Pages 945-948 in: Proc. 13th International Rapeseed Congress, Prague, CZ, June, 2011

Abstract Waterlogging tolerance of 100 rapeseed varieties were investigated by the method of testing related traits after germinated seeds anoxic stress. The results revealed that, compared with blank control, seed anoxic stress inhibited the growth of seedlings significantly; genetic variation was abundant in all of the six traits; coefficient of variation ranged from 23.66% (relative fresh weight) to 60.73% (RVI) among the 6 indexes. The RVI conform to normal distribution and varied from 0.04 to 0.83. Correlation analysis results suggested that very significant or significant positive correlation showed between indexes. Subordinate function analysis revealed that the subordinate value can represent the comprehensive waterlogging tolerance of rapeseed. Based on the subordinate value, we selected 10 waterlogging tolerance rapeseed varieties; we also found that waterlogging tolerance among three rapeseed species were different. Principle component analysis showed that according to cumulative contribution rate standard ≥ 85%, seedling vigor factor（$\lambda 1=3.50$）, seedling recovery growth factor （$\lambda 2=1.20$）and membrane stability factor （$\lambda 3=0.71$）were selected, the above three principle components account for 90.11% of total variations and covered most of the waterlogging resistance information. In conclusion, genetic variation was abundant in waterlogging tolerance among rapeseed varieties and some of them were resistant to waterlogged condition.