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Associations Among Nitrogen Harvest Index and Other Traits Within Two *Avena* Species[1]

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The partitioning efficiency of nitrogen in crop plants is measured via nitrogen harvest index (NHI), which is the ratio of the weights of grain nitrogen to total plant nitrogen. To determine what associations, if any, exist between NHI and other plant traits for oats, 40 *Avena sativa* lines and 52 *A. sterilis* collections were studied.

Significant variations occurred between and within species for NHI, groat yield (GTY), groat protein percentage (GTP), groat protein yield (GTPY), straw yield (SY), straw protein percentage (SP), total plant protein yield (TPPY), harvest index (HI), and vegetative growth rate (GR). Traits significantly associated with NHI within both *Avena* species were HI, GTY, GTPY, SP, and heading date (HD).

Uptake and partitioning of nitrogen between grain and straw were not related in *A. sativa*, suggesting that these two phenomena were controlled by separate physiological mechanisms. Total dry matter accumulation and not protein percentage was the major factor influencing protein yields of both grain and straw. NHI was not correlated with either GTY or GTP in *A. sativa*, suggesting that selecting for high NHI may break the inverse relationship between GTY and GTP within this species.

INDEX DESCRIPTORS: Oats, *Avena sativa*, *Avena sterilis*, grain protein, nitrogen harvest index

Uptake of nitrogen into plants and the partitioning of it between grain and straw are the two major physiological components of nitrogen utilization in cereals. Partitioning of nitrogen between grain and straw may be of prime importance where soil nitrogen or moisture is limiting. If cereal genotypes more efficient in nitrogen uptake and/or in translocating nitrogen to grain could be developed, perhaps greater yields of high-protein grain could be obtained with moderate to low rates of nitrogen fertilization. The partitioning efficiency of nitrogen, what Austin et al. (1977) have called nitrogen harvest index (NHI), is the ratio of the weights of grain nitrogen to total plant nitrogen.

Cereal crops generally show a negative correlation between grain protein percentage and grain yield (Grant and McCalla, 1949). Some researchers suggest that increasing the NHI in cereals may improve the grain-nitrogen yields and break this inverse relationship (Dalling and Loyn, 1976). And indeed, some high-protein cultivars of winter wheat (*Triticum aestivum L.*), rice (*Oryza sativa L.*), and oats (*Avena sativa L.*) are more efficient than others in translocating nitrogen from the vegetation of the plant to the grain (Johnson et al., 1967; Perez et al., 1973; Peterson et al., 1975).

Variation in NHI exists among cultivars of oats, durum wheat (*T. durum L.*), and winter wheat (Wiggans and Frey, 1956; Desai and Bhatia, 1978; Austin et al., 1977). Some lines of *Avena sterilis*, a wild oat species from the Middle East, have high groat-protein percentage, and this trait has been transferred to genotypes of cultivated oats (Frey, 1977). Further, much variation exists for straw-protein percentages among *A. sterilis* genotypes (Frey et al., 1975), and recently, Fawcett and Frey (1982) showed that there is genetic variation for NHI among genotypes of this species.

Our objectives were to determine what associations, if any, exist between NHI and other plant traits in *A. sterilis* and in cultivated oats.

MATERIALS AND METHODS

Forty *A. sativa* lines and 52 *A. sterilis* collections were used for our study. *A. sterilis* collections were chosen to represent a wide range of both groat- and straw-protein percentages and to represent many geographic origins. The *A. sativa* entries could be divided into several groups: (a) 13 lines adapted to Iowa: Diana (CI 7021), Grundy (CI 8445), Cherokee (CI 5444), Spear (CI 9203), Dal (CI 9159), Goodland (CI 9202), Otee (CI 9086), Lang (CI 9257), Noble (CI 9194), Stout (CI 9195), Wright (CI 9201), Clintford (CI 7463), and CI 9170; (b) 10 cultivars: Craigs Afterlea (CI 7317), A465, Black Rival (CI 807), Chernishevka (CI 2059), Blanca Alemana (CI 4506), Korean Native oats (CI 3456), Pusa Hybrid X27 (CI 3442), Golden Giant Liguleless (CI 1606), CI 2109, and CI 2410, chosen at random from 10 countries around the world; (c) five high-protein lines from B525 and three from B590 were also included, (B525 was a composite of 12 three-way crosses, and B590 was a mass-selected subpopulation of B525); and (d) nine genotypes were from a program for the introgression of *A. sterilis* germplasm into cultivated oats.

The 92 oat entries were sown 18 April 1979 on a Coland loam (Cumulic Haplaquolls) soil near Ames, Iowa. The experiment was conducted in a randomized complete-block design with four replicates. A plot consisted of 10 seeds sown in a hill, with hills spaced 30.5 cm apart in perpendicular directions. Nitrogen (N), phosphate (P_2O_5), and potash (K_2O) were topdress applied one week after planting at rates of 112-75-75 kg/ha. To assure an adequate N supply, 112 kg/ha was applied on 31 May (10 days before anthesis).

Adequate soil moisture for plant growth and N uptake was maintained throughout the growth cycle by supplementing rainfall with irrigation. Plants in each plot were tied to stakes to prevent lodging, and were sprayed with a fungicide at weekly intervals from anthesis to maturity to control foliar diseases. Heads of *A. sterilis* entries were bagged after anthesis with delnet PG 218 nonwoven mesh bags (hi-density polyethylene, mfg. by Hercules, Inc., Wilmington, DE 19899) to catch seed that shattered.

Heading date (HD) was recorded as the number of days after sowing when 50% of the panicles in a plot were fully emerged. At maturity, plants in a plot were harvested at ground level, air-dried, and weighed to give bundle weight (BWT). Subsequently, the culms were threshed, and grain yield (GY) was recorded. Straw yield (SY_2) was calculated as BWT - GY, and vegetative growth rate (GR) was computed as SY_2/HD. All yields were recorded in grams/plot (g/plot) and converted to quintals/hectare (q/ha).

All traits were calculated considering the hulls as a component of the straw. After threshing, ten random spikelets from a plot were weighed and dehulled. Groats (caryopses) were weighed, and groat percentage (GP) was the ratio of groat to spikelet weights.

Groat yield (GTY) was computed as GY × GP, and hull yield

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Table 1. Means for 10 traits of *A. sativa* and *A. sterilis*.

Trait	Abbreviation	Unit of Measure	Species	
			A. sativa	*A. sterilis*
Nitrogen harvest index	NHI	%	55**	38
Groat yield	GTY	q/ha	28**	14
Groat protein percentage	GTP	%	18.6**	21.5
Straw yield	SY	q/ha	68**	57
Straw protein percentage	SP	%	6.2**	8.7
Groat protein yield	GTPY	q/ha	5.2**	3.0
Straw protein yield	SPY	q/ha	4.2	4.8
Total plant protein yield	TPPY	q/ha	9.4**	7.8
Harvest index	HI	%	30**	20
Vegetative growth rate	GR	g/plot/day	0.97**	0.55

** Means for species differ significantly at 1% level.

(HY) was calculated as GY × (1-GP). Straw yield including hulls (SY) was calculated as $SY_2 + HY$, and harvest index (HI) was calculated as (GTY/BWT) × 100.

Next, straw from a plot was ground to pass through a 15-mesh sieve, and ground samples from replicates one and two and from replicates three and four were bulked to form two protein replicates. Groats were bulked similarly. Groat-N percentage was determined by using a micro-Kjeldahl technique, as described by Cataldo et al. (1974), eliminating the predigestion step. Straw-N percentage was determined with the Neo-Tec Model 41 near-infrared analyzer. Groat-protein percentage (GTP) and straw-protein percentage (SP) were calculated by multiplying the respective N percentages by 6.25. Groat-protein yield (GTPY) was calculated as GTY × GTP, straw protein yield (SPY) as SY × SP, and total plant protein yield (TPPY) as GTPY + SPY. NHI was calculated as (GYPY/TPPY) × 100.

Before the data were analyzed, means for all traits were calculated for replicates one and two and for replicates three and four so they would correspond to the protein replicates; thus, the data were analyzed with two replicates rather than four. Significance of variations due to various sources was judged from analyses of variance, and correlation coefficients among traits were calculated by using trait means.

RESULTS

NHI, which ranged from 19 to 50% among *A. sterilis* entries and from 38 to 65% among *A. sativa* entries, varied significantly among genotypes within both species (Figure 1). Also, there were significant variations between and within species for GTY, GTP, SY, SP, GTPY, TPPY, HI, and GR. Significant variation for SPY existed within but not between species. Means of NHI, GTY, SY, GTPY, TPPY, HI, and GR were greater for *A. sativa* than for *A. sterilis*, whereas those for GTP, SP, and SPY were greater for *A. sterilis* (Table 1).

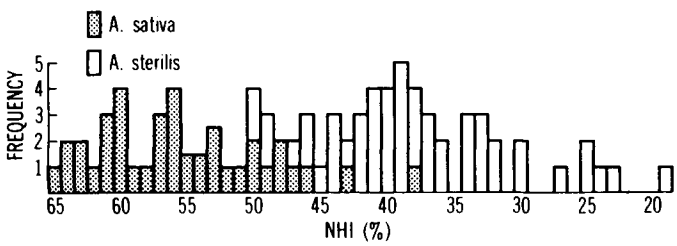

Fig. 1. Frequency distribution of NHI for *A. sativa* and *A. sterilis*

HI and NHI were highly and positively correlated within both *A. sativa* and *A. sterilis* (Table 2), which shows that partitioning of N was closely associated with partitioning of plant dry matter. Also, strong positive correlations existed between GTY and GTPY and between SY and SPY within both species, but no associations existed between GTP and GTPY within either species or between SP and SPY within *A. sativa*. There was a significant, but low, negative correlation between SP and SPY for *A. sterilis*, which may be an indirect manifestation of the strong negative correlation between SP and SY. These associations indicate that the major factor influencing protein yields in both grain and straw of oats was total dry matter accumulation in the plant parts and not protein percentages. Positive correlations occurred between GTY and NHI for both species, but the one for *A. sativa* was not significant.

TPPY and NHI were not correlated within *A. sativa*. A small, but significant positive correlation was found between TPPY and NHI for *A. sterilis*. GTPY and NHI were positively and significantly correlated in both species. SPY and NHI were negatively correlated in *A. sativa*, but not associated in *A. sterilis*. NHI and GTP were not correlated in either species, but strong negative correlations occurred between SP and NHI in both species. A negative correlation was found between SY and NHI in both species. A negative correlation was found between SY and NHI in *A. sativa*, but no correlation occurred in *A. sterilis*. NHI and HD were strongly negatively correlated in both species. The correlations suggest that the traits associated with variation in NHI within both *Avena* species were HI, GTY, GTPY, SP, and HD. Note that significant negative correlations existed between GTY and GTP in both species even with a soil application of 224 kg/ha of N. Additionally, negative correlations existed between SY and SP for *A. sterilis* and between GTY and SP for both species. SP and HD were not significantly correlated for either species.

DISCUSSION

The genetic variation found for NHI within both *Avena* species shows that this trait could be manipulated to a desired level through selection. Nitrogen uptake and its partitioning between grain and straw were not related in *A. sativa*, suggesting that these two phenomena were controlled by separate physiological mechanisms. Desai and Bhatia (1978) also found no correlation between NHI and TPPY in durum wheat, and some researchers have found that nitrogen uptake was greater in low grain-protein than in high grain-protein cultivars of wheat (Johnson et al., 1967; Salem and Youssef, 1975).

The nonsignificant correlations of NHI with GTY and GTP that we found within *A. sativa* and that Desai and Bhatia (1978) found for

Table 2. Correlations among traits for entries within *A. sativa* and *A. sterilis*.

Species	Trait	NHI	GTP	GTY	SP	SY
A. sativa	GTP	0.19	—	—	—	—
A. sterilis	GTP	−0.17	—	—	—	—
A. sativa	GTY	0.28	−0.41**	—	—	—
A. sterilis	GTY	0.68**	−0.41**	—	—	—
A. sativa	SP	−0.57**	0.15	−0.45**	—	—
A. sterilis	SP	−0.68**	0.11	−0.74**	—	—
A. sativa	SY	−0.37*	−0.21	0.66**	−0.26	—
A. sterilis	SY	0.12	−0.26	0.74**	−0.62**	—
A. sativa	GTPY	0.41**	0.06	0.88**	−0.43**	0.61**
A. sterilis	GTPY	0.71**	−0.24	0.98**	−0.76**	0.74**
A. sativa	SPY	−0.61**	−0.15	0.49**	0.15	0.91**
A. sterilis	SPY	−0.12	−0.23	0.57**	−0.35*	0.95**
A. sativa	TPPY	−0.14	−0.06	0.79**	−0.15	0.90**
A. sterilis	TPPY	0.28*	−0.26	0.85**	−0.60**	0.96**
A. sativa	HI	0.81**	0.13	0.22	−0.19	−0.55**
A. sterilis	HI	0.78**	−0.21	0.41**	−0.34*	−0.11
A. sativa	GR	−0.09	−0.15	0.71**	−0.23	0.77**
A. sterilis	GR	0.37**	−0.38**	0.86**	−0.67**	0.87**
A. sativa	HD	−0.57**	−0.14	0.22	−0.15	0.76**
A. sterilis	HD	−0.63**	0.22	−0.29*	0.17	0.23

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

T. durum suggest that selecting for high NHI may break the inverse relationship between GTY and GTP within cereal species. The negative relationship between GTY and GTP for both species supported the findings of Terman (1979). In contrast, Hageman et al. (1976) reported that the negative correlations between grain-protein concentration and grain yield in cereals was due to limited soil nitrogen.

The positive correlations between NHI and GTPY and negative correlations between NHI and SPY in both species show that selecting for high NHI improves the efficiency of nitrogen utilization in oats. Strong positive correlations between NHI and GTPY within both species might be expected because GTPY is the numerator in the formula used to compute NHI. However, a high GTPY would not necessarily mean efficient use of N taken up because SPY could be higher than required to meet the grain demand, with a resultant wastage of N. This would be especially critical where available N was limited.

The very strong correlation between SY and SPY, and between GTY and GTPY, and the low correlations between SP and SPY and between GTP and GTPY indicate that grain and straw yields and not protein percentages determine protein yields. Takeda and Frey (1979) also found a strong association between grain-protein yield and grain yield and a weak one between grain-protein yield and grain-protein percentage in oats. This is evident also in the significant positive correlations between HI and NHI. However, variation in HI accounted for only 66% of the variation in NHI within *A. sativa* and 61% within *A. sterilis*, so other factors were operating in determining NHI. The high negative correlation between NHI and SP shows the importance of this factor in influencing NHI. The lack of correlation found between SP and HD contrasts to the high positive correlation found by Campbell and Frey (1974) for this trait.

A. sterilis entries had higher GTP's and SP's than did *A. sativa* entries. *A. sterilis* can be a useful donor of high GTP to *A. sativa* as shown by Frey (1977), but such interspecific matings also may contribute genes for high SP. Evidence for the concomitant contribution of genes for high SP and high GTP comes from Y-entries from the Iowa *A. sterilis* introgression program (Fawcett, 1980). The range of SP values for the Y accessions was 6.3 to 7.7 ($\bar{x}=7.1$), whereas the range for adapted entries of pure *A. sativa* was 5.1 to 6.4 ($\bar{x}=5.7$). Mean NHI was lower for *A. sterilis* than for *A. sativa* (Table 1), which suggests that *A. sterilis* may not be a useful source of genes for increasing NHI of cultivated oats. However, Y10-34-15 and Y20-3-8 have high NHI's (Table 3), which shows, as with other traits, that the usefulness of *A. sterilis* germplasm for improving cultivated oats cannot be predicted until the germplasm from this species is substituted into a cultivated oat genetic background. Lawrence and Frey (1976) noted a similar situation in which genes from *A. sterilis* entries increased grain and straw yields of oats materially when placed in an adapted genetic background.

SUMMARY

Nitrogen harvest index (NHI) ranged from 19 to 50% among *A. sterilis* entries and from 38 to 65% among *A. sativa* entries. Mean NHI's were 38 and 55%, respectively, for the two species.

Traits positively associated with NHI were harvest index, groat yield, and groat protein yield. Those negatively associated were straw protein percentage and heading date. The low associations between NHI and total plant protein yield suggest that uptake of nitrogen and its partitioning between straw and grain were controlled by separate physiological mechanisms. The nonsignificant correlations of NHI with groat yield and groat protein percentage within *A. sativa* suggest that selecting for high NHI may break the inverse relationship between grain yield and grain protein percentage, thus providing a method by which oats with both high grain yield and high grain protein percentage may be selected.

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Table 3. NHI values for the 10 *A. sativa* and 10 *A. sterilis* entries ranked highest for this trait.

A. sativa		*A. sterilis*	
Entry	NHI (%)	Entry	NHI (%)
CI 9170[a]	65	PI 412494[b]	50
Otee (CI 9086)	64	PI 412498	50
Spear (CI 9203)	64	PI 411505	49
B590-801	63	PI 411614	49
Grundy (CI 8445)	63	PI 411516	47
B525-76	62	PI 320801	46
B525-73	61	PI 411515	46
Diana (CI 7921)	61	PI 412418	45
Y10-34-15[c]	61	PI 296245	44
Y20-3-8	60	PI 298151	44

[a] CI refers to Cereal Index Number registered with the U.S. Department of Agriculture.

[b] PI refers to Plant Introduction Number registered with the U.S. Department of Agriculture.

[c] Y is a prefix of accession numbers in the Agriculture and Home Economics Experiment station for oat strains from the Iowa *A. sterilis* introgression program.

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