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Soil N Availability and Nitrogen Harvest Index of Oats[1]

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A population of 480 random lines of oats (*Avena sativa* L.) was grown on soil that received no application of nitrogen (N) or 112 kg of N ha^{-1} (defined as low- and high-N environments, respectively) to evaluate the effect of N availability in the soil on the plant's ability to partition N between vegetative tissue and the grain, a ratio defined as nitrogen harvest index. Also, comparisons were made between low- and high-N environments for grain yield, straw yield, biological yield, groat protein yield, groat protein percentage, vegetative protein yield, straw protein percentage, total plant protein yield, and harvest index.

Genotype x N level interaction was not significant for nitrogen harvest index. The high-N environment caused significant increases in total plant protein yield, vegetative protein yield, and straw protein percentage and significant reductions in nitrogen harvest index and harvest index. Grain yield, straw yield, biological yield, groat protein yield, and groat protein percentage were not different in low- and high-N environments. Nitrogen harvest index and total plant protein yield were negatively correlated in the low-N environment but independent in the high-N environment. Nitrogen harvest index was positively correlated with grain yield and groat protein yield in both environments and positively correlated with groat protein percentage only in the high-N environment.

INDEX DESCRIPTORS: *Avena sativa*, straw nitrogen percentage, groat-protein yield, groat-protein percentage

Grain yield and grain protein concentration tend to be inversely related in cereals (Frey, 1977). Hageman et al. (1976) and Frey (1977) suggested that this negative relationship may be due to limited nitrogen (N) in the soil rather than a genetic association. However, Terman (1979), who worked with wheat (*Triticum aestivum* L.), found a negative correlation between these traits at several levels of soil N.

Grain N of cereals is derived largely from remobilization and translocation of N from vegetative tissue (Cataldo et al, 1975; Dalling and Loyn, 1976). Therefore, the N or protein content of the grain of cereals should be dependent upon the efficiency with which a plant partitions N between vegetative to reproductive tissue. This N partitioning efficiency, which is measured as the ratio of grain N to total plant N, is called nitrogen harvest index (NHI) (Austin et al., 1977; Desai and Bhatia, 1978). NHI and protein content are positively and significantly correlated in oats (*Avena sativa* L.) (Fawcett and Frey, 1982), but not in wheat (Löffler and Busch, 1982). Fawcett and Frey (1982) found a positive correlation between NHI and protein yield of oats.

According to Fawcett and Frey (1982) and Desai and Bhatia (1978), uptake of N from the soil by oats and durum wheat (*T. durum* L.), respectively, was independent of efficiency of N partitioning to the grain.

High soil N increased straw protein percentage (Eagles et al, 1978) and plant protein yield (Fawcett and Frey, 1982) of oats, but NHI of oats (Wiggans and Frey, 1956; Fawcett and Frey, 1982; Rattunde and Frey, 1986) and wheat (Halloran, 1981) declined as soil N increased. Fawcett and Frery (1982) suggested that the depression of NHI at high soil N was due to an increase in vegetation without a concomitant increase in grain yield. Greater NHI values with lower soil N also may be caused by depressed N uptake at later growth stages (McNeal et al., 1968). Therefore, fertilizing soil with N does not necessarily increase grain protein yield. In fact, Terman (1979) suggests that plants absorb only as much N as they need for growth.

Rattunde and Frey (1986) found the greatest range of genotypic values for NHI of oats and the lowest genotype x year interaction when the testing was done in a high-N environment. Thus, they suggested that selection for NHI would be most effective when done in a high-N environment. Halloran (1981) found the NHI values varied with soil N and suggested that selection for this trait should be conducted at an N level similar to the field conditions where selected genotypes would be grown.

The objectives of this study were to (1) survey the variability for NHI among random lines of oats, (2) assess the effect of soil N on NHI expression, and (3) estimate associations between NHI and other traits.

MATERIALS AND METHODS

Genetic Materials.

The material used for this study was a population of 480 random F_3-derived, F_6 oat lines composed of 80 lines from each of six matings made by Murphy (1981). In addition, 20 strains, 10 with high NHI (CI 9170, Otee, Spear, B509-801, Grundy, B525-76, Y10-34-15, Diana, B525-73, and A465) and 10 with low NHI (Clintford, Y6-13-9, Blanca Alemana, Chernishevka, CI 9268, Golden Giant Liguleless, Pusa Hybrid, CI 2109, Black Rival, and Korean Native oats) were used as check entries.

Field Evaluation.

The oat lines and checks were tested at the North Central Research Center near Kanawha, Iowa, in 1985, in low- and high-N environments. The field in which these experiments were conducted had been sown to oats continuously for 20 years with no fertilization. The low-N environment received no N application, and the high-N environment was created by applying 18-5-9 (N, P, and K) fertilizer in a split application to give rates of 78 and 34 kg of N ha^{-1} at planting and anthesis, respectively.

The 500 oat entries were tested in a randomized complete-block design with four replications in each environment. Additionally, a two-replication experiment was grown at the Agronomy Field Research Center near Ames, Iowa. A plot was a hill sown with 30 seeds, and hills were spaced 30.5 cm apart in perpendicular directions. Two rows of hills were sown around each experiment to provide competition for peripheral plots. The soil type at both Kanawha and Ames is a Clarion-Webster clay silty loam (fine-loamy, mixed mesic, Typic Haplaquoll). Planting dates were 19 April at Ames and 12 April at Kanawha. Plots were hand-weeded, and a systemic fungicide (Bayleton) was sprayed onto the plants post anthesis to prevent the development of fungal diseases.

Heading date was recorded as number of days from sowing *until* 50% of the panicles completely emerged. Plant height was recorded as distance in cm from the ground level to panicle tips. Heading date and plant height were measured on a plot basis only at Ames.

At maturity, each plot was harvested at ground level, air dried, and

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weighed to give biological yield. The air-dried culms were threshed, and the weight of threshed grain was recorded as yield. Straw yield was calculated as biological yield minus grain yield, and harvest index (HI) was computed as (grain yield/biological yield) × 100.

Grain lots from the same entry from replications 1 and 2 of the experiment grown at one N level at Kanawha were combined. Also, grain samples from replication 3 and 4 for the entry grown at the same N level were combined. Ten-gram samples from the two-replication composites of an entry were dehulled, and the resulting groat samples were analyzed for N content. Similarly, straw lots were combined, and N content was determined on each two-replication composite. Groat samples were analyzed for N content by using a Neo-Tec model 41 infrared analyzer, and straw samples were analyzed by using a micro-Kjedahl procedure (Appreciation is expressed to Dr. David Peterson, director of the U.S. Department of Agriculture Oat Quality Laboratory, Madison, WI for conducting the groat and straw analyses). Groat and straw protein percentages were obtained by multiplying N percentages × 6.25. Also, a groat percentage was determined on a 1-g sample from each two-replication composite of grain. The sample was weighed and dehulled, and the resulting groat sample was weighed. Groat percentage was computed as (groat weight/seed weight) × 100. Groat yield was calculated as grain yield multiplied by groat percentage, and vegetative yield was calculated as biological yield minus grain yield. Groat protein yield was calculated as groat yield multiplied by groat protein percentage, vegetative protein yield as vegetative yield multiplied by straw protein percentage, and total plant protein yield was calculated as groat protein yield plus vegetative protein yield. Nitrogen harvest index (NHI) was computed as groat protein yield/total plant protein yield × 100.

Analyses of variance were computed for each trait in each environment and for N environments combined. Phenotypic correlations were computed by using entry means within N environments.

RESULTS AND DISCUSSION

Variability in NHI and Other Traits.

Genotypes varied significantly for all traits in both N environments. The 480 random oat lines differed significantly and were nearly normally distributed for NHI values, with the range from 48 to 80% and a mean of 68% in the low-N environment and from 40 to 74% with a mean of 60% in the high-N environment. Check strains had narrower ranges than the random lines but they differed significantly also. Our random oat lines had greater variation than found by Fawcett (1980) and Wiggans and Frey (1956), who reported ranges of 45 to 74% in a low-N and 38 to 65% in a high-N environment for 40 oat lines, and 70 to 88% in the low-N and 44 to 63% in a high-N environment for six oat cultivars, respectively. Oat lines had NHI values similar to those for durum wheat (Desai and Bhatia, 1978) but greater than for winter wheat (Dubois and Fossati, 1981). Genotypic variances among lines were 13.1 in both environments. This is contrary to the results by Rattunde and Frey (1986), who found greater genotypic variance for NHI when the oat lines were tested in a high-N environment.

Effects of Soil N on NHI and Other Traits.

When analyzed across N levels, there was no genotype x N level interaction for NHI, which corroborates the results of Fawcett and Frey (1982) and Rattunde and Frey (1986). All other traits showed significant genotype x N level interactions.

Overall Mean.

Mean NHI was significantly lower in the high-N than in the low-N environment. The differences were 8% and 11% for the means of random lines and check strains, respectively (Table 1). These results corroborate those of Rattunde and Frey (1986), Fawcett and Frey (1982), and Wiggans and Frey (1956). Mean HI of the random lines was significantly though not importantly lower in the high-N than in the low-N environment, but the means of HI of check strains were similar in both environments. Means for straw protein percentage, vegetative protein yield, and total plant protein yield were significantly greater in the high-N than in the low-N environment for both random lines and check strains (Table 1). The increase in straw protein percentage corroborates the results of Eagles et al. (1978). Fawcett (1980) found that roots of oats contain very little protein, so total plant protein yield essentially is a measure of the amount of N taken up by the whole oat plant. The greater total plant protein yield in the high-N environment means that greater availability of soil N caused high N uptake by the oat plants. If the greater total accumulation of N was due to a continuous uptake during the whole growth cycle, including grain filling, as described by Evans and Wardlaw (1976), could not be discerned from this study.

Table 1. Means for 10 traits measured on 480 oat lines and 20 check strains in low-N and high-N environments.

Traits	Unit of measure	Lines		Checks	
		Low	High	Low	High
GY	Mg ha^{-1}	3.23	3.20	2.88	2.71
SY	Mg ha^{-1}	4.31	4.40	4.25	4.08
BY	Mg ha^{-1}	7.54	7.62	7.12	6.79
SPP	%	3.61	5.30**	3.80	6.14**
GTPP	%	17.67	17.60	18.66	18.73
GTPY	Mg ha^{-1}	0.41	0.42	0.39	0.38
VPY	Mg ha^{-1}	0.19	0.28**	0.19	0.29**
TPPY	Mg ha^{-1}	0.60	0.70**	0.58	0.67**
NHI	%	68	60**	67	56**
HI	%	43	42**	41	40

**Significantly different between low-N and high-N environments at 1% level.

Differential soil N caused no differences for groat protein percentage and groat protein yield (Table 1). Johnson et al. (1973) found that N fertilizer indeed did increase protein percentage of wheat grain. The high-N and low-N environments resulted in similar values for grain, straw, and biological yields (Table 1). In contrast, Fawcett and Frey (1982), who found that high-N fertilization caused significant in-

Table 2. Means of NHI, GY, and GTPP for NHI deciles in low-N and high-N environments.

Decile	NHI (%)		GY (Mg ha^{-1})		GTPP (%)	
	Low	High	Low	High	Low	High
1	63	50**	2.97	2.82*	17.83	17.49**
2	66	55**	3.19	3.01	17.65	17.44**
3	67	56**	3.37	3.29	17.59	17.29**
4	67	58**	3.24	3.21	17.69	17.50*
5	69	59**	3.26	3.23	17.84	17.78
6	69	61**	3.27	3.34	17.62	17.47
7	70	62**	3.34	3.28	17.63	17.53
8	70	63**	3.25	3.38*	17.66	17.76
9	71	65**	3.28	3.19	17.76	17.90
10	72	69**	3.21	3.46**	17.77	18.37**
Range	63 – 72	50 – 69	2.97 – 3.37	2.82 – 3.46	17.59 – 17.84	17.29 – 18.37
LSD (0.05)	8	10	1.19	1.48	0.96	1.40

*, **Significantly different between low-N and high-N environments, at 5% and 1% levels, respectively.

creases in straw yield and biomass, suggested that NHI was reduced in a high-N environment because greater vegetative growth occurred without a concomitant increase of grain production. In this study, the reduction was caused by N concentrating in the vegetative tissue and not being remobilized for translocation to the grain. The oat plants, when grown in the high-N environment, were able to take up more N but they did not mobilize and translocate the additional N to the grain.

Decile Mean.

As another method for studying the effects of soil N on NHI and other traits, the 480 oat lines were divided into deciles on the basis of NHI values from the high-N environment. All deciles showed significant reduction in mean NHI from the low-N to high-N environment. However, the lower NHI deciles showed much greater depression than the higher ones, which corroborates the result of Rattunde and Frey (1986). For example, the depression was 13% for decile 1 and only 3% for decile 10 (Table 2). All deciles showed greater vegetative protein yield, total plant protein yield, and straw protein percentage in the high-N environment than in the low one (Figs. 1 and 2). Interestingly, all deciles had the same total plant protein yield (Fig. 1), indicating that N uptake was similar for oat lines in all NHI deciles. Because the deciles differed in NHI (Table 2), oat lines did have inherent differences in their abilities to remobilize and translocate N to the grain. As this ability of oat lines increased, vegetative protein yield decreased linearly, and groat protein yield tended to increase, (Fig. 1) in both N environments. For the least efficient decile (i.e., low NHI), a large proportion of the N remained in the vegetative tissue, whereas for the most efficient decile (i.e., high NHI), a large proportion of N was translocated to the grain.

When the lines were divided into deciles on the basis of N uptake (i.e., total plant protein yield values) in the high-N environment, the deciles did not have different NHI means in either the low-N or high-N environment (Fig. 2). Vegetative protein yield increased with increasing total plant protein yield in both environments, but it decreased with increasing NHI (Fig. 1), indicating that N was translocated to the grain at the expense of N in the vegetative tissue. Groat protein yield increased with increasing N uptake (Fig. 2), but this was due to increasing dry matter rather than to protein concentration.

The ability of oat plants to mobilize and translocate N to groats would be expected to influence the concentration of groat protein, but when averaged over lines, groat protein percentage did not increase with greater soil N. When the lines were divided into NHI deciles, the four deciles with lowest NHI were significantly lower for groat protein percentage in the high-N environment (Table 2). However, there was an indication that high soil N could increase protein concentration in the groats if the lines were efficient at N translocation; i.e., groat protein percentage of decile 10 was significantly greater in the high-N environment than in the low one.

Means for grain yield of NHI deciles, when measured in low-N and high-N environments, showed a relationship similar to the results reported by Fawcett and Frey (1982). That is, NHI decile 1 (NHI = 50%) had significantly greater grain yield in the low-N than in the high-N environment, whereas deciles 8 and 10 (NHI = 63% and 69%, respectively) have significantly greater grain yield in the high-N than in the low-N environment.

Association Among Traits.

Protein yield has become a trait of significance in developing countries because protein in human diets tends to be limiting. Negative correlations between groat protein yield and groat protein percentage indicate that selecting for high groat yield of oats would reduce protein concentration of the groats. This difficulty in combining high protein content and high yield has been almost universal in cereals until Kuenzel and Frey (1985) discovered a germplasm source in oats in which these traits were inherited independently. Our results indicate that selecting oat lines for high NHI could be a route for increasing protein yield. That is, NHI was positively correlated with groat protein yield, and NHI was positively correlated with groat protein percentage in the high-N environments and independent in the low-N environment. The positive correlation between NHI and grain yield, even though low, suggest the possibility of using NHI to select oat lines with both high grain and high protein yields.

NHI was negatively correlated with total plant protein yield in the low-N environment, but the two traits were not associated in the high-N environment (Table 3), indicating that, when soil N was limited, the grain had priority on the N present in the plant. However, when N was unlimited, N remobilization and translocation were independent from N uptake. A similar result was reported for wheat by Spratt and Gasser (1970). The independency of N partitioning and N uptake has been reported in oats (Fawcett and Frey, 1982) and durum wheat (Desai and Bhatia, 1978). That total plant yield and groat protein yield were highly correlated seems to contradict the independency of N uptake and N partitioning. But the positive correlation between total plant protein yield and groat yield combined with the negative association between total plant protein yield and groat protein percentage show that greater N uptake caused higher protein yield via yield of dry matter and not via protein content.

NHI was negatively correlated with vegetative protein yield and straw protein percentage which indicates that, with increasing ability of plants to transfer N to the grain, a smaller proportion of the N is left in the vegetative tissue.

NHI was positively correlated with HI in both N environments.

Table 3. Phenotypic correlations among traits of oat lines in low-N (above diagonal) and high-N (below diagonal) environments.

Traits	GY	GTY	GTPP	GTPY	SPP	VY	VPY	TPPY	NHI	HI
GY		0.98**	−0.62**	0.93**	0.05	0.69**	0.52**	0.90**	0.14**	0.50**
GTY	0.98**		−0.60**	0.96**	0.03	0.64**	0.47**	0.89**	0.21**	0.51**
GYPP	−0.59**	−0.56**		−0.36**	0.08	0.41**	−0.33**	−0.41**	0.08	−0.34**
GTPY	−0.91**	0.94**	−0.27**		0.01	0.61**	0.43**	0.91**	0.28**	0.49**
SPP	−0.15**	−0.18**	−0.06	−0.25**		0.13**	0.70**	0.34**	−0.74**	−0.10*
VY	0.81**	0.77**	−0.48**	0.70**	0.06		0.78**	0.79**	−0.38**	−0.26**
VPY	0.58**	0.52**	−0.43**	0.44**	0.57**	0.84**		0.77**	−0.73**	−0.24**
TPPY	0.89**	0.89**	−0.40**	0.88**	0.14**	0.90**	0.81**		−0.14**	−0.23**
NHI	0.20**	0.28**	0.19**	0.41**	−0.81**	−0.24**	−0.62**	−0.06		0.64**
HI	0.58**	0.58**	−0.37**	0.54**	−0.35**	0.02	−0.16**	0.26	0.64**	

*, ** Significant at 5% and 1% levels, respectively.

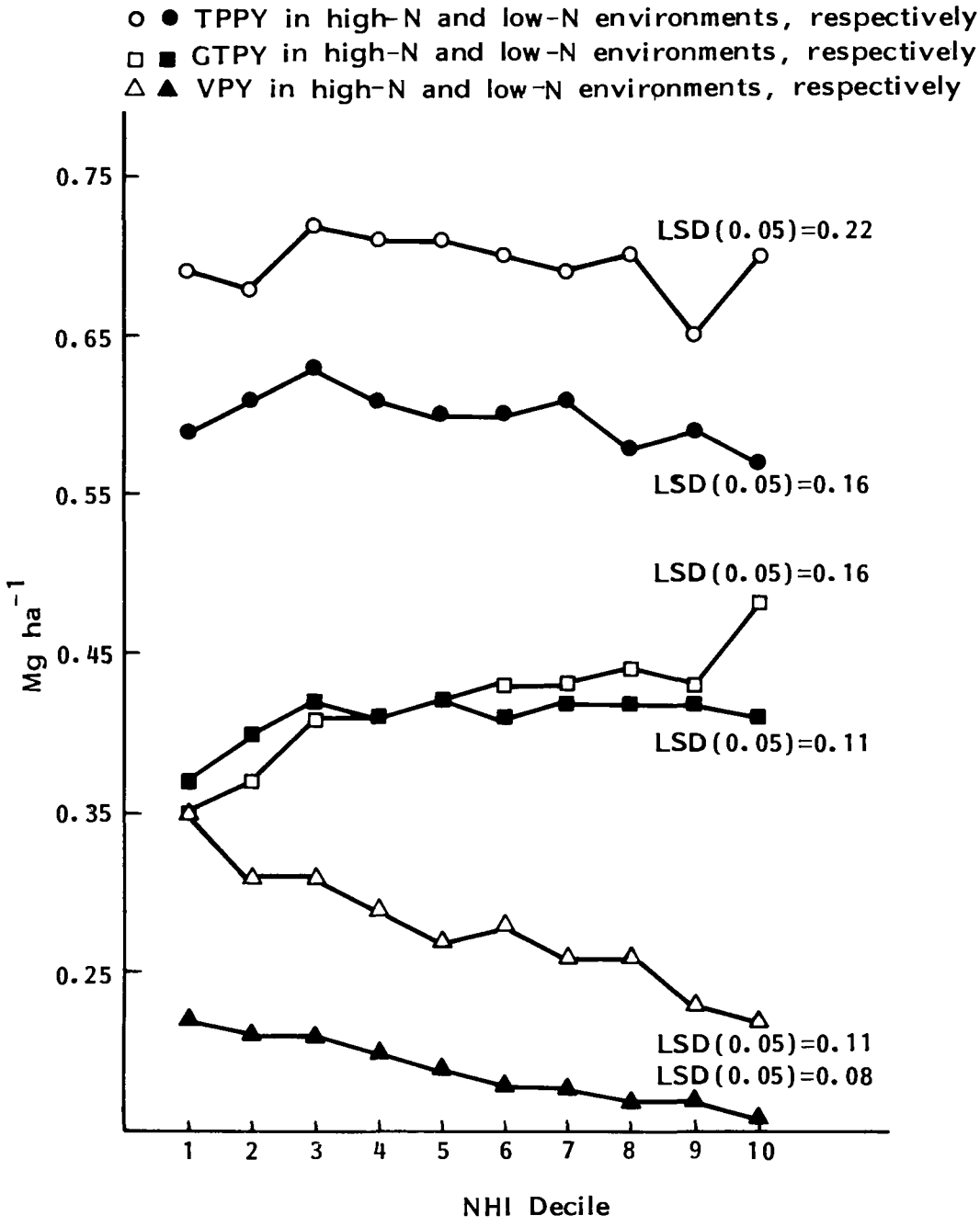

Fig. 1. Plots of TPPY, GTPY, and VPY means for NHI deciles within low-N and high-N environments.

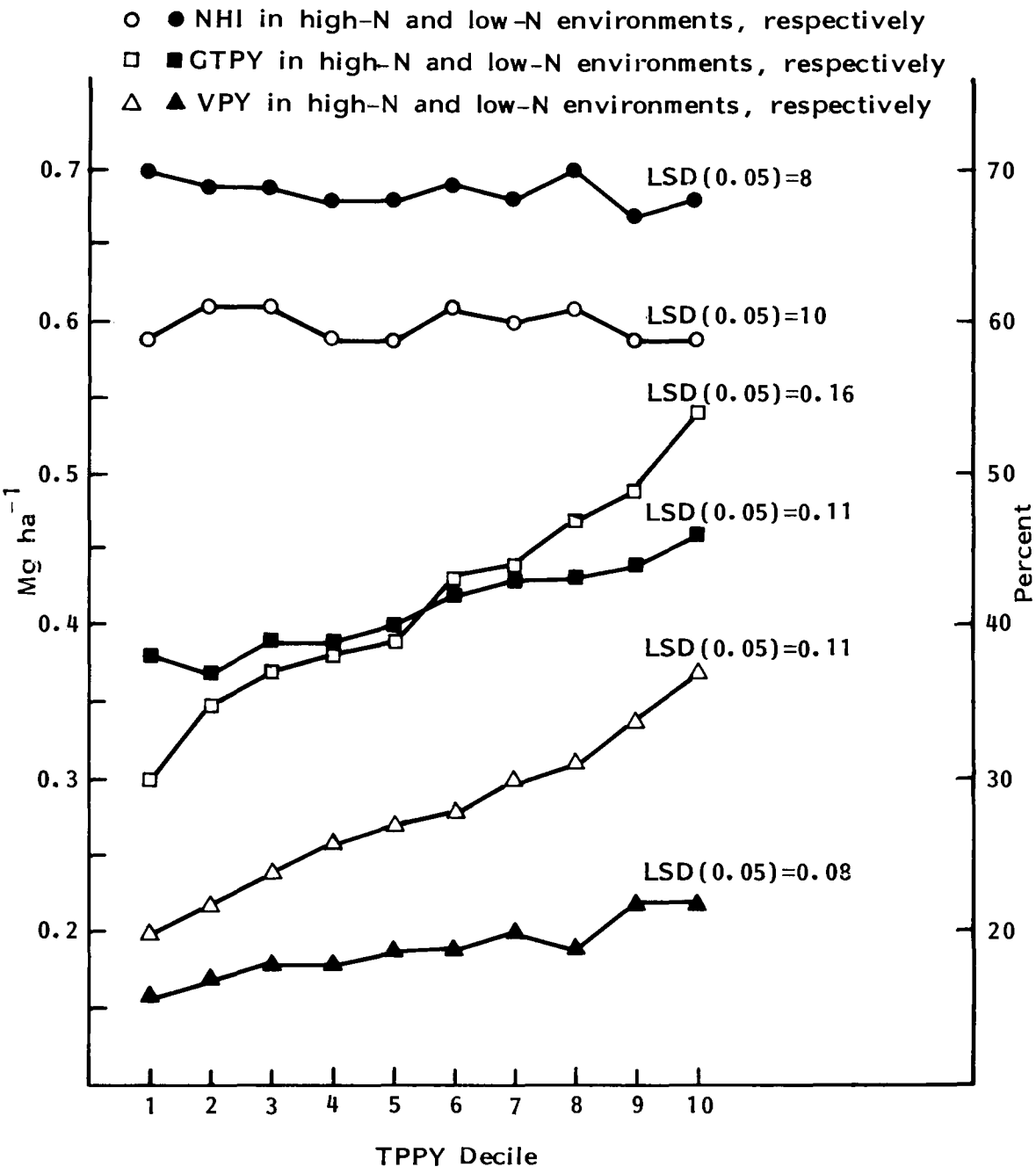

Fig. 2. Plots of NHI, GTPY, and VPY means for TPPY deciles within low-N and high-N environments.

Thus, as suggested by Desai and Bhatia (1978), N translocation is associated with carbon (C) translocation. HI was negatively correlated with groat protein percentage indicating that C translocation to the grain was greater than N translocation. This causes an N dilution in grain as shown by Dubois and Fossati (1981). NHI was negatively correlated with plant height ($r = -0.21^{*}$) and heading date ($r = -0.35^{**}$), showing that the tall and late lines were inefficient in remobilizing and translocating N to the grain. Fawcett and Frey (1982) found a negative correlation in both wild and cultivated oats.

SUMMARY

N application to the soil caused greater N uptake by the oat plants, but this did not increase the protein percentage of the grain. Protein percentage of the grain was not determined by NHI, which was affected by N availability in the soil and was independent from N uptake. Therefore, in the high-N environment, a large proportion of N was left in the vegetative tissue which caused depression of NHI values. Positive association of NHI with groat protein yield and independence from groat protein percentage indicated the possibility of using NHI as a trait to select for varieties with both high yield and high protein content.

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