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Zinc and Phosphorus Responses in Transplanted Oilseed Rape *(Brassica napus)*

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Raising seedlings in a nursery and then transplanting them into the mainfield is a common practice for intensive cropping systems but the special nutrient requirements of the transplanted field *crop* have seldom been considered. In the present study, the sensitivity of oilseed rape seedlings to post-transplanting zinc (Zn) and phosphorus (P) deficiency was examined in seven field experiments in Hubei province, central China.

Oilseed rape was sown in nurseries in late September according to standard farming practice for transplanting at the 4-6 leaf stage into mainfields treated with seven Zn levels from 0-45 or 0-60 kg ZnSO4 ha’ in late October to mid- November.

Increase of soil Zn supply resulted in the increase of shoot dry matter of plants at the rosette stage by up to 100%, at the green bud stage by up to 50%, and seed yield by up to 18%. That Zn fertilizers stimulated seed yield even on soils with O.S4 mg Zn kg suggests that Zn uptake by oilseed rape was inefficient. That oilseed rape plants from the rosette stage through the green bud stage contained more than adequate Zn in their young leaves for growth suggests that the plants were free of Zn deficiency for all but a short period after transplanting. The strong relative responses of oilseed rape to Zn at the rosette stage, and the weakening of the response with time suggests that oilseed rape experienced a temporary Zn deficiency after transplanting which limited final seed yield. The significance of these results for the nutrition of transplanted crops is discussed.

Key Words: Brassica napus, leaf zinc, seed yield, transplanting, zinc.

Many horticultural and some field crops are transplanted from nursery beds or from nursery-raised pots in order to decrease the length of the time the crop spends in the mainfield. The need to transplant may arise because the normal growing season is too short for direct-sown crops or because it is the only way of growing two or three consecutive crops in a 12-month period. Whatever the underlying reasons, transplanting may induce nutritional problems that are not experienced by direct-sown crops.

Transplanting of oilseed rape is the usual practice for winter rape in most of China. Oilseed rape seedlings are raised in densely sown nursery beds and the process of pulling seedlings damages the roots. As seedlings raised in nursery beds are pulled with minimal care, most roots are broken, recovery of the root system is 50% or less and the root shoot ratio changes markedly. Plants are transplanted into rainfed fields during the end of autumn when the temperature is decreasing and rainfall erratic (Table 1). As a result, transplanted seedlings may be exposed to periodic drought, waterlogging, or sub-zero temperatures. The rapid recovery of the seedlings from transplanting is considered to be a pre-requisite for successful overwintering by the plants so that they can exploit the increasing temperatures and rainfall availability in the late winter to initiate reproductive growth (Table 1).

Most of what is known about post-transplanting recovery of field crops is derived from studies of rice (DeDatta 1981). Rice is particularly sensitive to Zn deficiency after transplanting into flooded soils (Marschner 1993). In part the sensitivity can be attributed to the chemistry of flooded soils which enhances Zn adsorption by hydrated iron and manganese oxides in the oxygenated rhizosphere of the rice roots and to the strong inhibition of Zn uptake by bicarbonate ions in solution (Marschner 1993). It can also he attributed to the sensitivity of the transplanted rice seedlings to Zn deficiency. Indeed a small amount of Zn placed around the roots by dipping them in a slurry of ZnO at transplanting is often sufficient to correct the deficiency in the transplanted rice seedlings (Takkar and Walker 1993; Xie et al. 1981). That Zn deficiency is common in rice in China (Liu 1991) in areas where rice is rotated with oilseed rape suggests that the susceptibility of oilseed rape to Zn fertilizer application requires further studies.

In the present study, the objective was to examine the response of seed yield of oilseed rape to Zn fertilizer. Seven field experiments were set up in Hubei province, central China on a variety of soils ranging from 0.26 to 0.84mg Zn kg^{-1} in DTPA extractable Zn levels and treated with seven Zn levels at 0 to 45 or 0 to 60 kg $ZnSO_4$ ha^{-1}. Effects of Zn treatments on plant growth, leaf Zn concentrations, and seed yield were determined. In two experiments, the effects of high and adequate phosphorus (P) fertilizer levels on the Zn response were also investigated.

MATERIALS AND METHODS

Seven field experiments were set up in Hubei province, central China, two in 1992-1993 (Experiments 1 and 2), and five in 1993-1994 (Experiments 3-7). Experiments were conducted mostly on recent alluvial soils in the Han and Yangtse river valleys on which much of the agricultural production of Hubei province is based and the remainder on the Red soils (Paleustults) of the widespread fringing low hills (Table 2). Before sowing, representative samples were collected from each site at 0-20, and 20-60cm depths for the determination of: pH(H_20); DTPA-Zn (Lindsay and Norvell 1978); texture: and organic matter (Allison 1965)

Table 1. Mean monthly temperatures and rainfall during the oilseed rape growing season for Xianning, Zhicheng, and Qianjiang in Hubei province, P.R. China.

Month	Temp. (°C)			Rainfall (mm)		
	Xianning	Zhicheng	Qianjiang	Xianning	Zhicheng	Qianjiang
September	23.6	23.3	22.9	86	112	79
October	17.9	18.1	17.4	79	77	82
November	11.6	12.3	11.3	76	46	55
December	6.2	6.7	5.8	51	23	27
January	4.0	4.7	3.8	51	20	31
February	5.8	6.4	5.4	80	27	47
March	10.9	11.0	10.0	124	62	83
April	16.8	16.8	15.7	193	106	126
May	21.5	21.3	21.0	224	137	154

(Table 2). Profiles at each site were described for classification according to Soil Taxonomy (Table 2).

Seven Zn rates were applied as follows:

0, 3, 6, 9. 15, 30, 45 kg $ZnSO_4$ ha^{-1} - Experiments 1, 6. 7,

0, 7.5, 11.25, 15, 22.5, 30, 60kg $ZnSO_4$ ha^{-1} - Experiments 2, 3, 4, 5.

In Experiments 6 and 7, each plot was split and treated with either the basal rate of P (P1) or twice that rate (P2). Basal fertilizer was added at 150 kg N ha^{-1} (as mono-ammonium phosphate (MAP) plus urea): 40 kg P ha^{-1} (as MAP or KH_2PO_4); 95 kg K ha^{-1} (as K_2S0_4 or KH_3PO4); 24 kg S ha^{-1} (as K_2S0_4); and 11.75 kg borax ha^{-1}. Fertilizer was broadcast on plots at transplanting then hoed into the 7 cm surface layer. At Qianjiang (Experiment 2), Zn fertilizer was applied together with basal fertilizer: at the remaining sites, the Zn fertilizer was applied separately by banding it in furrows at 5-10cm depth below the rows where seedlings were transplanted.

Oilseed rape cv. 821 (Experiments 1 and 2) or cv. Zhongshuang 4 (Experiments 3-7) seeds were sown into nursery beds in late September for transplanting on October 26 at Dongxihu, November 7 at Qianjiang (Experiment 2), November 15 at Qianjiang and Ezhou, and November 20 or 21 at Zhicheng and Xianning. Seedlings were transplanted at a density of 132.000 plants ha^{-1} with a 25 X 33cm spacing. Gross plot area was 21 m with 189 plants available per plot for harvesting and sampling in a 15.8 m^2 net plot.

At the time of transplanting, whole shoots in Experiments 1 and 2 were collected for determination of dry matter. Youngest mature leaves (excluding the petioles) (YML) in Experiments 3-7 were sampled at the rosette stage (Code 1,7-1,10 according to Sylvester- Bradley 1985), and green bud stage (Code 3,4). At the green bud stage in Experiments 3-7 and at the rosette stage in Experiments 3-5 and 7, whole shoots of 10 plants per plot were harvested for dry matter determination. At maturity, seeds were harvested for yield determination.

Zinc concentration in leaves was determined after extraction by 1 N HCl. Half a gram of milled leaf samples were added to 20 ml 1 N HCl and shaken continuously for 30 mm with a horizontally rotating shaker. The sample solutions were allowed to stand overnight at room temperature

Table 2. Soil properties at seven experimental sites in Hubei province, P.R. China.

Soil property	Depth (cm)	Exp. 1 Xianning	Exp. 2 Qianjiang	Exp. 3 Ezhou	Exp. 4 Qianjiang	Exp. 5 Zhicheng	Exp. 6 Xianning	Exp. 7 Dongxihu
Soil Taxonomy		Typic Paleustult	Fluva-quentic Huma-quept	Mollic Endo-aquept	Fluva-quentic Huma-quept	Typic Endo-aquept	Typic Paleustult	Hydra-quent
Parent material		Shale	Alluvium	Calcareous alluvium	Alluvium	Calcareous alluvium	Shale	Alluvium
Texture class	0–20	Silty clay	Silty clay	Sandy loam	Silty clay	Silty clay	Silty clay	Clay loam
$pH(H_2O)$	0–20	5.7	7.2	7.8	6.9	7.5	5.0	7.0
	20–60	6.4	7.9	7.9	7.7	7.7	6.0	7.8
Organic matter (%)	0–20	1.66	2.05	0.69	2.34	1.72	1.99	1.82
	20–60	0.90	0.55	0.48	1.08	0.82	0.33	1.01
DTPA extract-able Zn ($mg\ kg^{-1}$)	0–20	0.62	0.26	0.28	0.47	0.49	0.56	0.84
	20–60	0.53	0.18	0.19	0.40	0.25	0.25	0.41

Table 3. Effect of zinc (Zn) supply on seed yield (kg ha^{-1}) of oilseed rape at Xianning (Experiment 1) and Qianjiang (Experiment 2), Hubei province.

Zn suppley (kg $ZnSO_4$ ha^{-1})	Xianning	Zn supply (kg $ZnSO_4$ ha^{-1})	Qianjiang
0	2,250	0	2,160 b
3	2,320	7.5	2,300 a
6	2,250	11.25	2,260 ab
9	2,260	15	2,260 ab
15	2,340	22.5	2,190 b
30	2,310	30	2,270 ab
45	2,320	60	2,210 ab
F test	ns	*F* test	*

Values are means of four replicates. Values followed by the same letter are not significantly different, $p=0.05$.
* Significant at $p=0.05$. ns, not significant.

Table 4. Effect of zinc (Zn) supply on shoot dry matter (g 10 $plants^{-1}$) of oilseed rape at rosette and green bud stages, and seed yield (t ha^{-1}) at Ezhou, Qianjiang and Zhicheng, Hubei province.

Zn supply (kg $ZnSO_4$ ha^{-1})	Exp. 3 Ezhou	Exp. 4 Qianjiang	Exp. 5 Zhicheng
Rosette stage			
0	32	42	31
7.5	28	67	43
11.25	38	71	40
15	30	69	37
22.5	30	88	42
30	46	76	40
60	50	88	42
LSD 0.05	18	17	7
Green bud stage			
0	96	131	80
7.5	94	143	89
11.25	105	142	92
15	104	141	89
22.5	100	156	91
30	106	168	90
60	118	169	93
LSD 0.05	19	22	ns
Seed yield			
0	—	1.61	0.81
7.5	—	1.76	0.82
11.25	—	1.74	0.83
15	—	1.73	0.85
22.5	—	1.72	0.87
30	—	1.78	0.91
60	—	1.81	0.91
LSD 0.05		0.08	0.06

—, seed yield not available.

(21-26°C) and then filtered through Whatman No. 1 filter paper. The filtrates were analyzed directly for Zn concentration by ICP emission spectrometry. Prior comparisons indicated that Zn concentrations determined by HCl extraction were not different from those determined by the standard procedure of digestion by concentrated HNO_3 at l3°C followed by ICP determination of Zn (Zarcinas et al. 1987).

Results were subjected to an analysis of variance. When F-values were significant at $p = 0.05$, means were compared by least significant differences.

RESULTS

In 1992-1993, Zn fertilizer application increased the seed yield of oilseed rape by an average of 7% at Qianjiang but not at Xianning where the soil Zn content, in the 20 cm surface layer was 0.62 compared to 0.26 mg kg^{-1} of the responsive site (Tables 2, 3).

In 1993-1994, at all sites, Zn application increased shoot dry matter at either the rosette stage or the green bud stage, or both: it also increased seed yield at maturity at all the sites except the Ezhou site where seeds were not harvested (Tables 4, 5). At the rosette stage, the shoot dry matter response to Zn fertilizer was weakest at the Dongxihu site where soils also showed the highest level of soil Zn (Tables 2, 4, 5). By contrast, at the green bud stage and at maturity, there was no obvious relationship between the magnitude of the response and soil Zn levels (Fig. 1; Table 2). At maturity, for example, a 12% average increase in seed yield was obtained from Zn fertilizer at 0.49 mg Zn kg^{-1} in the alluvial soil at Zhicheng and a 18% average increase with 0.84 mg Zn kg^{-1} at Dongxihu (Tables 2, 4, 5).

The relative effect of Zn fertilizer on growth promotion was generally most pronounced at the early shoot dry matter harvest at the rosette or green bud stage and weaker at maturity for seed yield (Fig, 1). Nevertheless, where Zn fertilizer application significantly increased seed yield, average increases of 9 to 18% were obtained and Zn application increased seed yield at every site except the Ezhou site where seed yield could not be obtained: at Ezhou the 22% increase in dry shoot matter with Zn

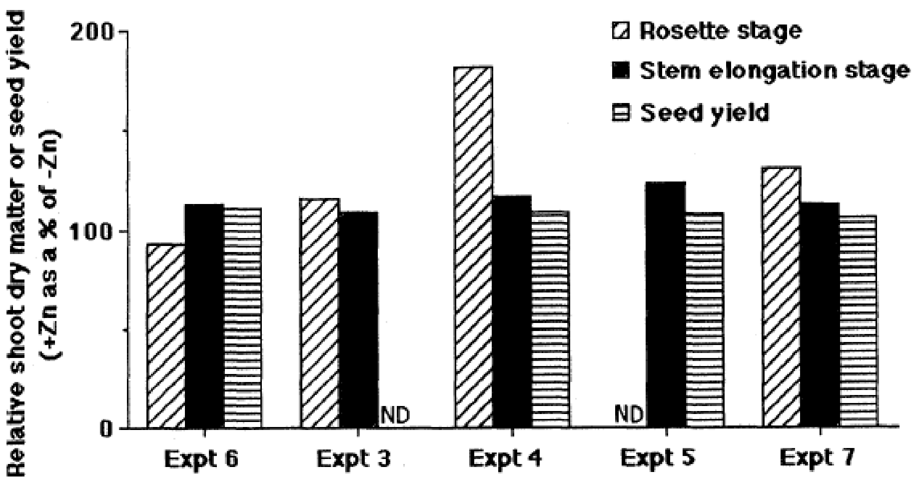

Fig. 1. Effect of zinc (Zn) on relative shoot dry matter at rosette and green bud stages, and on relative seed yield of oilseed rape in Experiments 6, 3-5, and 7. Values calculated by taking the average shoot dry matter or seed yield of Zn fertilized treatments which responded significantly to Zn (referred to as +Zn treatments) divided by respective values for plots without Zn fertilizer (−Zn) expressed as a percentage.

Table 5. Effect of zinc (Zn) and phosphorus (40, 80 kg P ha^{-1}: P1, P2, respectively) supply on shoot dry matter (g 10 $plants^{-1}$) of oilseed rape at rosette and green bud stages and on seed yield (t ha^{-1}) at Xianning and Dongxihu, Hubei province.

Zn supply (kg $ZnSO_4$ ha^{-1})	Exp. 6 Xianning		Exp. 7 Dongxihu	
	P1	P2	P1	P2
Rosette stage				
0	—	—	22	21
3	—	—	24	25
6	—	—	16	28
9	—	—	18	24
15	—	—	18	21
30	—	—	24	24
45	—	—	22	23
LSD 0.05			2	2
Green bud stage				
0	132	195	112	141
3	169	197	116	190
6	160	217	121	161
9	156	226	126	175
15	167	225	140	193
30	158	232	129	195
45	169	234	125	195
LSD 0.05	7	39	16	33
Seed yield				
0	0.88	0.99	2.08	2.21
3	0.92	1.05	2.23	2.35
6	0.96	1.11	2.23	2.44
9	0.98	1.14	2.31	2.49
15	0.98	1.18	2.30	2.64
30	1.03	1.19	2.24	2.58
45	1.05	1.23	2.26	2.41
LSD 0.05	0.06	0.06	0.17	0.33

Values are means of four replicates. —, data not collected.

fertilizer application at the green budding stage suggested that a seed yield response would have been obtained if yield results were available. Combined with the results of the 1992-1993 experiments, application of 3 to 15 kg $ZnSO_4$ ha^{-1} was sufficient to achieve maximum seed yield of oilseed rape.

As in the first year experiments, in Experiments 3-7, Zn concentrations in YML at the rosette and green bud stages were rather high (Tables 6, 7). Moreover, leaf Zn concentrations at ZnO, and their response to added Zn bore little relationship with the magnitude of the Zn fertilizer effect on either shoot dry matter or seed yield. Thus, leaf Zn concentrations at ZnO were as high or higher at Qianjiang than at Ezhou despite the fact that Zn fertilizer doubled shoot dry matter at the former site but increased it by 50% at the latter (Tables 4, 6).

At Xianning and Dongxihu, both Zn and P fertilizers increased the shoot dry matter and seed yield (Table 5). The effects of P were largely additive to Zn and there was no indication from growth responses or leaf Zn concentrations that P interfered with the Zn uptake by oilseed rape (Table 7). That P2 depressed Zn concentrations in leaves compared to P1 can be attributed to dilution by the extra dry matter produced (Table 5).

Table 6. Effect of zinc (Zn) fertilizer supply on Zn concentrations (mg Zn kg^{-1} dry matter) in the youngest mature leaf at rosette and green bud stages in oilseed rape grown at Ezhou, Qianjiang, and Zhicheng, Hubei province.

Zn supply (kg $ZnSO_4$ ha^{-1})	Exp. 3 Ezhou	Exp. 4 Qianjiang	Exp. 5 Zhicheng
Rosette stage			
0	53	56	—
7.5	46	61	—
11.25	51	57	—
15	50	61	—
22.5	54	67	—
30	58	65	—
60	62	67	—
LSD 0.05	13	6	
Green bud stage			
0	31	65	48
7.5	34	64	64
11.25	35	61	48
15	43	69	49
22.5	34	70	56
30	45	74	51
60	52	93	61
LSD 0.05	15	6	14

Values are means of four replicates. —, samples not taken.

Table 7. Effect of zinc (Zn) and phosphorus (40, 80 kg P ha^{-1}: P1, P2, respectively) supply on Zn concentrations (mg Zn kg^{-1} dry matter) in youngest mature leaves of oilseed rape at green bud stage at Xianning and Dongxihu, Hubei province.

Zn supply (kg $ZnSO_4$ ha^{-1})	Exp. 6 Xianning		Exp. 7 Dongxihu	
	P1	P2	P1	P2
0	67	56	60	56
3	89	67	58	58
6	96	81	63	69
9	122	89	64	60
15	143	110	62	55
30	202	135	65	64
45	224	173	72	57
LSD 0.05	25	28	10	13

Values are means of four replicates.

DISCUSSION

At five sites in Hubei province with a range of soil properties and DTPA extractable Zn levels of 0.26 to 0.84 mg kg^{-1}, Zn fertilizer application increased the seed yield of oilseed rape by 9 to 21%. Indeed Zn fertilizer application failed to promote growth or enhance seed yield at only one out of seven sites. In a comprehensive survey of 3,000 soil samples throughout Hubei province, 87% of the soils, most of them collected in farmers' fields, contained less than 1 mg Zn kg^{-1} (Xie et al. 1990). The results of the survey and the present study suggest that widespread benefits of Zn fertilizer application on oilseed rape could be achieved in central China. Combined with the results of previous studies in central China which reported 7-35% seed yield increases after the application of 15 kg $ZnSO^4$ ha^{-1} in 10 out of 12 field experiments with oilseed rape (Liu et al. 1992), there is clear evidence that yields of oilseed rape can be increased significantly by the application of Zn fertilizer, mostly by less than 25%. Zinc fertiliser rates of 3 to 15 kg $ZnSO^4$ ha^{-1} were sufficient to reach maximum yields.

The response of oilseed rape to kg $ZnSO^4$ cannot be attributed to the correction of sulfur (S) deficiency since S was added in the K_2S0_4 fertilizer at 34 kg S ha^{-1} and besides, leaf analysis showed that plants contained >0.4% S (data not shown) and confirmed that they were not limited by S deficiency (Reuter and Robinson 1986).

Notwithstanding the above conclusions about the positive responses of oilseed rape to Zn fertilizer, the results obtained were puzzling in several aspects which distinguish them from typical responses to Zn on low Zn soils (e.g. Reuter et al. 1982). At both rosette and green bud stages in the present study, Zn concentrations of less than 30mg Zn kg^{-1} were not found in YML of oilseed rape. Most of the leaf Zn concentrations in the ZnO plants were >50 mg kg^{-1} and in cases where strong growth responses to Zn fertilizer were obtained. Zn concentrations of 60-70 mg kg^{-1} were obtained in the YML of ZnO plants at the rosette or green bud stage. Yet Reuter and Robinson (1986) reported that >22mg Zn kg^{-1} is adequate for maximum seed yield of this crop. Our results suggest that plant growth is not depressed until Zn concentrations in the YML reach 7-8 mg Zn kg^{-1} (Huang et al. 1995). Neither of these reports supports the argument that plants were deficient in Zn from late December when first sampled through mid-February (Experiments 3-7) or mid-March (Experiments 1 and 2). Neither is it likely that Zn deficiency occurred later in crop growth since growth responses were generally already evident at the rosette stage and the relative response to Zn fertilizer became weaker with time (Fig. 1).

Clearly the causal response of oilseed rape to Zn fertilizer was associated with the early post-transplanting growth and not with the later growth. Factors inducing an early response to Zn fertilizer appeared to have largely disappeared by late December, 6-9 weeks after transplanting, when leaf Zn concentrations indicated that the plants at all levels of Zn supply including ZnO contained ample Zn for growth. A similar situation can be observed in the plant response to seed P where increases in the seed P concentration strongly promote initial plant growth especially in P-limiting substrates, followed by a weakening of the relative effect of the seed P levels as the plant ages (Thomson et al. 1992). Indeed Thomson et al. (1992) found that seed P affected growth during the first 4 d after sowing but that subsequently, relative growth rates of plants in P adequate solutions were unaffected by seed P. The delay in initial growth induced by a temporary P deficiency in the seedlings continued to decrease the amount of shoot dry matter even though it had no persistent effect on the relative growth rate and the P concentrations in the shoots indicated that subsequent growth was not P limited. By analogy, we postulate that inadequate Zn supply during the immediate post-transplanting period delayed the initial growth of oilseed rape in the present study and that even though Zn was not limiting during the remainder of the crop growth, plants without Zn fertilizer were unable to catch up with those treated with Zn at transplanting.

That oilseed rape should respond in central China so consistently to Zn fertilizer does not agree with results from Canada (Grant and Bailey 1993) where Zn deficiency in oilseed rape is uncommon and associated with high application of P fertilizer. The present results for leaf analysis at the rosette, green bud and flowering stages indicated the presence of rather high Zn concentrations in the leaves even on soils with as little as 0.3 mg DTPA-extractable Zn kg^{-1}. Critical Zn levels in soils have not been defined for oilseed rape but in mustard *(Brassica juncea),* 0.6 mg DTPA extractable Zn kg^{-1} soil was deficient for seed yield on an alkaline alluvial soil in India (Sachdev and Deb 1992): in most of the other crops, soil levels < 0.4mg Zn kg^{-1} are deficient for growth (Sims and Johnson 1991). In a glasshouse experiment on a low Zn soil, we found that low levels of Zn fertilizer which were inadequate for the correction of Zn deficiency in peanut (Bell et at. 1990) and subterranean clover (Reuter et al. 1982) completely alleviated the deficiency in oilseed rape (Huang et at. 1995). By contrast, Grant and Bailey (1993) referring to unpublished results from the eastern Prairies of Canada suggested that canola has a higher Zn requirement than barley.

Cultivar variation in Zn efficiency is one plausible explanation for the varying responses of oilseed rape to low Zn soils. Cultivar variation in Zn efficiency has been reported among germplasm accessions of the related species, *B. juncea* (Randhawa and Takkar 1976; Takkar 1991). Graham et at.: (personal communication) have also found substantial differences in Zn efficiency among *Brassica napus* genotypes when grown on low Zn soils. Zhongyou 821 which was grown in Experiments 1 and 2 was included in the cultivars screened by Graham et at.: preliminary ranking by Graham et al. suggests that it was neither Zn-efficient nor inefficient. As yet, we have no data on the Zn efficiency of cv. Zhongshuang 4 which was grown in Experiments 3-7.

That the reputation of oilseed rape for responding only infrequently to Zn deficiency was derived from direct sown crops (Grant and Bailey 1993) rather than transplanted crops suggests that transplanting and its consequences for Zn uptake enhanced the sensitivity to Zn deficiency. Consequently, it is proposed that transplanting increased the external Zn requirements of oilseed rape. Firstly, as discussed above, the deficiency of Zn must have been temporary as it was no longer observed within 6-9 weeks after transplanting. In central China, transplanted oilseed rape seedlings may experience a loss of leaf turgor during the day light hours for up to 2 weeks after transplanting suggesting that it takes at least that long for new root growth to occur. After transplanting, senescence of 2-4 leaves occurs followed by the resumption of leaf emergence. Within 4-8 weeks after transplanting, plants had essentially recovered their pre-transplanting leaf number, with six to eight green leaves. During the recovery period, root : shoot ratios of plants decrease, restricting the uptake of nutrient elements especially those that are immobile in the soil.

Secondly, like Zn, P Fertilizer increased shoot dry matter at the rosette and green bud stages leading later to increased seed yield. The parallels extend further because the relative response to P was stronger at the green bud harvest and decreased for seed yield. At Dongxihu where P fertilizer application increased the shoot DM by 37% at green budding stage, the P concentrations in the YML were 1.0-1.1% (data not shown), nearly four times higher than the minimum requirement for maximum growth (Pinkerton et al. 1989; Pinkerton 1991). Thus, like the Zn response. there was no evidence based on plant analysis that plants grown with the lower fertilizer P level were P-deficient at the green bud stage or probably thereafter until maturity. The response to P fertilizer, like that to Zn, evidently occurred early in crop growth soon after transplanting and possibly as a consequence of it.

Of particular significance to the P nutrition of transplanted oilseed rape seedlings may be the loss of root tips that occurs when the seedlings are pulled from the nursery bed. Based on observations, pulling of seedlings from the nursery bed recovers no more than two thirds of the root system and breaks tips of a higher percentage of roots. Oilseed rape excretes organic acids, notably malic acid, from behind the root tip in order to increase the availability and uptake of P when it is limiting (Hoffland et al. 1989). The loss of root tips which is likely to limit the plant ability to absorb P. results in the increase of the sensitivity to P deficiency during the recovery from transplanting. Indeed, in solution cultures, where root exudation is ineffective in increasing the uptake from low solubility P sources, the P uptake efficiency of oilseed rape is low (Brewster et al, 1976). Given the parallels between the responses of oilseed rape to P and to Zn, it seems reasonable to assume that exudation of organic acids by roots from behind the root tips is important for the uptake of Zn by oilseed rape under normal conditions. Marschner (1993) reviewed evidence from a range of species of dicots and concluded that root exudation of organic acids and chelators, and root induced changes in rhizosphere pH were significant for Zn uptake. Thus the damaged root system of transplanted seedlings, devoid of root tips and the capacity to modify the rhizosphere may require higher than normal external Zn concentrations in order to absorb enough Zn for recovery growth. Furthermore it can be postulated that once new roots are developed, a lower external Zn concentration will be sufficient for the growth of oilseed rape.

The extent to which Zn or P limits post-transplanting growth of oilseed rape may vary with the duration of the recovery phase which ill in turn vary with environmental factors including soil water, soil and air temperature, waterlogging, soil nutrient supply and with plant factors like nutrient status of the seedlings, and cultivar vigour. In central China, transplanting takes place in late October to mid-November when the temperature decreases and rainfall is erratic (Table I). Extremes of cold may occur during November as well as extremes of dry soil conditions or waterlogging. The earliness of transplanting is dictated by the time when rice or cotton crops are harvested. Late transplanting is undesirable because of the rapidly declining temperatures (Table I). Of particular significance are those factors which limit new root growth. Given the variability in seasonal conditions during November, considerable variation may be expected from site-to-site and year-to-year in the recovery of oilseed rape seedlings from transplanting. However, the consistent responses to Zn fertilizer obtained in the experiments in the present study suggest that, although the environmental conditions may vary, they do not have an overriding influence on whether the response will occur.

Plant Zn content at transplanting is expected to affect the sensitivity of the transplanted seedlings to Zn deficiency. However, in wheat the mobility of Zn in the phloem varies among plant parts (Pearson and Rengel 1994), with the Zn supply and with the leaf function (Longnecker and Robson 1993) and the same phenomenon may occur in oilseed rape. Hence, endogenous Zn in roots and stems which in wheat was readily remobilized when the external Zn supply was interrupted (Pearson and Rengel 1994) may also be remobilized in oilseed rape seedlings after transplanting. Leaf senescence enhances the remobilization of Zn and treatments such as high N application are expected to delay it (Longnecker and Robson 1993), suggesting that while leaves of seedlings with a high N status may contain a large amount of Zn, little of it can be retranslocated to the roots where it is needed for new root growth. However, at high Zn concentrations in the shoot, the mobility of Zn is enhanced (Longnecker and Robson 1993). Thus, it is suggested that the most suitable seedbed nutrition strategy would be to maintain the N supply at minimal levels compatable with adequate seedling growth, and to maintain high Zn levels. Alternatively, dipping roots in a slurry of ZnO, as practiced with rice transplanted into a mainfield with low Zn levels (Xie et al. 1981) may be effective for transplanting oilseed rape seedlings into low Zn soils. The possibility of transplanting seedlings with healthy intact root tips should also be explored. Gentle removal of roots from the seedbed to minimize damage may be feasible but would be more time-consuming unless the seedbed consists of porous materials with low soil strength. Propagation of seeds in small pots made of decomposable fibers would allow direct transplanting of the pot into the mainfield without damage to the roots.

That both P and Zn fertilizers enhanced growth and yield suggests that other deficiencies may limit the post-transplanting growth of oilseed rape. Particular attention should be given to elements which like P and Zn are immobile in the soil and hence depend on new root extension for adequate uptake by plants. Studies on the recovery of root function after transplanting, especially rhizosphere modifications that enhance the availability of elements such as Zn and P should be carried out.

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