Zinc efficiency as related to distribution and internal requirement

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Abstract

Zinc deficiency limits yield of cereals on vast areas in the world, and developing genotypes with the ability to grow and yield on zinc deficient soils is considered a long-term sustainable approach. A good understanding of this ability will facilitate breeding for this agronomically important trait. In a growth room study, using a soil culture, we compared some of the physiological differences in two wheat genotypes previously shown to differ in zinc efficiency. Our results indicate that higher zinc efficiency may be achieved through greater distribution to younger parts and lower internal requirement. Selection for such attributes can be considered in breeding programs aiming to develop zinc efficient genotypes for cropping zinc deficient soils.

Media summary

Developing wheat genotypes with lower internal Zn requirement and greater Zn distribution to younger parts may increase productivity of wheat on Zn deficient soils.

Key words

Zinc, efficiency, distribution, internal requirement, wheat

Introduction

Worldwide, zinc (Zn) deficiency occurs on many millions hectares of cereal-growing areas (Graham et al., 1992) resulting in significant reductions in yield and quality. The use of Zn-efficient genotypes is considered a practical approach (Graham et al., 1992; Cakmak et al., 1999) for cropping such soils especially in cases where fertilisers are expensive and not always effective (Genc and McDonald, 2004). Nutrient efficiency is defined here as the ability of a genotype to grow and yield well in soils too deficient for a standard genotype (Graham, 1984). This ability may be achieved through greater Zn uptake, root to shoot transport, remobilisation or utilisation. Low Zn requirement may be one of the mechanisms of Zn efficiency. Differences in Zn requirement of plant species are well known, but differences amongst the genotypes of the same species and their relations to Zn efficiency are rarely reported. By comparing two genotypes markedly differing in efficiency, we investigated whether higher Zn efficiency in wheat was related to lower Zn requirement and/or greater distribution to younger parts.

Materials and methods

The bread wheat genotypes (*Triticum aestivum* L.) used in this study were Stylet (Zn-efficient) and VM506 (Zn-inefficient). The two genotypes were selected based on their responses both in the field (Lewis et al., 2001) and in controlled environmental experiments. The bioassay, growing conditions and sample preparation for nutrient analysis were described previously (Genc and McDonald, 2004). The Zn levels used in this study were 0, 0.05, 0.1, 1, and 2 mg/kg soil. Plants were grown in a growth room and harvested 32 days after transplanting (DAT). At harvest, the whole tops were separated into youngest emerged leaf blades (YEBs), oldest leaves and the remainder of the plant. The experiment was set up as a completely randomised block design with three replicates. Analysis of variance, pair-wise comparisons and data transformation were performed as described elsewhere (Genc et al., 2002b). A modified

Mitscherlich growth model (see Genc et al., 2002a for details) was used to determine critical deficiency concentration of Zn (Ware et al., 1982), a measure of Zn requirement.

Results

Visual symptoms and Zn efficiency

At 20 DAT, typical deficiency symptoms, reduction in shoot growth usually followed by chlorotic spots in young leaves, were visible in plants of Zn-inefficient VM506 when no Zn was applied to the soil. At this stage, such symptoms were absent in Zn-efficient Stylet. By harvest (32 DAT), those symptoms in VM506 became very severe, while they were only slight in Stylet (Photo 1).

Photo 1. Visual symptoms and growth in wheat genotypes VM506 (left) and Stylet (right) as affected by Zn fertilisation (from left to right, 0, 0.05, 0.1, 1 and 2 mg Zn/kg soil).

Zn efficiency (relative shoot dry matter) was affected by both genotype and Zn fertilisation. Under Zn deficiency (≤0.05 mg Zn/kg soil), Stylet had higher Zn efficiency than VM506, while both genotypes achieved similar efficiencies at other Zn fertilisation levels, ≥ 0.1 mg Zn/kg soil (Figure 1).

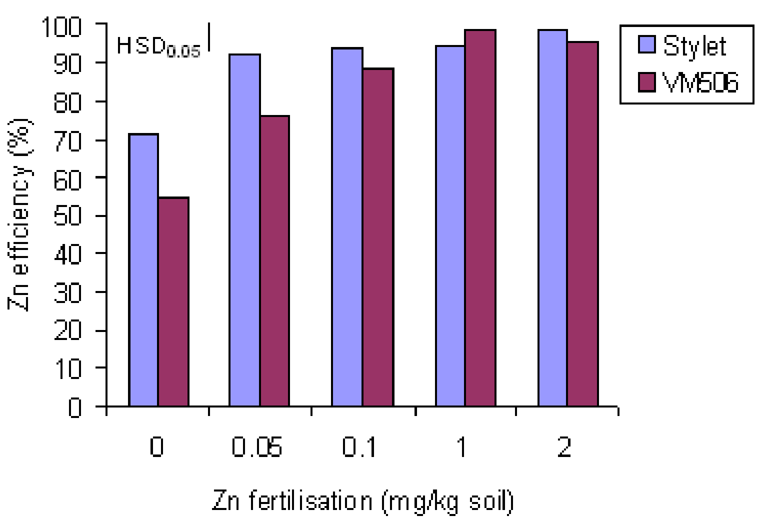

Figure 1. Zn efficiency as influenced by Zn fertilisation in wheat genotypes Stylet and VM506

Concentration, content and distribution of Zn within the plant

Concentration of Zn varied with plant part, genotype and Zn fertilisation. Stylet had higher tissue Zn concentrations both when Zn supply was deficient (YEBs, 0.05 mg/kg soil) and adequate or high (oldest and remainder of the plant (1 and 2 mg/kg soil) (Table 1). In general, oldest leaves had higher Zn concentration than youngest leaves and the remainder of the plant.

Table1. Zn concentration (mg/kg DW) in different parts of whole tops in wheat genotypes Stylet and VM506

	Stylet			VM506		
Zn fert.	Oldest leaf	Remainder	YEBs	Oldest leaf	Remainder	YEBs
0	12.6 (1.10)[a]	8.7 (0.94)	7.1 (0.85)	12.7 (1.10)	8.7 (0.94)	7.4 (0.87)
0.05	16.3 (1.21)	12.7 (1.11)	12.2 (1.09)	14.3 (1.16)	11.3 (1.05)	9.5 (0.98)
0.1	16.9 (1.23)	15.6 (1.19)	14.0 (1.14)	17.0 (1.23)	14.3 (1.16)	13.0 (1.11)
1	270 (2.43)	96 (1.98)	75 (1.88)	186 (2.27)	77 (1.88)	71 (1.85)
2	477 (2.67)	142 (2.15)	117 (2.07)	363 (2.56)	126 (2.10)	126 (2.10)

Tukey's $HSD_{0.05}$[b]
Genotype x Zn fert.x Plant part (0.05)

[a]Numbers in parentheses refer to averages obtained from the analysis of variance of transformed data (logarithmic-transformation
[b]The $HSD_{0.05}$ values are applicable to transformed data

Zn content (accumulation) also varied with plant part, genotype and Zn fertilisation. Stylet accumulated more Zn in younger parts of the plant than did VM506 (e.g. YEBs and remainder of the plant excluding old leaves) but this effect was most apparent under Zn deficiency, ≤0.05 mg Zn/kg soil (Tables 2 and 3). It was also interesting to note that Stylet had greater Zn accumulation in the oldest leaves under high and luxury Zn supply (1 and 2 mg Zn/kg soil, respectively). In terms of total Zn content in the whole tops, Stylet had a higher value than VM506, but there was no significant interaction involving genotype x Zn fertilisation (data not shown).

Table 2. Zn content (?g/plant part) in different parts of whole tops in wheat genotypes Stylet and VM506

	Stylet			VM506		
Zn fert.	Oldest leaf	Remainder	YEBs	Oldest leaf	Remainder	YEBs
0	0.40 (0.15)[a]	4.30 (0.72)	0.47 (0.17)	0.47 (0.17)	3.57 (0.65)	0.23 (0.09)

0.05	0.53 (0.19)	8.37 (0.97)	1.00 (0.30)	0.53 (0.19)	6.50 (0.88)	0.57 (0.19)
0.1	0.57 (0.20)	10.33 (1.05)	1.13 (0.33)	0.60 (0.20)	9.57 (1.02)	0.97 (0.29)
1	8.43 (0.97)	64.93 (1.82)	6.00 (0.85)	6.50 (0.87)	58.67 (1.78)	5.27 (0.80)
2	14.47 (1.19)	96.20 (1.99)	9.20 (1.01)	11.97 (1.11)	93.70 (1.98)	9.13 (1.00)
Tukey's $HSD_{0.05}$ [b]						
Genotype x Zn fert.x Plant part			(0.04)			

[a]Numbers in parentheses refer to averages obtained from the analysis of variance of transformed data (logarithmic-transformation

[b]The $HSD_{0.05}$ values are applicable to transformed data

Table 3. Distribution of Zn (% of total plant Zn content in different parts of whole tops in wheat genotypes Stylet and VM506

	Stylet			VM506		
Zn fert.	Oldest leaf	Remainder	YEBs	Oldest leaf	Remainder	YEBs
0	8	83	9	11	84	5
0.05	5	85	10	7	86	8
0.1	5	86	9	5	86	9
1	11	82	8	9	83	7
2	12	80	8	10	82	8

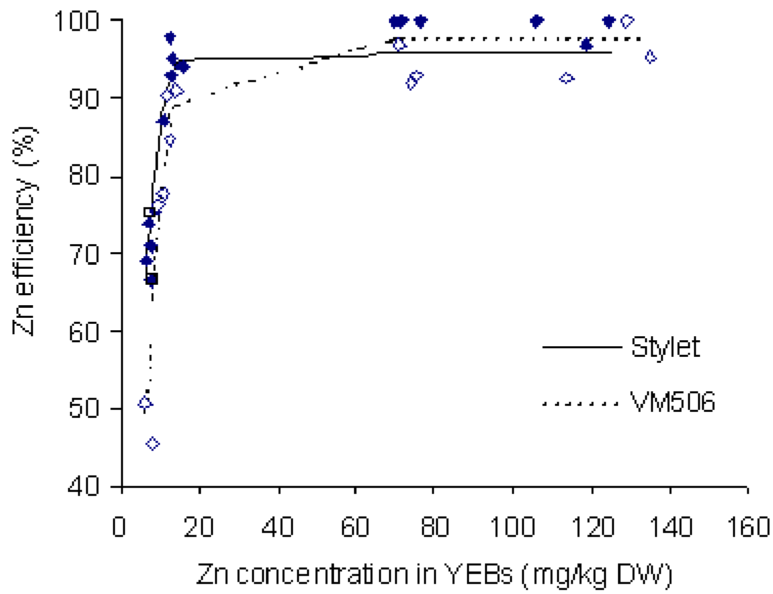

Figure 3. The relationship between Zn efficiency (relative shoot dry matter) and Zn concentration in youngest emerged leaf blades (YEB) in wheat genotypes Stylet (closed squares) and VM506 (open squares). The curves were fitted by Mitscherlich Growth Model.

When we examined the distribution of Zn (proportion of total Zn content of the whole tops in a plant part, %), it was clear that when no Zn was applied to the soil, Stylet had distributed more Zn to younger plant parts (YEBs) as compared with VM506, which may be due to its greater ability to remobilise Zn from the oldest leaves. When Zn was applied at above 0.05 mg Zn/kg soil, both genotypes had a similar distribution of Zn amongst the plant parts studied. Overall, depending of Zn fertilisation, distribution ranged 5-12%, 5-10% and 80-86% for the oldest leaves, youngest leaves and remainder of the plant, respectively (Table 3).

Differences in zinc requirement: critical deficiency concentration in YEBs

A significant difference in Zn requirement of two genotypes was observed in the present study. Zn-efficient Stylet had a lower requirement of Zn than Zn-inefficient VM506 to achieve the same level of growth (90%). The critical deficiency concentrations estimated by Mitcherlich growth model (based on individual replications, means ? standard errors) were 10.2?0.3 and 13.3?1.3 mg Zn/kg DW for Stylet and VM506, respectively. A difference of this magnitude appears to be significant given the fact that large differences in (Zn efficiency) occurred despite small increases in Zn concentration of YEBs (Table 3 and Figure 3). For example, in VM506, Zn efficiency increased significantly (54-76%) when Zn concentration increased by only 2 mg/kg DW. Similarly, Stylet achieved higher Zn efficiency than VM506 (93% vs 76%) when the difference in Zn concentration between the two genotypes was only approximately 3 mg/kg DW.

Conclusion

The results of this study suggest that low Zn requirement may indicate Zn efficiency (e.g. the ability to maintain metabolic functions with limited Zn). However, this may be only one of many mechanisms of Zn efficiency. Once this is proven upon testing of a large number of contrasting genotypes, then breeding genotypes with low Zn requirement can be considered a sustainable approach for cropping soils of low Zn status. Our results also suggest that higher Zn accumulation in youngest leaves may be further contributing to higher Zn efficiency.

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