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Responses of contrasting oat genotypes to abiotic stresses

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Outline

- General introduction of abiotic stresses
- Terminologies for assessing tolerance of crop plants to abiotic stresses
- Examples of characterizing tolerance of oat genotypes to N stress
- Concluding remarks

Introduction

- Abiotic stress: Adverse environmental conditions that threaten plant growth and development; one of the major threats to agriculture
- Drought, salinity and nutrient limitation concurrently occur during crop growth in many parts of the world
- It is estimated that N deficiency, drought and salinity cause extensive losses to agricultural production
- The greatest concern and largely unknown are the interaction of among different types of stresses will have on many crops including oats.

Responses of oat crops to abiotic stress

● Oat is recognized as an important cereal food crop.

● Grain yield of hulless oat is < that of hulled oats.

● Oat is well adapted to nutrient-poor soils, low rainfall and moderate soil salinity levels.

● Hulless oat has excellent grain quality, attractive to producers and industry, for specialized markets.

● There has been little improvement in oat yield and nutrient management as lodging occurs with increasing N supply.

● N nutrition is an important determinant for crop growth, yield and food quality.

● Timing and rate of application are the two major factors affecting N uptake, partitioning, remobilization and use efficiency.

Terminologies

- NUE: Plant N uptake as a ratio of applied fertilizer N. Two methods:
  - Difference method: (plant TN_f – plant TN_{uf})/ fertilizer N
  - ^{15}N labeling approach: ratio of plant ^{15}N a.e. to fertilizer N a.e.
- aNUE (AE_N): kg grain yield increase Gw / kg N applied Ns
- Partitioning (Moll et al. 1982. Agron. J. 74:562-564):
  - N uptake efficiency: Plant N Nt / Ns
  - N utilization efficiency: Gw / Nt
- pNUE: The ratio of net photosynthetic rate to leaf N content
- N Fertilizer replacement value (NFRV): N fertilizer that should be applied on unmanured or monocultured lands to obtain the yield
- Cost/value ratio: cost of 1 kg fertilizer N/price of 1 kg yield, e.g. $1/kg N and $0.2/kg corn, Cvr = 1/0.2 = 5
- Economically optimum N rate or most economic rate of N (EORN): minimum of fertilizer N needed for max economic yield (Neeteson and Wadman, 1987. Fert. Res. 12: 37-52)

N nutrition index

- N nutrition index (NNI), proposed as a plant-based approach for assessing crop N nutrition:

$$NNI = \text{Actual [N]} / N_c$$

Where, N_c is minimum [N] in shoot biomass required for maximum growth rate

- N_c can also be defined as the min [N] required to achieve max aboveground biomass (Lemaire and Salette, 1984).
- The relationship between N_c and biomass:

$$N(\%) = aW^{-b}$$

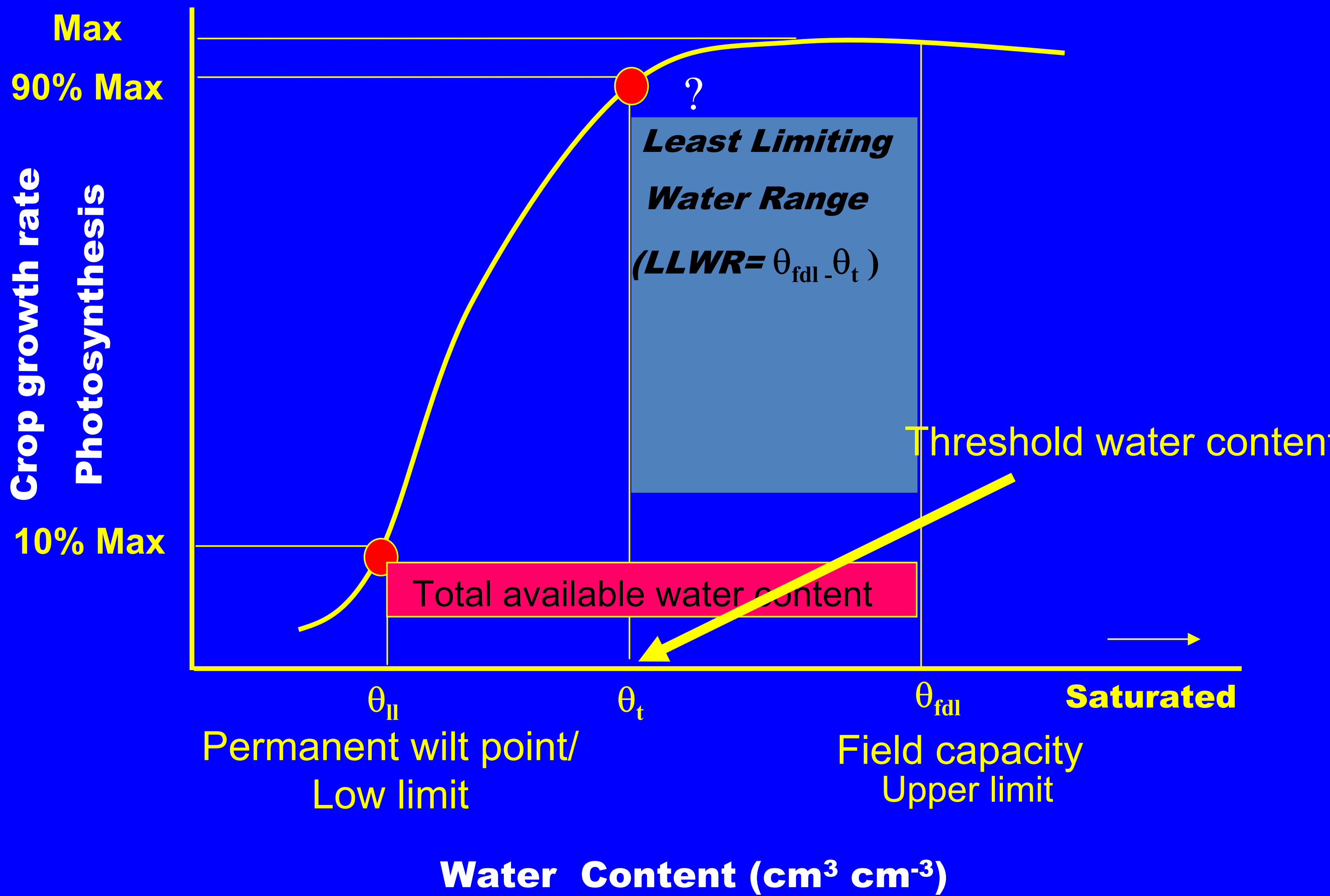
Where, W = shoot biomass (t/ha), a and b are derived constant, e.g. $N\% = 5.3W^{-0.44}$ for wheat

- NNI vs. Leaf Chl or NNI vs. NDVI,

e.g. $NNI = -0.64 + 0.039\ CM$

Drought Stress

- Drought is the major limiting factor for crop production
- Unpredicted stress
- Once every 4-5 years in past 50 years in NA.
- Annual losses =17% of total production
- Drought is dependent on the soil moisture content


Max
90% Max
10% Max
Crop growth rate
Photosynthesis
?
Least Limiting
Water Range
(LLWR= θfdl - θt)
Threshold water content
Total available water content
θll
θt
θfdl
Saturated
Permanent wilt point/
Low limit
Field capacity
Upper limit
Water Content (cm3 cm-3)

WUE

- Definition: yield of plant product (*Y*) per unit of crop water use (*ET*), WUE = Y / ET

- ET = E (non-productive evaporation) + T

- Physiological WUE:
  - Leaf level: $WUE_L = P_N / G_s$
  - Canopy level: WUE_P = BM / ET

Salinity

● Salinity like drought, remains one of the world's oldest and most serious problem for agriculture.

● Negatively affect many morphological, physiological and biochemical processes including seed germination, growth, yield and NUE of crop plants.

● Both salinity and drought reduce nitrate flux in roots and thus decrease nitrate reductase activity in leaves.

● In fact, there is scanty of information regarding the effect of salinity or water stress on N uptake and use efficiency, growth and yield of both hulless and hulled oat cultivars.

The main research objectives are:

- To identify critical N requirement and develop N application strategy for high grain yield of oat
- To assess the impact of drought and salinity on phenological, morphological, physiological processes, growth and yield of contrasting genotypes
- To explore the impact of salinity and drought on N uptake, partitioning, remobilization and N use efficiency of hulless and hulled oat cultivars
- To optimize agronomic measures and physiological processes to improve yield of hulless and hulled oats.

Materials and Methods

4 greenhouse and 1 field exps. to address the above-mentioned objectives. Here I describe one of the exps.

Genotypes: Prescott, VAO-2

N treatments:

T_1, Control - N supply from seedling to PM

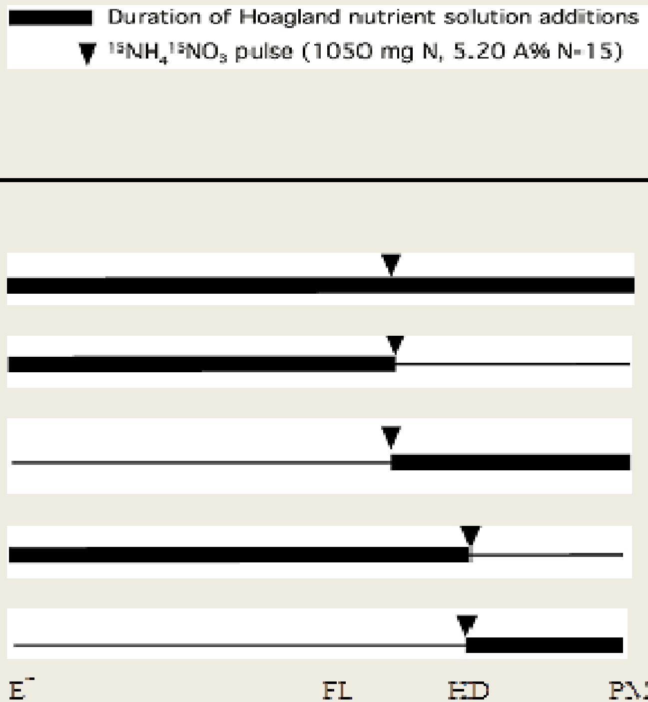
T_2, N supply from seedling to flag leaf

T_3, N supply from flag leaf to PM

T_4, N supply from seedling to heading

T_5, N supply from heading to PM.

Determining NUE and source of plant by ^{15}N labelling



N treatment	Hoagland nutrient solution addition	Hoagland nutrient solution addition	Total N applied from Hoagland – ^{15}N pulse
	No.	mg N pot^{-1}	mg N pot^{-1}
T_1	36	540	1590 – 1050
T_2	14	210	1260 – 1050
T_3	22	330	1380 – 1050
T_4	20	300	1350 – 1050
T_5	16	240	1290 – 1050

NUE was determined according to *Subedi* and *Ma* (2005b):

$$\text{NUE (\%)} = \frac{\sum_{i=1} \left[W_i \times N_i \left({}^{15}N_{i1} - {}^{15}N_{i0}\right)\right] \times 100}{f\,(a-b)}$$

Sources of plant total N, was originated from two major sources: the labelled NH_4NO_3 (Labelled-N) and the non-labelled source (Hoagland solution plus soil mix).

Labelled N % = total ^{15}N x [100 /(5.20-0.37)] / total N x 100

Subtracting the labelled N% from 100%, to get the plant N originating from the non-labelled source.

Source	Genotype (G)	N treatment (T)	G × T	Error	CV (%)
^{15}N A%					
Grain	0.56**	3.26**	0.42**	0.07	10.1
Shoots	0.25**	2.47**	0.107**	0.014	4.3
Roots	0.18*	1.77**	0.04	0.04	7.8
^{15}N content					
Total	10.9**	5.8**	0.4	0.16	14.3
Grain	0.04	0.53**	0.13**	0.02	21.2
Shoots	8.4**	3.2**	0.4**	0.13	17.5
Roots	0.04**	0.01**	0.0003	0.001	26.1
NUE					
Total	767.7**	448.3**	27.4	10.8	14.5
Grain	14.0**	31.1**	2.16	1.77	24.6
Shoots	507.6**	246.8**	24.5*	8.92	18.1
Roots	2.06**	0.44**	0.08	0.05	28.6
N from the labelled NH_4NO_3					
Total	131.7***	1548.9***	47.2***	7.38	6.2
Grain	19.4	3220.6***	492.9***	27.8	11.0
Shoots	153.3***	1280.5***	54.4**	9.88	7.5
Roots	305.8*	643.5***	130.6*	41.59	14.0
^{15}N distribution					
Grain	182.3*	200.6**	155.7**	29.4	24.5
Shoots	111.9	199**	164.5**	29.1	7.3
Roots	8.1**	2.92**	0.35	0.59	22.2

Treatment		¹⁵N enrichment				¹⁵N distribution				N from labelled				NUE			
		VAO-2		Prescott		VAO-2		Prescott		VAO-2		Prescott		VAO-2		Prescott	
Grain	T1	2.07	c	2.40	b	12.9	d	31.6	a	24.1	c	47.7	c	5.5	b	6.0	ab
	T2	2.88	b	2.71	b	21.7	b	25.1	ab	62.1	b	58.5	b	8.3	a	7.5	a
	T3	3.29	a	3.27	a	31.2	a	28.0	a	71.0	a	70.5	a	7.2	ab	5.1	bc
	T4	1.95	c	1.52	c	13.8	cd	18.8	b	29.2	c	22.0	d	5.8	b	4.0	c
	T5	3.56	a	2.67	b	20.6	bc	17.9	b	76.9	a	57.6	b	3.3	c	1.6	d
Shoot																	
	T1	2.13	c	1.89	c	83.6	a	65.7	b	47.9	d	40.8	c	18.9	c	12.5	b
	T2	2.57	b	2.60	b	74.6	c	72.0	ab	70.0	b	63.0	b	29.2	a	21.3	a
	T3	2.59	b	2.57	b	65.0	d	69.1	b	56.7	c	61.2	b	15.1	cd	12.5	b
	T4	2.02	c	1.87	c	83.1	a	78.4	a	50.2	d	42.4	c	23.5	b	11.2	bc
	T5	3.23	a	2.94	a	74.1	c	78.4	a	74.7	a	72.6	a	13.6	d	7.1	c
Root																	
	T1	2.28	d	2.06	c	3.5	b	2.8	a	59.8	b	40.9	c	0.6	c	0.5	bc
	T2	3.24	b	2.92	b	3.8	b	2.9	a	54.8	b	56.2	b	1.5	a	0.8	a
	T3	2.62	c	2.84	b	3.8	b	2.9	a	55.8	b	55.4	b	0.9	b	0.5	bc
	T4	2.32	d	1.96	c	3.2	b	2.8	a	43.6	c	40.4	c	0.9	b	0.4	c
	T5	3.46	a	3.36	a	5.3	a	3.7	a	69.9	a	63.4	a	0.9	b	0.3	c
Whole plant																	
	T1									42.7	d	42.6	c	25.0	c	19.0	b
	T2									67.5	b	61.6	b	38.9	a	29.6	a
	T3									60.5	c	63.3	b	23.2	c	18.1	b
	T4									45.2	d	36.2	d	30.2	b	15.6	bc
	T5									75.0	a	69.0	a	17.8	d	9.1	c

Related publications

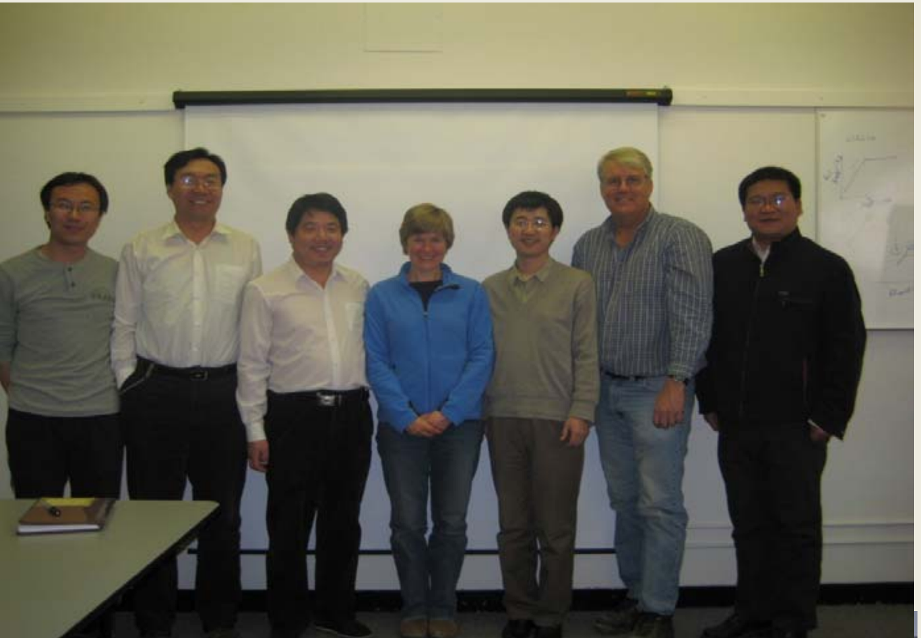
- 79. Zhao, G.Q., B.L. Ma, and C. Z. Ren. **2007**. Growth, gas exchange, chlorophyll fluorescence and ion content of naked oat in response to salinity. Crop Sci. 47: 123-131.
- 84. Ren, C.Z., B.L. Ma, V. Burrows, J. Zhou, Y.G. Hu, L. Guo, L. Wei, L. Sha, and L. Deng. **2007**. Evaluation of early mature naked oat varieties as a summer-seeded crop in dryland northern climate regions. Field Crops Res. 103: 248-254.
- 94. Zhao, G.Q., B.L. Ma, and C.Z. Ren. **2009**. Response of nitrogen uptake and partitioning to critical nitrogen supply in oat varieties. Crop Sci. 49: 1040-1048.
- 97. Zhao, G.Q., B.L. Ma, and C.Z. Ren. **2009**. Salinity effects on yield and yield components of naked oat. J. Plant Nutr. 32: 1619-1632.
- Zhao, B.P., B.L. Ma, Y.G. Hu, and J.H. Liu. **2011**. Leaf photosynthesis, biomass production, water and nitrogen use efficiencies of two contrasting (naked vs. hulled) oat genotypes subjected to water and nitrogen stresses. J. Plant Nutr. 34:2139-2157.
- 125. Ma, B.L., D.K. Biswas, Q.P. Zhou, and C.Z. Ren. **2012**. Comparisons between cultivars of wheat, covered and hulless oats: Effects of N fertilization on growth and yield. Can. J. Plant Sci. (*in press*).
- 126. Zhao, G.Q., B.L. Ma, C.Z. Ren, and C. Liang. **2012**. Timing and level of nitrogen deficiency on nitrogen distribution and recovery in two contrasting oat genotypes. J. Plant Nutr. Soil Sci. (*in press*).

Conclusions

- The naked oat had 21% greater total DM, 18% higher plant TN than the covered oat.
- N supply was more critical before heading.
- Overall, restriction of N supply from seeding to flag leaf stage reduced grain yield by 26%.
- Restriction of N supply from seedling to heading reduced yield by 65%, and N uptake by 75%.
- N partitioning towards grains lower in naked than in covered oat cultivar.

Conclusion cont'd

- N supplied from seedling to maturity, 61% more ^{15}N in the shoots, but 46% less ^{15}N in the grain of the naked than of the hulled variety.
- Withholding N supply until flag leaf stage increased ^{15}N in the grain, resulting in the highest NUE.
- A larger portion of N was derived from the labelled source in the naked than the covered oats.
- Higher NUE in VAO-2 was associated with N in the vegetative tissues, partitioning of N to the grain in VAO-2 was less efficient.
- Early N supply is critical for both grain yield and total N uptake.
- Enhancing N utilization efficiency is important for naked oat yield and NUE improvement.



Thanks!