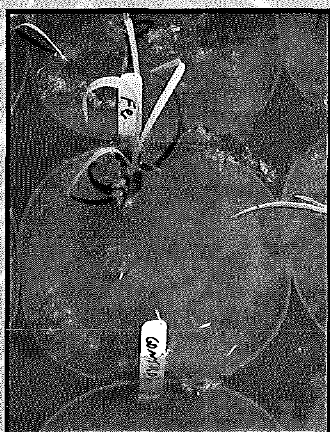
Minnesota Wild Rice Research—2001

January 2002



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WILD RICE GROWING SEASON AND PRODUCTION – 2001

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The total number of growing degree days (GDD) were higher in 2001 compared to 2000 at all Locations (Tables 1 and 2). Aitkin, Grand Rapids, Crookston and Waskish all recorded above normal total GDD: 536, 353, 145 and 721 respectively. In general, each month of the 2001 growing season was warmer than normal at all locations. The two notable sites were: Aitkin (104 for June, 136 for July, 203 for August more GDD) and Waskish (181 for June, 179 for July, 264 for August above normal).

Table 1. Growing degree days[a] comparisons for 2000, 2001 and normal (61-90).

	Aitkin			Grand Rapids		
Month	2000	2001	Normal	2000	2001	Normal
	----------	----------	----------	GDD	----------	----------
April	146	150	127	141	154	130
May	477	485	417	489	491	434
June	594	750	646	590	755	674
July	779	917	779	892	914	858
August	800	886	683	820	903	768
Total	2796	3188	2652	2932	3217	2864

[a] $\frac{\text{Maximum + minimum temp.}}{2}$ - 40°F; data from Mark Seeley, Department of Soil, Water and Climate, U of MN.

Table 2. Growing degree days[a] comparisons for 2000, 2001 and normal (61-90).

	Crookston			Waskish		
Month	2000	2001	Normal	2000	2001	Normal
	----------	----------	----------	GDD	----------	----------
April	142	139	151	113	103	103
May	499	547	488	418	469	369
June	659	750	743	481	696	518
July	927	945	926	825	821	642
August	890	939	867	724	827	563
Total	3117	3320	3175	2561	2916	2195

[a] $\frac{\text{Maximum + minimum temp.}}{2}$ - 40°F; data from Mark Seeley, Department of Soil, Water and Climate, U of MN.

Total precipitation during the 2001 growing season was greater than in 2000 and higher than the long-term normal at all locations (Tables 3 and 4). Waskish had the largest increase above normal by 8.21 inches, coming in the Spring and late Summer. Aitkin recorded 2.42 inches over normal, with most of it falling in April and May. Grand Rapids received 1.85 inches over normal rainfall during April and May. Whereas, Crookston experiences about the same increase over normal, 1.77 inches but it came in late summer, July and August.

Table 3. Precipitation comparisons for 2000, 2001, and normal (61-90).[a]

	Aitkin			Grand Rapids		
Month	2000	2001	Normal	2000	2001	Normal
	--------------	--------------	--------------	inches	--------------	--------------
April	2.55	6.27	2.30	2.64	4.57	2.10
May	4.31	4.68	2.88	3.34	5.32	3.04
June	4.14	4.57	4.09	4.23	3.92	4.11
July	1.99	2.25	4.14	1.80	1.94	3.89
August	3.77	1.89	3.83	4.52	2.83	3.59
Total	16.76	19.66	17.24	16.53	18.58	16.73

[a]Data from Mark Seeley, Department of Soil, Water and Climate, U of MN.

Table 4. Precipitation comparisons for 1999, 2000 and normal (61-90)[a] .

	Crookston			Waskish		
Month	2000	2001	Normal	2000	2001	Normal
	--------------	--------------	--------------	inches	--------------	--------------
April	1.03	1.69	1.45	1.47	4.00	1.70
May	1.08	2.39	2.45	2.25	4.82	2.33
June	5.72	1.53	3.44	4.39	3.14	4.25
July	3.22	4.34	2.77	2.71	4.16	3.42
August	1.38	4.81	2.88	6.06	7.11	3.32
Total	12.43	14.76	12.99	16.88	23.23	15.02

[a]Data from Mark Seeley, Department of Soil, Water and Climate, U of MN.

The total amount of processed wild rice produced in Minnesota in 2001, estimated at 4.3 million pounds, was the lowest since 1989 (Table 5). Production was down 1.1 million pounds from 2000 and 1.9 million pounds less than 1999. The reduction in total production is likely linked to the storms in August and reduction of production acreage.

Table 5. Minnesota and California paddy wild rice production[a] (1000 processed pounds).

	Production			Production	
Year	Minnesota	California	Year	Minnesota	California
1968	36	0	85	4200	7900
69	160	0	86	5100	9000
70	364	0	87	4200	4200
71	608	0	88	4000	3500
72	1496	0	89	3978	4000
73	1200	0	90	4800	4200
74	1036	0	91	5500	5500
75	1233	0	92	6100	7500
76	1809	0	93	5300	7500
77	1031	0	94	5300	5000
78	1761	100	95	4500	6440
79	2155	200	96	6000	7600
80	2320	400	97	6002	9000
81	2274	500	98	5840	8800
82	2697	880	99	6200	15575
83	3200	2500	2000[b]	5400	13035
84	3600	2500	2001	4300	18000

[a] 1968-1982 Minnesota values from Winchell and Dahl and 1983-1999 from Minnesota Department of Agriculture; 2001 values from Minnesota Cultivated Wild Rice Council. California values from Hiram Oilar, Wild Rice Processor and IWRA President.

[b]Estimated.

The estimated value of the Minnesota crop to producers was $5.89 million, which is the lowest crop value since 1977 (Table 6). Both components of total crop value declined; the price/lb dropped from $1.42/lb to $1.37/lb and total production was down.

Table 6. Processed wild rice harvested and value from cultivated fields in Minnesota.

Year	Production	Price to Producer	Value
	1,000 lb	$/lb	$ Millions
1968	36	3.30	0.12
1969	160	2.55	0.41
1970	364	2.80	1.02
1971	608	2.70	1.64
1972	1496	2.30	3.44
1973	1200	2.05	2.46
1974	1036	2.37	2.46
1975	1233	2.50	3.08
1976	1809	2.70	4.88
1977	1031	4.35	4.48
1978	1761	5.10	8.98
1979	2155	5.01	10.80
1980	2320	4.47	10.37
1981	2274	3.79	8.62
1982	2697	3.41	9.20
1983	3200	3.35	10.72
1984	3600	3.30	11.88
1985	4200	2.97	12.47
1986	5100	2.60	13.26
1987	4200	1.50	6.30
1988	4000	1.65	6.60
1989	3978	1.65	6.56
1990	4800	1.70	8.16
1991	5300	1.70	9.01
1992	6100	1.70	10.37
1993	5300	1.65	8.74
1994	5300	1.65	8.74
1995	4300	1.50	6.45
1996	6000	1.50	9.00
1997	6002	1.50	9.00
1998	5840	1.55	9.05
1999	6200	1.55	9.61
2000	5400	1.42	7.67
2001[a]	4300	1.37	5.89

[a]Estimated values for 2001.

CARFENTRAZONE-ETHYL ACTIVITY ON AQUATIC WEEDS AND WILD RICE TOLERANCE IN MINNESOTA -2001

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Experiments were carried out at Aitkin and Grand Rapids, Minnesota to determine weed control efficacy and wild rice (*Zizania paulustris*) tolerance to carfentrazone-ethyl. The Aitkin site was a natural, reseeded stand of cultivated wild rice that had been thinned on the farm of Tom Godward. Common water plantain (*Alisma plantago-aquatita*) and giant burreed (*Sparganium eurycarpum*) were present at this site. Wild rice tolerance was determined in a weed free paddy at the Grand Rapids Research and Outreach Center to avoid confounding with weed competition. This site was fall tilled in 2000. Following an initial stand failure, four row plots (10 ft long rows on 12 in row spacing) were re-established by transplanting in early June. 40 lbs/A of urea nitrogen was applied at planting. Plant stand and seed yields were measured from the middle two rows end trimmed to 8 ft at the Grand Rapids site. All herbicide treatments were applied with a CO_2 backpack type sprayer delivering 20 gpa at 28 psi with 11002 flat fan nozzles. All experiments had a randomized complete block design with four replications and plot size 7 feet wide by 10 feet long. Application data and results are presented below.

Application Data

Site	Aitkin Burreed Site	Aitkin Water Plantain Site	Grand Rapids ---
Date	7/12/01	7/12/01	7/19/01
Air Temp (°F)	--	86	82
Soil Temp (°F)	--	76	74
Sky	partly cloudy	partly cloudy	partly cloudy
Wind (mph)	S 0-2	S 0-2	SE 0-5
Relative Humidity (%)	70	70	--
Wild Rice			
Size (inch)	36-72	36-72	30-42
Stage	vegetative to early flower	boot to early flower	early to mid tiller
Giant Burreed			
Size (inch)	36-60	--	--
Stage	early flower	--	--
Common Water Plantain			
Size (inch)	--	12-42	--
Stage	--	emergence to flower	--

Common water plantain was at the end of the carfentrazone application window where good control would be expected. At the time of herbicide application, common water plantain scapes were emerged on about 50% of the plants and flowering just beginning, a few with immature seed development. The common water plantain pressure was heavy contributing 50% or more of the vegetation present. Wild rice was boot to early flower, a stage where wild rice injury potential exists, mostly via abnormal development of seed heads from the 2,4-D component. Compared to the 2000 study where plantain flower scapes were just beginning to emerge at application, this study defines the upper limits of common water plantain control. Nozzle plugging was severe and heroic measures (electric drill paint stirring and mallet handles) were used to get the carfentrazone suspended to get the plots sprayed. This plugging increased the variability (standard error) evident in data analysis. Some contact burn leaf necrosis on wild rice upper leaf surface was apparent 7 DAT on July 19th ratings (Table 1). However, no wild rice seed head development injury from 2,4-D was apparent. Wild rice height was variable and no significant growth reduction was apparent. The highest efficacy of common water plantain was achieved with treatments > 0.2 lb of carfentrazone-ethyl plus 0.25 lb ai 2,4-D amine/ac. The addition of 2,4-D did not necessarily improve the efficacy of carfentrazone-ethyl on common water plantain as evident in comparing the 0.2 lb ai rate with or without the addition of 2,4-D, contrary to the results of 2000 study. Fewer common water plantain seeds were produced on carfentrazone-ethyl or carfentrazone-ethyl + 2,4-D treated common water plantain than on plants treated with 2,4-D alone (personal observation). It appears that if common water plantain is beyond the ideal treatment stage, that of vegetative or early scape emergence, the rate of carfentrazone-ethyl needs to be increased from 0.2 lb ai to 0.3 lb ai.

The giant burreed plot had severe burreed pressure comprising greater than 95% of the vegetation in the study area, with the remainder common water plantain or wild rice. Most of the burreed was vegetative (70% vegetative: 30% early flowering) at herbicide application. Nozzle plugging was less common with the mixing techniques developed when spraying the plantain plots earlier the same day. The addition of 2,4-D to carfentrazone-ethyl did not improve the efficacy of the carfentrazone-ethyl on giant burreed (Table 2) as seen in the 2000 study. It appears that carfentrazone-ethyl reduced flower and seed production of giant burreed at all rates tested with or without the addition of 2,4-D, with almost complete inhibition of seed set at rates of 0.3 lb ai carfentrazone-ethyl or higher. For control of giant burreed, 0.2 lb ai/ac carfentrazone-ethyl gave adequate suppression and the addition of 2,4-D did not appear to improve performance when evaluated on August 9. Injury to burreed is such that the 81 to 82% necrosis with carfentrazone- ethyl without or with 2,4-D, respectively, is a recommended target rate since little but green tissue remains at the base of the plant and competition with wild rice is eliminated. The minimal improvement in control or seed set gained by using the higher 0.3 lb ai rate may not justify the additional costs for the higher herbicide rate. It appears that 2,4-D used alone resulted in little injury of giant burreed and is not needed unless other susceptible species are present. The effect on burreed crown and rhizome survival the following season was not determined in this study.

Tolerance of wild rice to carfentrazone-ethyl and tank mixtures with 2,4-D was determined in weed free plots at the Grand Rapids Research and Outreach Center. Wild rice, cv. Petrowski Purple, had to be reestablished with transplants and the resultant stand and plant height was variable at the time of herbicide application, though still typical of cultivated wild rice. Wild rice was at the early- to mid-tiller stage of development at application. Nozzle plugging was so severe that the highest rate, the 0.4 lb ai treatment was abandoned. There were no visible impacts of any of the herbicide treatments on wild rice stand or height and no leaf necrosis developed (data not shown). There was no reduction in grain yield due to herbicide treatment (Table 3). As seen in the 2000 study, tolerance of wild rice at the early- to mid-tillering stage is excellent.

In summary, in this trial conducted in 2001 it appears that the target rate for control of common water plantain that is further developed (50% scapes emerged at application) would be 0.3 lb carfentrazone-ethyl. In the 2000 trial, scape emergence was just beginning and a lower rate of carfentrazone-ethyl, the 0.2 lb ai rate + 0.25 lb 2,4-D gave the most economical and efficacious results. The 2000 trial would be typical of the stage fo development of common water plantain at the most optimal time for application, when wild rice is developing aerial leaves, beyond the floating leaf stage. The floating leaf stage is when wild rice is most susceptible to injury from carfentrazone. In both 2000 and 2001, 0.2 lb ai carfentrazone-ethyl gave excellent control of giant burreed. In both years, the addition of 2,4-D did not improve the efficacy on giant burreed over that obtained with carfentrazone used alone. Therefore, the addition of 2,4-D is optional depending on other weed species present that would be controlled with the addition of 2,4-D. There appears to be no significant concerns for tolerance of wild rice for up to 0.3 lb carfentrazone-ethyl tank mixed with 0.25 lb 2,4-D when applied at the early to mid-tiller stage of development as shown in the Grand Rapids wild rice tolerance trials conducted in 2000 and 2001. (Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul).

Table 1. Carfentrazone-ethyl activity on aquatic weeds and wild rice tolerance in Minnesota - 2001. Activity on common water plantain at Aitkin, MN (Becker et al.)

		Wild Rice	**Common Water Plantain**	
Treatment	**Rate**	**Necrosis (7/19)**	**Necrosis (7/19)**	**Control (8/9)**
	(lb ai/A)	---------------------(%)-------------------		
Carfentrazone	0.2	20	36	64
2,4-D Dimethylamine	0.25	10	26	25
Carfentrazone + 2,4-D dimethylamine	0.05 + 0.25	14	39	39
Carfentrazone + 2,4-D dimethylamine	0.1 + 0.25	11	40	50
Carfentrazone + 2,4-D dimethylamine	0.2 + 0.25	13	36	65
Carfentrazone + 2,4-D dimethylamine	0.3 + 0.25	9	35	85
Carfentrazone + 2,4-D dimethylamine	0.4 + 0.25	20	40	80
Untreated		0	0	--
LSD (0.05)		11	ns	23

Table 2. Carfentrazone-ethyl activity on aquatic weeds in wild rice tolerance in Minnesota - 2001. Activity on giant burreed at Aitkin, MN (Becker et al.)

		Giant Burreed		
Treatment	**Rate**	**Necrosis (7/19)**	**Necrosis (8/9)**	**Seed Pod Reduction (8/9)**
	(lb ai/A)	---------------------(%)-----------------		
Carfentrazone	0.2	77	81	66
2,4-D dimethylamine	0.25	8	5	39
Carfentrazone + 2,4-D dimethylamine	0.05 + 0.25	46	41	48
Carfentrazone + 2,4-D dimethylamine	0.1 + 0.25	47	56	56
Carfentrazone + 2,4-D dimethylamine	0.2 + 0.25	62	82	68
Carfentrazone + 2,4-D dimethylamine	0.3 + 0.25	74	91	90
Carfentrazone + 2,4-D dimethylamine	0.4 + 0.25	86	96	88
Untreated		0	0	--
LSD (0.05)		12	10	21

Table 3. Carfentrazone-ethyl activity on aquatic weeds in wild rice tolerance in Minnesota - 2001. Wild Rice Tolerance at Grand Rapids, MN (Becker et al.)

		Wild Rice	
Treatment	**Rate**	**Yield**	**Stand**
	(lb ai/A)	**(lb/A)**	**(#/A)**
Carfentrazone	0.2	809	74188
2,4-D dimethylamine	0.25	936	74868
Carfentrazone + 2,4-D dimethylamine	0.05 + 0.25	848	74868
Carfentrazone + 2,4-D dimethylamine	0.1 + 0.25	790	77591
Carfentrazone + 2,4-D dimethylamine	0.2 + 0.25	869	74868
Carfentrazone + 2,4-D dimethylamine	0.3 + 0.25	796	77591
Carfentrazone + 2,4-D dimethylamine	0.4 + 0.25	--	--
Untreated		881	76910
LSD (0.05)		ns	ns

PRELIMINARY EXPLORATION OF THE ALLELOPATHIC POTENTIAL OF *BRASSICA* SPECIES IN WILD RICE PRODUCTION

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Objectives

Conduct preliminary experiments on the use of allelopathic *Brassicas* in wild rice production systems.

Background

Common water plantain (Alisma plantago - aquatica) (Ransom and Oelke 1982) and giant burreed (Sparganium eurycarpum) (Clay and Oelke 1987) are two of the most common weeds in wild rice. Both can severely reduce yield in wild rice. Cultural control of common water plantain is not always successful, but fall flooding, burying corms by plowing, and adequate water depth help reduce populations. Few cultural control methods provide control of giant burreed. Tillage will help reduce the infestation of burreed, but will not completely control it. Partial control of common water plantain can be obtained with 2,4-D, but 2,4-D will not control giant burreed (Ransom and Oelke 1988, Clay and Oelke 1990). New and better herbicides or allelopathic alternatives are needed to control weeds in wild rice. Carfentrazone- ethyl was studied for a second year as one component of management options and is reported separately. *Brassica* species offer the potential to control unwanted weeds through allelopathy (biofumigation) Table 1 (Boydston and Hang 1995,,Grossman 1993, Eberlein et al. 1998). The use of *Brassicas* for weed control have been explored (Jimenez-Osornio and Gliessman 1987, Lucchesi and Oliveira 1988, Vera et al. 1987) with greenhouse (Leather and Einhellig 1985, Petersen et al. 2001) and field methods (Boydston and Hang 1995, Eberlein et al. 1998) to test allelopathic response. Numerous herbicidal glucosinolates have been identified in *Brassica* species (Brown and Morra 1995) by plant part (Brown and Morra 1996) and alleopathic potential characterized by *Brassica* species (Vaughn and Boydston 1997, Eberlein et al. 1998). The use of methyl bromide is being discontinued and an alternative must be found. *Brassica* spp. may offer a nonherbicide weed management alternative, and may benefit other soil borne disease or insect pest management issues.

Progress To Date

This fall/winter, the screening procedures of Boydston and Hang (1995) are being used to screen common plantain, common giant burreed, and a cultivar of wild rice for allelopathic impacts of shoot tissue and root tissue of dwarf Essex rape. Additional weed species will be screened to determine the potential effects of dwarf Essex on seedling germination and growth. Seed of common water plantain and giant burreed were collected this fall at the Godward farm, from nursery stock on the St. Paul campus at the University of Minnesota, and from the nursery established in the cultivated wild rice research lagoons at the Grand Rapids Research and Outreach Center. Tearleaf smartweed seed was collected at the Rosemount Extension and Outreach Center. Reed canarygrass was included as well. The seeds were kept refrigerated in preparation for use in greenhouse assays. The dwarf Essex rape was selected for use as the initial

Table 1. Hairy nightshade (SOLSA) and longspine sandbur (CCHPA) fresh weight and number of seedlings at 3 wk after emergence after adding 20 g rapeseed or potato fresh tissue to 400 g dry loamy sand soil in the greenhouse.[a] (Boydston and Hang 1995)

	SOLSA		CCHPA	
Soil amendment	**Weight**	**No. seedlings**	**Weight**	**No. seedlings**
	g/pot	no./pot	g/pot	no./pot
Rapeseed	0.7 c	6.4 c	0.7 b	3.5 b
Potato	4.0 b	13.3 b	4.2 a	5.5 a
None	6.8 a	25.1 a	4.1 a	5.4 a

[a] means within a column followed by the same letter are not different at P=0.05 according to LSD test.

screen because of its proven herbicidal level of glucosinolates (Eberlein et al.1998) and because of seed availability.

Dwarf Essex rape seed were planted in 8 inch azalea pots containing greenhouse potting soil mix in the greenhouse on November 26 , 2001 to generate biomass for use in the allelopathic screen. Plants were thinned to 10 per pot, watered daily and fertilized biweekly. Lighting was adjusted to simulate 16 hour day length. On Dec 19, both shoots and roots were harvested and immediately frozen. Shoots were clipped, bagged and frozen. Roots were removed from pots and washed in two sequential water baths to remove all soil, then bagged and frozen. Shoots and roots from one pot were weighed, dried and weighed to determine percent dry matter.

On Jan 16, 500 g of still frozen mustard root material was chopped to < 1 cm lengths prior to adding to 7500 g of greenhouse potting soil mix. After thorough mixing, twenty 4 inch pots were filled with the soil/root mixture. 500 g of shoot material were similarly chopped, blended and potted. A check treatment of 20 pots of the greenhouse potting soil only filled out the treatment list. Seeds of five species were seeded in each pot and then covered by enough soil to cover the burreed seeds. Burreed seeds were soaked in water for 24 hours, then a 1-2 mm cut was made at the tip of each seed just prior to planting to enhance germination. (Anderson, 1968.) The species and number of seeds per pot are:

Giant burreed *Sparganium aurycanum* (6)
Common waterplantain *Alismo plantago aquatico* (10-12)
Tearleaf smartweed *Polygonium* (10-12)
Reed canarygrass *Phalaris arundinacea L.* (12-15)
Wildrice *Zizania aquatica L.*(10)

In the greenhouse, the 20 pots of each treatment were sub-irrigated to the soil surface level in the pots. Supplemental lighting simulates 16 hour day length.

Data collection at 3 wk will include visual ratings for each specie with respect to stand reduction, growth reduction and chlorosis or necrosis of shoots. Four wk after planting the number of each specie per pot will be recorded and shoot biomass will be determined.

Looking Ahead

Screening wild rice is important to determine the potential for the use of *Brassica* species to expedite the transition to new cultivars by accelerating the elimination of the previous wild rice seedbanks and conversely, is important to determine the potential for detrimental effects to the crop if used for weed control prior to crop production. Work by Boydston and Hang (1995) and Eberlein et al (1998) have shown reductions in weed seed germination and weed competitiveness and concluded that the use of *Brassicas* hold promise for supplementing weed control efforts. In extremely high value crops such as strawberries, solarization has been used in conjunction with biofumigation to provide complete suppression of economically damaging pathogens and weeds (Stapleton et al. 2000), but biofumigation with *Brassica* spp. alone was not acceptable. It is anticipated that *Brassica* use in wild rice will supplement, not replace other management practices. Completion of these studies by February 2002, depending on our success in breaking dormancy of the weed seeds collected. Future work will adapt to screen new, promising *Brassica* based on the present work by Dr. Jack Brown, University of Idaho, and Rick Boydston, Washington State University, for species selected for high glucosinolate levels.

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FACTORS LIMITING YIELD OF WILD RICE IN PADDIES AND NATURAL STANDS

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Micronutrient Trials

Fertility studies on grower paddies and grower observations have shown that on some soils, even with best practices and adequate NPK, poor yields are obtained. On some fields or areas in fields the growth of rice is consistently very poor. Plant analysis from some of these areas also suggests that micronutrients and/or sulfur may be the problem.

In the summer of 2000 strip trials were conducted on one site in the Aitkin area on the Godward farm and on the Petrowske farm in the Waskish area to determine the response of wild rice to topdress additions of: S, Mn, Cu, Fe or a combination treatment of all 4 elements plus B, Mo, and Zn. These treatments did not show any positive response.

Similar trials were conducted in 2001 using incorporated micronutrients instead of top dressing as done in 2000. In the fall of 2000 trials strips were fertilized on fields near the sites of the 2000 field trials. The design used was similar to the summer of 2000 study. However Mg replaced the Fe treatment. During preparation of the 2001 strip trial, soil was taken from areas in or near the strip plots for study of micronutrient response in pots.

Methods for Trials in Pots

Soil was taken from areas in or near the plots that were prepared in the fall of 2000 for the 2001 strip trials. The soil from the Petrowske field was taken from within the field plot area whereas the soil from the Godward field was obtained from near the center of the field where the soil was even poorer that at the field site. The wild rice was grown in 8 in. pots with one plant per plot. The treatments included dolomitic limestone (limestone with Mg), copper sulfate, sulfur as gypsum and combination treatments including lime, and the control with only N and P. The soil was stored in buckets in a field moist condition prior to the experiment.

<u>Treatments</u>

1. Control.
2. Lime (50% Mg plus 50% Ca) -- 4,000 lb calcium carbonate equivalent per ac.
3. Sulfur as gypsum 30 lb/ac.
4. Copper 25 lb/ac.
5. Complete without lime: S as sulfate salts of microelements, 12 lb/ac copper, 30 lb/ac zinc, 91 lb/ac magnesium, 19 lb/ac manganese, and 9 lb/ac boron.
6. Complete with lime: Same as 5 with 4,000 lb calcium carbonate equivalent per ac.

All treatments were fertilized with N and K. The treatments were replicated 6 times. The soil was wetted (but not flooded) for 2 weeks before planting Franklin half-sibling seeds.

Results of the Pot Study

We had much difficulty getting the plants started in the Petrowske soil and we had to replant and inject chelated iron (Fe-EDTA) to provide the iron needed to get the plants started. In both soils growth was poor and variable from pot to pot. A period of several weeks of flooding is likely needed to mobilize iron even if soil is not air dried. Air drying is a well known factor in producing early Fe deficiency for wild rice in pots. Many of the plants grown in the Petrowske soil showed purpling of the tissue similar to what is seen in P deficiency. However the soil and plant data in Tables 1 and 2 suggest that P deficiency was not a factor that could explain the observed symptom.

The soils used were very different. The Petrowske soil was an organic soil with 77 % organic matter while the Godward soil was a fine sandy soil with only 1.5 % organic matter. Both soils had non-amended pH values of in the range of 6.4 - 7. In both soils the soil test P (Bray 1) was in the range that is considered adequate for good production; 14 for the Petrowske soil and 20 for the Godward soil. In both soils the soil test K was only slightly less than the value needed for good wild rice production; 128 for the Petrowske soil and 124 for the Godward soil.

The soil amendments did, in general, increase the soil test values for the elements added. For example, the addition of Zn, Cu and B in the combination treatments greatly increased the soil test values for these elements (Table 1). The addition of the Ca and Mg carbonates (lime treatment) increased pH, Mg, and Ca in the Godward soils and increased the pH in the Petrowske soil. However, in the Petrowske soil Ca and Mg were already very high and increases in the lime treatment were not obvious. The gypsum addition did not increase the soil test S at the end of the experiment. Additions of lime appear to decrease the soil test Zn, Cu, Fe and Mn. This is expected from the chemical behavior of these elements in soil. The Zn, Mn, Fe and Cu results for the Petrowske soil were much greater than for the Godward soil but this difference is exaggerated by the method the soil test laboratory uses to "correct for sample weight" for organic soils. This "correction" needs to be reviewed and possibly changed. The values for the Petrowske soil should be divided by a factor of 5 for comparison to mineral soils.

Table 1 Variation in soil test values at the end of the pot study.

	pH	S, ppm	Ca, ppm	Mg, ppm	Zn. ppm	Fe, ppm	Mn, ppm	Cu, ppm	B, ppm
Godward									
Control.	7.0	13	598	126	0.8	80.2	9.2	0.4	0.8
Lime	8.1	15	1145	235	0.3	55.2	6.4	0.3	0.6
Gypsum	7.1	14	509	91	0.3	84.8	9.8	0.4	0.6
Copper	6.8	17	498	121	0.3	88.5	8.7	10	0.6
Combination	6.7	25	397	134	10.1	83.5	10.5	6.6	2.1
Combination & lime	7.9	18	1269	261	7.3	65.7	12.6	4.9	2.6
Petrowske									
Control.	6.4	40+	4464	964	14.2	99.9+	73.6	3	8.7
Lime	7.3	40+	4428	999+	11	99.9+	47.2	2.2	8.3
Gypsum	6.6	40+	4665	995	13.4	99.9+	69.8	3.5	9.3
Copper	6.5	40+	4241	999+	13.2	99.9+	64.9	99+	10.3
Combination	6.5	40+	4241	955	99+	99.9+	99+	28.2	30.8
Combination & lime	7.3	40+	4948	999+	99+	99.9+	99+	40.7	26.5

The plant analysis data suggests the plants had adequate P, K, Ca, Mn, Zn, and B for all treatments (Table 2). The Cu plant contents for the non amended soil were marginal in both soils and increased greatly with the addition of Cu to the soil. Tissue iron was marginal in the Godward soil and low in the Petrowske soils despite the addition of chelated iron. These low iron values contrast with the much higher values seen for plants grown at the summer 2000 field plots. The Al contents were low for both soils. This contrasts with very high Al seen for the plants from the Godward summer 2000 soil plots. The summer 2000 soil plots were in a soil that was more acid than the soil used in the pot study. The addition of some elements; e.g. Zn, Cu, and B did consistently increase or these elements in plant tissue (Table 2). Addition of lime did decrease the contents of Zn, and Mn for plants grown on the Godward soil, but not on the Petrowske soil. The Petrowske soil is better buffered against pH changes and the lime only raised the pH to 7.3 as compared to 8.1 in the Godward soil. The addition of gypsum did not increase the S or Ca contents of the plants.

Table 2. Variation is tissue contents with addition of micronutrients to pots.

	S, %	K, %	P, ppm	Ca, ppm	Mg, ppm	Mn, ppm	Zn, ppm	Cu, ppm	B, ppm	Fe, ppm
Godward										
Control.	0.21	3.31	1664	3002	1527	226	27.9	2.9	10.9	92.5
Lime	0.32	3.89	2067	3554	2905	188	19.4	3.4	14.5	105.5
Gypsum	0.187	3.53	1773	3455	1329	209	29.5	3.0	10.9	91.7
Copper	0.206	3.37	1711	2766	1422	225	23.3	17.2	8.5	97.0
Combination	0.214	3.43	2039	2457	1498	273	46.2	11.0	30.7	81.4
Combination & lime	0.237	3.45	2242	3678	2364	155	36.1	5.1	49.5	93. 8
Petrowske										
Control.	0.262	3.72	3870	3617	1388	111	37.6	3.3	9.1	40.3
Lime	0.241	4.32	4103	3078	1326	115	36.5	2.4	9.0	40.7
Gypsum	0.244	3.38	3335	3704	1348	135	32.1	2.3	14.2	35.9
Copper	0.332	4.45	4403	3446	1223	122	38.2	10.9	8.5	43.8
Combination	0.52	4.73	5074	3214	1551	162	91.2	12.1	19.8	45.7
Combination & lime	0.288	4.09	3932	2894	1443	129	71.8	5.2	12.1	43.4

The yields showed a high variability from pot to pot (Table 3). For some treatments, in some pots, there was no plant tissue to harvest and the recorded value for yield was zero. In the Godward soil the addition of lime greatly decreased yields. Lime did not have as negative an effect for the Petrowske soil. Addition of Cu appeared to result in a negative yield response. Only gypsum gave an increase in yield for both treatments. The large variation across pots makes in difficult to make definitive conclusions but these results taken together with the preliminary pot study and the previous results obtained more that 10 years ago by Michael Meyer suggests that large additions of sulfate may indeed increase yields. The gypsum additions to the 2000 field plots were much less than added in the pot studies and an effect of gypsum was not seen. Much greater quantities of gypsum were added to the 2001 field plots.

The effect of gypsum may be indirect. Studies on white rice have shown that the addition of sulfate can be used to prevent the production of methane. This effect results from the ability of sulfate to slow the progress of the decrease in oxidation-reduction potential to the very low levels needed for methane production. The gypsum might prevent production of some of organic products produced at low oxidation-reduction potentials that can inhibit plant production

Table 3. Plant yields from the pot study.

	Yield, g/pot	Standard deviation, g/pot
Godward		
Control.	1.76	± 0.91
Lime	0.46	± 0.46
Gypsum	2.65	± 1.41
Copper	1.39	± 0.42
Combination	2.07	± 1.28
Combination & lime	0.83	± 1.50
Petrowske		
Control.	1.45	± 0.95
Lime	1.77	± 0.51
Gypsum	2.02	± 1.42
Copper	1.32	± 0.79
Combination	1.27	± 0.57
Combination & lime	1.63	± 0.49

Method for the Field Trial

Fertilizer strip trials were prepared in the fall of 2000 on fields near the sites of the 2000 field trials. The design used was similar to the summer of 2000 study. However Mg replaced the Fe treatment. The quantities of Cu and Zn were reduced by a factor of 2 and S was increased by a factor of 3. The fertilizer amendments were applied to 8 ft x 30 ft strips in duplicate using a rotor tiller.

The treatments, in duplicate, were:

1. 50 lb/ac Mn as a sulfate salt.
2. 100 lb/ac Mg as a sulfate salt (epsom salt).
3. 15 lb/ac Cu as sulfate salt.
4. 300 lb ac S as a sulfate salt (gypsum).
5. Combination: Mn, Mg, Cu at 1/2 the above plus 10 lb/ac B as borax and 30 lb/as Zn as sulfate. S is added with the metal micronutrients.
6. Control.

The plant sampling at the Godward site was affected by the lack of uniformity in the application of basal N. The fall urea was applied with a spreader truck that dropped most the urea directly behind the outlet, and very limits N at the limits of the spinner. We sampled in the high N strip that went across our plots.

Results from the Field Trial

The soil test results show that at the Petrowske site the soil is a highly organic peat and at the Godward site the soil is a mineral soil quite low in organic matter (Table 4). The pH is similar at both sites and somewhat low K at both sites. The P was lower at the Petrowske site. The B soil test value was very low for the Godward site suggesting possible deficiency.

Table 4. Soil test data for experimental sites.

	pH	Bray P ppm	K, ppm	Ca, ppm	Mg, ppm	B, ppm	Organic matter, %
Godward	6.37	28	101	769	171	0.22	2.2
Petrowske	6.00	8	67	4779	875	4.35	77.6

The N concentration in the plants from the Godward site was almost 2.5% at late boot, a value that is thought to be sufficient (Table 5). The N concentration in the plants from the Petrowske site was low at late boot. However by harvest the N content was only slightly lower at the Petrowske site. The K and P concentrations were adequate at both sites. The mean S concentrations were similar for both sites and were in the range that is normal for crops like white rice. The ratio N/S was greater at the Godward site because of the greater N. The concentrations of Ca, Zn, and B were in normal ranges. The B concentrations were normal even for the control treatment at the Godward site, despite the very low soil test B. This suggests problems with soil testing in wild rice. Plant tissue Cu was low at the Petrowoske site. It was slightly higher at the Godward site. Manganese and iron were normal the Godward site but low at the Petrowske site.

Table 5. Mean plant tissue content at late boot and harvest, mean and standard deviation.

		N,%	S,%	N/S	P, ppm	K, %	Ca, ppm	Mg, ppm
Godward								
late boot	mean	2.43	0.197	12.33	3720	4.0	3277	1340
	SD	0.356	0.019	0.92	370	0.15	536	71
harvest		1.44	0.136	10.6	2304	3.21	3059	1525
		0.05	0.005	0.38	225	0.40	562	294
Petrowske								
late boot	mean	1.77	0.178	9.90	4056	2.8	4158	1399
	SD	0.152	0.014	0.75	356	0.20	493	102
harvest	mean	1.43	0.145	9.87	3316	2.3	3783	1447
	SD	0.02	0.003	0.19	113	0.98	255	60

		Mn, ppm	Fe., ppm	Zn, ppm	Cu, ppm	B, ppm
Godward						
	mean	221	223	35.3	2.6	16.3
	SD	39	58	5.5	0.3	13.2
	mean	256	63.7	42.0	2.1	24.4
	SD	40	12.6	11.2	0.3	26.0
Petrowske						
	mean	79	66	29.9	1.9	7.1
	SD	16	8	3.2	0.3	0.5
	mean	109	63.7	35.9	1.5	5.4
	SD	12	12.6	1.6	0.2	0.3

The copper treatment increased the plant tissue content at both sites (Table 6). But unlike 2000 the increase in tissue Cu was barely discernable. Addition of B in the combination treatment increased the plant B at the Godward site but not at the Petrowske site. Boron binds to organic matter and the organic matter and the retention of retention of B in the peat decreased the plant availability. The Mn treatment at the Godward site resulted in very high plant B. This suggests that there was an error in this treatment. Addition of Mn did not significantly increase tissue Mn at either site. The lack of increase in tissue Mn at the Godward site may be due to the treatment error. Unlike the response in 2000 there was not an increase in the tissue Zn for the combination treatment. The difference may be due to the fall addition with a rototiller for the 2001 season as opposed to the top dress addition used in 2000. Fall addition allows for more contact with soils over a longer period of time, reducing plant availability. Direct comparison with data form 2000 is difficult because less Zn and Cu additions were less in 2001 but the data do suggest that the top dressing is a more efficient way of getting these elements into the wild rice plants

Table 6. Selected plant tissue contents at late boot.

Treatment	Mn, ppm		Zn, ppm		Cu, ppm		B, ppm	
	Boot	Harvest	Boot	Harvest	Boot	Harvest	Boot	Harvest
Godward								
control	253	288	34.8	40.7	2.55	1.92	9.01	8.46
Cu	187	240	30.4	32.8	3.12	2.14	8.24	7.92
Mg	238	205	40.1	37.8	2.41	2.10	8.49	7.48
Mn	237	236	31.9	39.6	2.33	2.36	41.91	47.85
S	206	251	32.8	37.2	2.28	1.74	8.23	8.26
Comb	207	318	41.9	64.2	2.69	2.44	21.99	66.42
Petrowske								
control	77	112	31.0	37.3	1.95	1.52	6.53	5.92
Cu	80	107	31.2	35.0	2.31	1.94	7.3	5.33
Mg	67	116	29.8	35.1	1.73	1.55	7.15	5.37
Mn	100	127	27.9	34.9	1.75	1.36	6.69	5.23
S	76	91	30.8	34.4	1.74	1.33	7.37	5.27
Comb	71	103	29.0	38.5	2	1.55	7.52	5.42

Table 7. Plant density and yields at harvest.

	Petrowske			Godward		
	Plants/ft^2	Straw lb/ac	Grain lb/ac	Plants/ft^2	Straw lb/ac	Grain lb/ac
Control	4.60	3552	731	2.74	3359	777
Cu	4.65	3482	820	2.97	3370	823
Mg	4.07	3050	834	2.53	3959	721
Mn	4.95	3430	817	2.60	3545	853
S	4.76	3718	864	2.70	3775	749
Zn and B	4.39	2507	699	2.79	3136	646
mean	4.57	3290	794	2.72	3524	761

The plant density was higher at the Petrowske site but the plant counts were in the normal range at both sites (Table 7). The total straw yields and hand harvested grain yields were similar at both sites. At both sites, no response was seen to the treatments except there was a tendency for some decrease in yield in response to the combination treatment. Because the trials were done only in duplicate it is not possible to detect small differences that might be economically significant.

Conclusions

Plant iron availablity was a problem in the pot trials. In fact, we had problems getting the plants started in the Petrowske soil because of low iron availability. There was no positive response to lime or any of the micronutrient additions. The large quantity of gypsum added did appear to increase yield but without increase in Ca or S in the plants. This may be an indirect response caused by the inhibition of the formation of organic products produced at very low redox potential. Further study will be needed to determine if the addition of gypsum produces consistent positive results.

In the field the treatments did not show any positive response. The 3–fold increase in gypsum addition compared to the 2000 field trial did not increase S or Ca in the plants. Comparison with data for 2000 where topdressing was used suggests that topdressing is a more efficient way to add Cu and Zn to wild rice. The data clearly indicate that there are very significant problems with soil testing in wild rice and soil test results in mineral soils are not comparable to the results in peats.

Factors Controlling Yield in Natural Stands

Introduction

Wild rice grows very well in many shallow lakes in Minnesota but yield can vary wildly from year to year and competition with aquatic perennials can negatively affect yields. Natural resource managers are very interested in the obtaining more information on the factors that control the yields of wild rice in lakes. In 2000 we initiated a study to investigate the factors affecting the growth of wild rice on Rice Lake, a highly productive 4200 ac lake located on the Rice Lake National Wildlife Refuge. On Rice Lake, control structures and dikes have decreased lake flooding and the lake is maintained at a more constant level during summer months than before the installation of the control structures.

Observations by the refuge staff corroborate data collected from 1985 to 1995, which suggest that pickerelweed is gradually increasing in abundance and competing with wild rice. Pickerelweed is a perennial aquatic species that spreads slowly through rhizomes, provided that no major disturbances disrupt its growth.

The results reported in 2000 suggest that depth is negatively correlated with yield and sediment soil test P is positively correlated with yield. Differences in ammonium N content in the sediment was suggested as an important factor in wild rice production. The data also suggest that nutrient competition is not the main mode of pickerelweed competition with wild rice. Pickerelweed, however, is much earlier than wild rice and appears to compete well for light.

In 2001 we continued to monitor the growth and elemental content of plant tissue along the transects and in small experimental plots on Rice Lake. In the plot studies we continued to evaluate the response of wild rice to additions of zinc and copper. In addition we set out plots to determine the effects of ammonium build up and storage in sediment where plants were not allowed to grow in 2000. We also evaluated the response to P fertilizer in areas with low soil test P in the sediment and we evaluated the effect of shading on yield.

Methods

Three persistent wild rice beds and one persistent pickerelweed bed currently exist on Rice Lake. In 2000 four transects were chosen for evaluation of the factors controlling wild rice yield in these beds. During the summer of 2001, observations, sediment samples, and plant samples were collected along the same transects that were marked in 2000. Transects 1 and 2 traversed thick wild rice beds, while Transect 3 traversed a bed with mixed plant species and Transect 4 traversed a bed dominated by pickerelweed. Within a transect PVC pipes, located at sites 750 ft. apart, were used to mark the major sampling and observation positions. The area within 16 ft of each pole was characterized by measuring water pH, water temperature and documenting plant species. Lake depth was measured by lowering a Secchi disk until it stopped sinking and measuring the rope length.

In late July, plant species identity and abundance were characterized along each transect. Every 150 ft a 1m x 1m PVC hoop was tossed onto a site representative of the area. At the transect markers, the plants in the hoop were sampled. At the locations between markers the depth, plant number for each species, number of flowers, health and average height of plants were recorded without collecting biomass. At harvest time, only wild rice plants were collected and only at transect sites. Seed heads were harvested separately and all plant materials will be analyzed for nitrogen, sulfur, phosphorus and micronutrients.

A set of plots, 3m x 3m, were marked on both sides of a designated marker in each transect. The sets contained a nitrogen plot (N plot) where all plants were removed (rogued) every two to three weeks during the summer, and a control. The N plots were included to obtain experimental data on the role N might play in the annual fluctuations in wild rice production. The organic matter in the high organic sediments of Rice Lake continues to mineralize organic N to produce available ammonium N, whether or not wild rice plants are present to take up the ammonium N. We hypothesized that ammonium accumulates in the sediment in years of poor production. Preliminary data from the summer of 1999 suggested that wild rice plants in Rice Lake have low Zn and Cu contents. One copper and one zinc granular fertilizer treatment were added as additional plots at the south set of Transect 1 and the east set of Transect 2. The 2000 data suggested that low P was a factor in yield, so in the fall of 2000 plots in low soil test P sediment sites were fertilized with P fertilizer.

Results from 2000 suggested that shading, not nutrient uptake may be the main form of pickerelweed competition with wild rice. Thus we set out six shade boxes to look for differences in wild rice plants that only received 20% sunlight in the boxes, versus plants growing amongst pickerelweed and in pure wild rice stands.

Results and Discussion

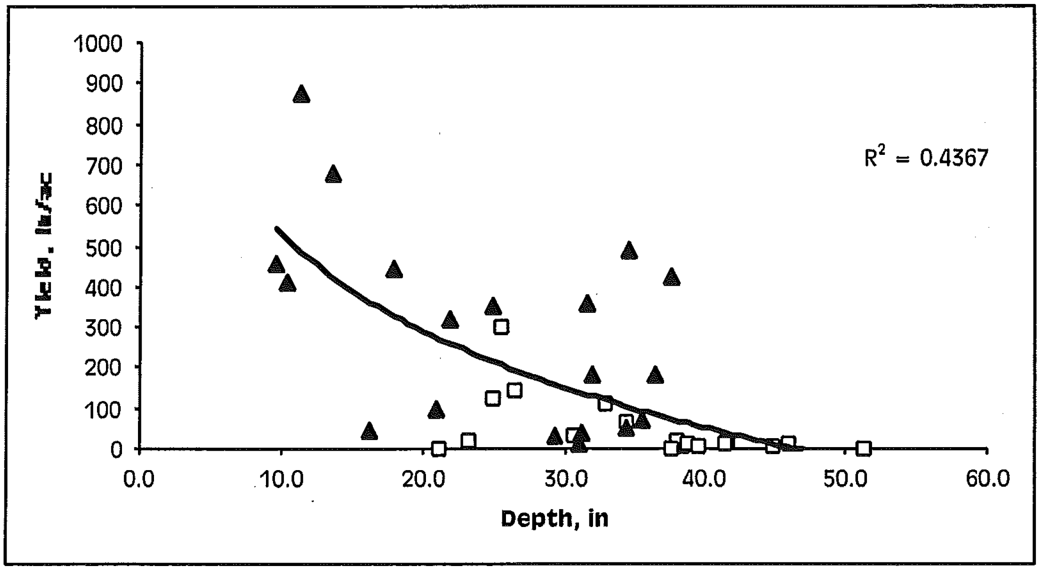
In 2001 yield of wild rice decreased greatly compared to 2000. The average harvest biomass obtained at transect sites decreased from 1383 lb/ac in 2000 to 170 lb/ac in 2001. Pickerelweed also had less overall biomass for 2001 (Table 8), but it did yield well in a few locations where rice yield was poor. The main reason for the large increase in wild rice yields appeared to be the high water in 2001. The average June water depth along transects, during the floating-leaf stage, was 43 inches in 2001 compared to 26 inches in 2000. The 2000 data showed that biomass and grain yields were negatively correlated with water depth at harvest both in 2000 and 2001(Figure 1). Another factor that may have contributed to low yields in 2001 was rotting straw from the previous season. The very high wild rice yields in 2000 produced a large amount of biomass, which built up along the shoreline and on the lake bottom, possibly forming a barrier to wild rice seedlings in 2001. This straw can create anoxic conditions in the sediments of the affected areas.

Table 8. Water depth and plant yield along transects in Rice Lake.

Distance from, shore, ft	Water depth at harvest, inches		Pickerelweed, lb/ac		Wild Rice, lb/ac Total biomass,		Seed Heads	
	2000	2001	2000	2001	2000	2001	2000	2001
Transect 1								
site 1	9.7	25.5			2363	1017	457	298
site 2	10.4	26.6			2288	475	413	147
Transect 2								
50	11.4	23.4			3851	36	878	20
800	21.9	34.5			1217	202	319	62
1550	31.3	38.5			184	21	37	4
2300	37.6	46.1			1989	58	428	10
3050	36.5	44.9			922	5	183	7
3800	35.6	41.7			402	61	69	18
4550	34.4	51.3	101		339	4	53	1
Transect 3								
50	16.3	--			245	46	49	14
800	25	32.9	497		1638	503	356	114
1550	31.9	38.1			780	122	185	20
2300	31.6	38.8			1376	57	358	16
3050	34.6	41.5			2532	54	492	10
Transect 4								
50	13.7	21.3	139		4731		681	
800	17.9	24.9	157	317	1246	476	444	127
1550	21.1	30.6	435	597	280	93	98	29
2300	29.4	37.7			362	4	33	0
3050	31	39.5			51	0	10	7

As in 2000 the copper and zinc treated plots did not produce greater biomass than adjacent control plots. However, the sediment in plots where plants were not allowed to grow in 2000 (were rogued) contained more ammonium N in June than in the adjacent control plots and the treated plots produced greater biomass than the control plots. Shading reduced seed yields to 30% or less than the yields in adjacent control plots. Because low P is only found in deeper areas of the lake the low P areas were greatly affected by the high water. We only obtained measurable yield at one of the P fertilized plot sites. At this site the P plot did have greater yield.

Figure 1. Seed yield *vs.* water depth at harvest.



Conclusions

Water depth and N appear to be the most important factors in wild rice production on Rice Lake. At depths greater that 30 inches the production is generally very low. When plant production is low, as when water is very high, the build up of N in the sediment can increase yield. Shading does greatly reduce yield and may be a factor in pickerelweed competition with wild rice. Low sediment soil test P near the center of the lake likely also contributes to low yields in deeper water but more research is needed to verify this. Copper and zinc are not limiting factors for wild rice production in Rice Lake.

WILDRICE POLLEN AND SEED RESEARCH

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Wildrice Pollen Travel

Introduction

Wildrice pollen travel is of interest both to growers of cultivated wildrice and Native Americans harvesting natural wildrice populations. The main concerns regarding pollen travel are to maintain varietal purity between cultivated paddies and to prevent pollen travel to natural populations from cultivated fields. The pollen travel experiment was set-up in the fall of 2001. The goal of the experiment was to use a male-sterile transplant method to determine the maximum distance that wildrice pollen travels in a cultivated paddy and the pollen load between two, 1/4-mile distant, paddies. A second goal was to determine the diurnal fluctuations of pollen release in the wildrice paddies.

Materials and Methods

On August 1, 2001 the pollen travel experiment was set-up at the Pine Lake wildrice farm north of Gonvick, MN (Paul Imle, cooperator). Male-sterile plants were selected from paddy SS-4, of the GIB variety. Plants were selected with one emerged panicle of the bottlebrush type and having 3 or more total tillers. Any emerged panicle was removed from each plant as it had probably already been pollinated. The plants were dug-up, along with some surrounding soil, from the field and placed in 5 gallon buckets.

Three transects were set up. Transect 1 heading east of paddy SS-4 (a large paddy with plants in full flowering) along an unmaintained road, transect 2 running south of paddy SS-4 along a dirt road, and transect 3 running north/south along a dirt road between two flowering paddies that are 1/4 mile apart. Buckets with male-sterile wild rice plants as described above were placed in duplicate at each of seven plots on transects 1 and 2, and at five plots along transect 3. Transects 1 and 2 had buckets at 0,100, 200, 300, 400, 800, and 1600 meters. The one exception to these distances was on transect 1. The road became impassible and thus the last plot was located at 1300m instead of 1600m. Transect 3 had buckets placed at 0/450, 100/350, 200/250, 300/150, 400/50 meters. The plots in transect 3 were located between two paddies, thus the first number indicated in the previous sentence is the distance from the south side of the paddy and the number to the right of the slash is the distance from the north side of the paddy. The buckets were placed partway down the ditches to the side of the roads. Each bucket was secured into place by rapping a bungee cord around the bucket and a metal pole, which at a minimum, was pushed about 6 inches into the soil.

Water was added to within an inch or two of the top of each bucket. On August 9, 2001, water was added to each bucket, and each was fertilized with 1/4 teaspoon of urea. This is equivalent to about 0.4 g of N and about 55 kg N/ha (49lb/A). On this day it was noticed that at the 100m, 400m, and 1300m plots along transect 1 there was a male sterile plant that had been thought to be a tiller of the main plant. These plants were removed but some pollen may have been released.

When the seeds were almost fully developed, and before shattering could occur, the panicles were removed from each plant. The panicles from all tillers on a single plant were combined but kept separate from seeds of the adjacent plant. The filled and unfilled seeds were separated and counted using an Agriculex ESC-1 seed counter.

A volumetric pollen collector was purchased to obtain a quantitative measure of pollen load over time. The battery for the pollen collector was not working properly and thus the second goal of this work was not completed this summer.

Plans are being made to repeat both the pollen travel experiment and to initiate an experiment to measure pollen load over time.

Results and Discussion

Tables 1-3 give the percent seed set for each plant at each plot and transect and the average for each plot. All plants had some pollination. Three plants died during the experiment and they are indicated in the tables.

Table 1: Percent seed set for transect 1.

Distance (plot)	Plant 1- % seed set	Plant 2- % seed set	Average- % seed set
0m	30.8%	69.2%	50.0%
100m	28.9%	59.2%	44.0%
200m	11.4%	Died	11.4%
300m	94.3%	74.9%	84.6%
400m	17.6%	8.7%	13.2%
800m	91.8%	1.5%	46.7%
1300m	Died	20.7%	20.7%

Table 2: Percent seed set for transect 2.

Distance (plot)	Plant 1- % seed set	Plant 2- % seed set	Average- % seed set
0m	68.2%	63.4%	65.8%
100m	20.0%	41.8%	30.9%
200m	78.7%	35.7	57.2%
300m	12.1%	17.0%	14.6%
400m	6.2%	17.9%	17.1%
800m	Died	20.3%	20.3%
1600m	5.1%	5.2%	5.1%

Table 3: Percent seed set for transect 3.

Distance (plot)	Plant 1- % seed set	Plant 2- % seed set	Average- % seed set
0/450m	52.0%	51.7%	51.9%
100/350m	11.5%	20.4%	15.9%
200/250m	22.0%	6.3	14.1%
300/150m	8.0%	94.7%	51.3%
400/50m	7.2%	45.0%	26.1%

It was not expected that enough pollen would reach the 1600m plots to produce any seeds. On transect 1, 20% seed set was observed at 1600m on the one surviving plant and, on transect 2, about 5% seed set was observed. During the run of the experiment a storm occurred which may have had 40-60 mph winds. This storm, combined with the lack of obstacles such as tree or buildings, may have lead to the pollination of plants even at 1600m. It is possible that wildrice pollen normally does not travel effectively to a distance 1600m from the source. Data from the 2002 field season will be instructive on this question.

Some of the pairs of plants at one plot show a large difference in percent seed set. These pairs are indicated in Table 1. The greatest difference was over 90% at the 800m plot on transect 1. The reasons for this difference are unclear. Perhaps some plants were unhealthy and not able to develop seeds even after germination. The health of the plants will be more closely examined during fall 2002 when this research will be repeated.

Transect 3 ran between two wildrice paddies. The expected pollination pattern for this transect was peaks at the 0/450m and 400/50m plots with the percent seed set falling off towards the middle of the transect. A pollination peak at 300/150m was observed that exceeded the percent seed set at the 0/450m plot. This could possibly be due to the 300/150m plot's location where it may have been receiving a high pollen load from two paddies.

A peak at 300 and 200 meters were also observed on transects 1 and 2 respectively. This is an interesting trend and data from the 2002 field season will help to sort out the cause of this phenomenon.

Summary of Other Ongoing Projects

Wildrice Seed Storage Research

There are three ongoing research projects aimed at improving medium term (1-3 years) wildrice seed storage. This research will especially benefit wildrice breeders who currently have very few methods of preserving wildrice seeds.

There is anecdotal evidence that adding ground sphagnum moss to wildrice during storage improves viability and decreases contamination. The objective for this experiment is to determine if peat moss improves viability and if so, whether it is due to the low pH or other compounds released by the sphagnum moss that effect wildrice viability. The seeds for this experiment will be stored in water for 1 year at 3°C. There are six treatments for this experiment; 1) a control of deionized water, 2) a control of autoclaved water from a greenhouse pond, 3) sphagnum added to the water (pH naturally around 4.5), 4) pH 4.5 using a buffer, no sphagnum added, 5) pH 7.0 using a buffer, with sphagnum added, 6) pH 7.0 using a buffer, without sphagnum added.

To store wildrice seeds for more than one year, a dry storage method will be needed to prevent early germination. The following two experiments look at medium term dry storage and will run for a total of two years.

The first of these two experiments compares the effects of two methods to reduce contamination during dry seed storage. The first treatment is the addition of ground sphagnum moss to the dry seeds. The second treatment was to precede storage with a 10-minute soak in a 10% bleach solution. The viability of these seeds will be compared to a control of untreated seeds after one and two years of storage at 3°C.

The second dry seed storage experiment looks at storage at various seed moisture contents at three storage temperatures. The storage temperatures used are 3°C, -4°C, and -15°C. For each of these temperature treatments, seeds at 0.2g water/g dry weight (or 17% moisture, fresh weight basis), 0.4 g water /g dry weight (29%), and fresh moisture content were prepared. For each of the first two moisture contents both a slow and a fast method were used to reach the desired moisture content. The viability of all treatments will be assessed after one and two years.

Research on the Natural Wildrice Population on Lake Itasca

Lake Itasca in Itasca State Park, MN has a natural wildrice population around the entire lake. The population on this lake varies from year to year as with all natural stands. This lake maintains a relatively constant water level, thus this is not considered a significant factor.

In order to better understand the causes of population variation on natural stands, six permanent transects have been established on the lake. These run perpendicular to the shoreline and include the deep and shallow extremes of the wildrice stand. On four plots along each transect depth, stem density, amount of other aquatic plants, soil quality characteristics, and shoot and root mass are measured. This has been done for 2000 and 2001 and will be repeated for the 2002 and 2003 field seasons. Soil quality characteristics will only be examined for 2000 and 2002.

Another factor that could affect the wildrice population on Lake Itasca is seed germination. A flat mesh packet was developed that holds wildrice seed while allowing it to germinate and be collected in the spring. Seeds were collected in the fall from Lake Itasca, mixed and 4 replicates of 100 seeds each placed in the packets. A HOBO tidbit temperature monitor was attached to each packet and set to record the temperature every 6 hours. These packets were placed at ten locations in lake Itasca in September 2001, all at 0.5m depths. Seed germination will be determined in spring 2002. Seeds that did not germinate will be replaced in the mesh and sampled again in spring 2003 in order to examine extended dormancy. Another packet with 4 replicates of 100 seeds will be sunk at each of the 10 sites in the fall of 2002 and examined in the spring of 2002. Water and soil quality measurements will also be taken at each of the ten sites in the spring of 2002.

Acknowledgments

We thank Paul Imle for support, plants, and space for the on-farm pollen travel experiment; Dr. Christina Walters for providing Joanna with advice and training on seed storage. This research was funded initially through a University of Minnesota Graduate School Fellowship to Joanna Cregan, and later through USDA-ARS Cooperative Agreement No. 58-3640-9-119 (secured largely through the efforts of the Minnesota Cultivated Wild Rice Council and University of Minnesota representatives).

DISEASES OF CULTIVATED WILD RICE

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Survival of Bipolaris oryzae (fungal brown spot) and the source of primary inoculum.

The fungus, B. oryzae, survives in infested wild rice residue, ONLY when residue remains dry over the winter. The fungi do not survive longer than a couple of days when exposed to moisture. Survival sites would be "clumps" of straw, bales of wild rice straw, or any place where infested rice has remained relatively dry during the winter and spring. The fungus has also been isolated from "floating" clumps of wild rice residue from fields in the spring.

Reed canary grass that grows on field dikes is a major source of inoculum to initiate fungal brown spot. This is the predominant grass that grows on most dikes surrounding cultivated wildrice fields. Previously we thought this grass was not a major source of inoculum because B. oryzae was infrequently isolated from reed canary grass lesions in the fall and from 1 of 12,000 reed canary grass samples taken the following spring. If we use our 1-years data taken during 1999 and 2000 as an example (over 30,000 samples from 2000-2001 are still being analyzed but the results appear to be similar to 1999-2000), B. oryzae was isolated from .045% of 2,500 leaf lesions on reed canary grass taken from four locations during the fall of 1999. In the spring of 2000 B. oryzae was isolated from only 1 of 12,000 leaf lesions on reed canary grass taken from these same four locations or .000083% of lesions. However, the dry weight of reed canary grass leaves in a square meter varies from 136-197 grams. We assume there is approximately one lesion per square centimeter of reed canary grass leaf tissue. The dry weight of a square centimeter is approximately .001 gram. Therefore the number of lesions per square meter in which B. oryzae may survive the winter and produce primary inoculum the following growing season varies from 11-16 (136 or 197/.001 =total potential number of lesions in a meter [TPNLM], TPNLM x .000083 = number of lesions in which B. oryzae may theoretically survive).

The number of conidia (primary inoculum units) that are produced from a single lesion varies tremendously. Given the proper environmental conditions of high humidity and temperatures, the number of conidia that can potentially be produced per lesion may exceed the thousands. Therefore, if reed canary grass remains dry or relatively dry during the winter and spring (we have observed that this commonly occurs), thousands of conidia can potentially be produced per square meter of plant material.

During the summer of 2000 and 2001, isolations were made from stands of wild rice in lakes and rivers. Contrary to previous information that river and lake stands of rice are infected only when plants are under stress, it was found that plants growing in optimum conditions were heavily diseased.

In the spring of 2001, B. oryzae was isolated from wild rice residue that had remained dry during the spring and winter. However, due to high water in lakes and rivers in the spring of 2001, lake and river wild rice residue was not commonly found at many sites that were sampled in 2000.

However, where residue remained, B. oryzae was commonly isolated. Thus residue from stands of lake and river wild rice that remains "relatively" dry serve as a source of inoculum.

Management Strategy

From our results on survival of B. oryzae on residue, I would recommend the following residue management for disease reduction:

1. Dikes should be still mowed in the fall. Infected reed canary grass will be exposed to melting snow in the spring thereby reducing inoculum.

2. No wild rice residue should be allowed to remain dry over winter. Wild rice straw should not be baled and left in field. This is an ideal site for disease organisms to overwinter.

3. All wild rice residue should be exposed to moisture for a prolonged period of a few days such as flooding. It does not appear to make any difference if residue is flooded in the spring or fall.

IMPORTANT. From my experience, it appears that growers can make a very crude qualitative prediction of disease incidence and severity the following growing season based on snow accumulation. A "heavy snowfall" usually results in less disease EARLY in the growing season. "Little snowfall or an open winter" will result in a greater incidence of disease early in the growing season. However, unless harvest occurs early in the growing season, disease eventually becomes the same later in the growing season regardless of snow cover.

Dissemination of Spores

From our results in greenhouse experiments, it appears spores of B. oryzae can be wind disseminated for a maximum distance of 18 meters (58 1/2 feet). However, most spores are only disseminated a couple of meters (6 1/2 feet). Therefore, most disease inoculum is probably of local origin.

Growth stage of plants as related to susceptibility to fungal brown spot and spot blotch

Symptoms of fungal brown spot of cultivated wild rice (Zizania palustris), caused by Bipolaris oryzae, initially occurred on the flag and lower aerial leaves of wild rice at the boot stage of development, whereas spot blotch symptoms, caused by B. sorokiniana, first occurred at the floating leaf stage of plant development on both the floating leaf and the first aerial leaves. The percentage of B. oryzae isolated from all lesions did not increase significantly until early grain formation. Lesion numbers then increased rapidly until plant maturity when B. oryzae was isolated from 36.9 and 49.3% of all flag and bottom aerial leaf lesions, respectively. On both the flag and lower aerial leaves, the percentage of lesions yielding B. sorokiniana increased slowly until early grain formation, then increased rapidly until plant maturity, 17.6 and 14.1%, respectively. Numerous spots on the floating and first aerial leaves, previously thought to be caused by Bipolaris spp. infections, were caused primarily by Nakataea sigmoidea, Colletotrichum spp., and Phoma spp. The number of conidia of B. oryzae produced per lesion, under laboratory conditions, was greatest from lesions on lower leaves from early-mid flowering until plant maturity. The number of conidia of B. sorokiniana from lesions on both upper and bottom leaves increased until early-mid flowering, then remained relatively constant until plant maturity except that the number of conidia from lesions on bottom leaves declined.

Infection of wild rice seed by Fusarium graminearum (scab)

An extensive effort was made to determine the status of scab-infested seed. Extensive sampling was conducted during all phases of harvest and processing. Most infected seed "shatters" or is ejected with chaff during harvest. Little effect occurs during the fermentation (in the piles) process but parching and hulling appears to remove the rest of the infected seed. We conclude that scab may significantly reduce the yield of cultivated wild rice but is not a concern in the finished product. Special thanks to Jule Wraa of Gourmet House and Don Barrons for their help in this study.

Fungicide research

Tilt, Stratego, and Quadris have been tested at various rates in replicated trials at different locations over the years. All fungicides reduced disease incidence and severity but no conclusions were drawn for disease ratings. All fungicides reduced the percentage of Bipolaris spp. recovered from spots. No fungicide consistently reduced the incidence of Fusarium head blight (scab); however, the incidence of disease varied widely from location to location.

I conclude that the fungicide Tilt, when properly applied at the 6 oz rate, will reduce disease incidence and severity. However, if the fungicide is applied too early, too late, or at an improper rate, disease control may be disappointing.

The following are recommended disease management strategies to control disease on cultivated wild rice:

Newer "varieties" of cultivated wild rice are more disease tolerant than older "varieties". However, field observations show that tolerance may vary under disease pressure in the field.

1. Cut or burn brass on dikes in the fall. Grass is more likely to stay wet for a longer period of time, especially from snow melt, when laying down thus aiding in the killing of overwintering fungi.

2. It is preferable to flood fields in the fall. Spring flooding is also acceptable except "clumps" of residue in which fungi may survive are more likely to be present.

3. Do not bale wild rice straw. Bales are an excellent source of disease inoculum.

4. Apply tile at the 6 oz rate. The first application should at the boot stage of plant development and a second application should be 2 weeks later. Do not apply fungicide earlier or later. Results will be disappointing.

5. Avoid growing cultivated wild rice in the vicinity of lake or river wild rice.

6. Timely harvest. Disease becomes more severe as plants mature. Delayed harvest may result in a complete loss due to disease.

WILDRICE BREEDING AND GERMPLASM IMPROVEMENT

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Variety Trials

Introduction

Variety trials in 2001 were conducted to assess the performance of released varieties and breeding populations for yield, hulled yield, seed size, resistance to shattering, disease, and lodging, and other traits.

Materials and Methods

In 2001, variety trials were planted in three locations: the Clearwater Wild Rice farm near Clear-brook, the Rennemo farm northwest of Waskish, and the Godward farm near Aitkin, east side (former Kosbau farm). The Waskish location was planted October 11, 2000; Clearbrook, May 4, 2001; and Aitkin, May 9, 2001. The Aitkin trial was planted on a mineral soil, while the other two trials were on peat soils. At Waskish, phosphorus and potassium were applied by the grower in accordance with soil tests and normal practices. Nitrogen was applied by researchers at planting at a rate of 50 lb of N per acre as urea under the rows of seeds. At Clearbrook, researchers applied nitrogen and potassium at a rate of 50 and 100 lb/A, respectively, in the seed rows. At Aitkin, researchers applied 75 lb/A of nitrogen and 40 lb/A of potassium at planting under the rows of seeds. Approximately 46 lb/A of N as urea were topdressed at early flowering. The topdress was repeated at Aitkin, but not at Waskish due to adverse conditions. Plant density at Clearbrook site was too low to provide useful data, so it was not harvested. Only plots with sufficient plants were harvested at other sites, although some harvested plots were marginal.

At each location, twenty entries (released varieties and breeding populations) were planted in 4 replicates in a randomized complete block design. Plots consisted of four 10-foot rows, 12 inches apart, with 3 feet between adjacent plots and 6-foot alleys between ranges of plots. Aitkin plots were inoculated with spore suspensions of Bipolaris oryzae, the causal agent of Fungal Brown Spot (FBS) disease. Approximately 100 ml of spore suspension (7500/ml) were sprayed over the four rows of each plot with a CO_2 sprayer, for a total of 750,000 spores/plot.

The center two rows of each plot were used for measurements-- namely, flowering, height, foliar disease rating, and lodging. Waskish plots were harvested August 20, 23, and 28, depending on the maturity of the entry. Aitkin plots were harvested August 22 and 27. At harvest, the plots were rated for disease and lodging. The center two rows of each plot were trimmed to a net length of 8 feet and harvested with a Yanmar binder. Bundles were immediately carried to a Kincaid raspbar thresher for threshing. Seed was weighed before drying, placed in a drying oven for at least one week at 130°F, and then weighed again to determine percent moisture. Later, samples were re-dried by heating to approximately 200°F overnight, then passed through a McGill sample huller twice, and weighed again. A 1-teaspoon (5 ml) sample of hulled seed was removed from each plot-sample and scanned on a flatbed scanner and analyzed for seed size measurements using WinSeedle version 5.1a (Regent Instruments, Inc., Quebec, Canada). Estimates obtained directly from the scan include seed length, width, and projected area. The cross-section of the seeds was assumed to be circular to obtain estimates of seed volume and surface area, as well as surface area to volume ratio. In addition to calculating the averages of the approximately 200 seeds per plot, individual seeds in each plot were placed into one of several length and width categories, according to the standards of a Minnesota processing plant: long (>20/64"), medium (12-20/64"), and short grain (<12/64"); and width grades A (>3.75/64th"), B (3.00-3.75/64"), and C (<3.00/64"). Percentage of long-grain seeds within A grade, and percentage of sample with length >24/64" (any width) were also calculated.

Seed measurement data from 2000 variety trial plots will also be presented for comparison. Seed size measurements were obtained in the same manner described above, except that 100-seed weight was also estimated for the 2000 plots. Hydration tests were carried out on the 5-ml samples from 2000 using the following protocol modified from Indian Harvest's Standard Method #IH-3B.

Protocol for Hydration Analysis of Wildrice Samples (modified by D. Braaten)

1. Sift dehulled rice sample in a petri dish with holes drilled by a 1/8 inch drill bit. This effectively removes broken seeds from sample.

2. Pre-weigh 3.00 g from sifted rice sample.

3. Bring 200 ml water in four separate 250 ml beakers to a rapid boil on one standard lab hotplate. Add teaball infuser (handle-opening type) once water gets warm in each beaker.

4. Add one sample to each infuser every 5 minutes and keep note of which sample is in what beaker/infuser.

5. Boil each sample for exactly 25 minutes, using four stop watches to keep track of each sample.

6. Shake the infuser once immediately. Wait 15 seconds and shake it once again. Then wait 15 more seconds and shake it a third time.

7. Pat dry the infuser mesh for 10 seconds to remove water retained in the mesh.

8. Transfer the sample to a tared plastic tray, place on scale, and read the weight after 20 seconds.

9. Replace the dirtied water from beaker with clean water and replace it back on the hot plate.

10. Repeat steps 6-9 with the remaining 3 samples as they complete 25 minutes boiling time.

11. Time may vary between samples, as long as they are boiled for exactly 25 minutes.

12. Hydration = (final weight – initial weight) / initial weight x 100%

Results and Discussion

Data from Aitkin and Waskish variety trials in 2001 are presented in Tables 1 and 2 respectively. Yields were unusually low, similar to yields reported among growers in Minnesota in 2001. Reason for the low yields may include excessive heat, windstorms, riceworms, and rice stalkborer (in some locations, especially in the Aitkin area). Disease pressure was also high, possibly due to the aforementioned stresses, and marginal plant density in some plots may have magnified other problems. Given the unusual season, it is difficult to draw reliable conclusions.

Shattering was high in both locations, but extremely variable at Aitkin, as reflected in the LSD and CV values. Although there were a few entries that differed statistically at Aitkin, the degree of variability and the unusual season make these shattering data untrustworthy. Shattering at Waskish was also high, though less variable. However, the fact that Petrowske Purple had the highest shattering loss at that location seems suspicious, given its previously reported shattering resistance (11% average, 1997-99). weakened its resistance. We recommend suspending judgment based on this year alone, but we will continue to monitor its performance closely.

Varieties also varied from their previous performance in Fungal Brown Spot disease as well (compare Tables 1 and 2 with Table 3). Average disease rating for Aitkin and Waskish this year were 4.7 and 5.2, respectively, compared to 4.2 in 2000. Petrowske Purple averaged 5.0 (intermediate on the 1-9 scale) in 2001, compared to 3.3 in 2000. PBM-C6, on the other hand, rated 3.3 and 3.5 in 2001 (resistant), compared to 3.8 in 2000 (still resistant, but bordering on intermediate). This was slightly higher than its sister, GIB-C9 (3.5 in 2000), which showed more disease in 2001 (4.0 and 4.9). Franklin rated 4.2 in 2000 (on the low end of the intermediate range), but this year varied from 3.7 at Aitkin to 6.2 at Waskish. Some of the older varieties, NACH-B, Voyager, and Petrowske Bottlebrush averaged in the moderately susceptible range in 2000 (5.2-6.3), and also in 2001 (4.7-6.3). It is possible that new strains of the pathogen (*Bipolaris oryzae*) are overcoming its resistance, or that other factors (heat, insects, etc.) 96F-111, a composite of several lines potentially fixed for nonshattering, rated moderately susceptible (5.5-6.8), but close inspection of the unhealthy leaves at Aitkin showed that the symptoms did not always correspond to FBS symptoms. Another disease may be involved. To address this problem, 96F-111 was inoculated and selected for disease resistance at Grand Rapids this year.

Lodging was higher at Waskish than at Aitkin in 2001. Petrowske Purple, previously more lodging resistant than most other entries, was intermediate in 2001. PBM-C6 still had very low lodging scores in 2001.Franklin was more intermediate in its lodging, and GIB-C9 was low to intermediate. 96F-111 was intermediate. Once again, caution is warranted in interpreting lodging in 2001. It may have been influenced by more random factors, such as stalkborer damage, which was not rated in the variety trial plots.

Seed size in small grains is often measured easily as 100-seed weight (see Table 3). There was a high correlation between 100-seed weight and seed volume (r^2=0.82). The correlation could have been even higher if broken kernels had been removed from the sample before counting and weighing them. Although in each case the same sample was scanned to calculate seed volume, broken seeds were selected on-screen to be excluded from the analysis, so seed volume was probably a more precise measurement. This is confirmed by the lower LSD and CV values.

Table 1 **Yield and other varietal characteristics for 2001 Aitkin trial**

Entry	Yield	Moisture	Shattering	Hulled Yield	Lodging	FBS disease	Plant height	Panicle length
	lb/A[1]	%[2]	%[3]	lb/A[4]	score[5]	score[6]	in.	in.
96F-111	226	41	39	55	2.0	5.5	62.5	7.6
FSP5-C4	506	38	15	157	2.0	3.7	72.2	8.1
FY-C7	515	38	18	138	1.0	4.2	72.0	7.9
Franklin	367	41	15	122	1.9	3.7	67.0	8.0
GIB-C9	563	38	10	182	1.0	4.0	65.1	7.5
K2-C10	524	38	13	163	1.5	4.2	70.1	8.0
K2EF-C2	82	42	50	35	1.0	6.2	63.0	7.9
K2F-C10	470	36	23	147	1.8	4.0	71.4	7.6
K2	355	39	17	119	2.0	5.0	69.0	8.0
NEBR-C1	183	41	53	63	1.0	7.0	59.2	6.9
P2BR-C5	438	42	16	164	1.0	3.5	69.3	7.9
PBM-C6	780	36	13	253	1.0	3.3	72.7	7.9
PLAR-C6	666	38	17	159	1.8	4.3	71.6	7.6
PM3E-C10	716	42	14	154	1.0	3.7	66.9	7.4
PS-C6	300	47	32	44	1.9	5.0	64.7	8.9
PeB-2	163	42	33	50	1.0	6.5	65.9	7.2
PeB-3	190	48	26	100	2.0	4.7	68.6	8.3
Petr. BB	265	41	35	74	2.2	6.3	62.6	7.5
Petr. Purple	322	38	26	89	1.7	5.0	65.3	7.4
Voyager	278	40	34	89	1.9	4.7	68.5	7.8
Mean	395	40	25	118	1.5	4.7	67.4	7.8
LSD.05	192	7	21	62	0.6	1.5	3.7	0.9
CV	34%	12%	60%	37%	27%	23%	4%	8%

[1] Adjusted to 40% moisture.
[2] Percent moisture in grain at harvest, fresh weight basis.
[3] Expressed as a percentage of shattered seed plus grain yield per unit area.
[4] Yield of seeds that were left after drying and hulling.
[5] Using a 1-5 scale where 1 = stems completely erect, 3 = stems averaging 45° angle, 5 = stems prostrate.
[6] Fungal Brown Spot disease rating on a 1-9 scale where 1 = no significant disease lesions and 9= completely susceptible (dead)

Table 2 **Yield and other varietal characteristics for 2001 Waskish trial**

Entry	Yield	Moisture	Shattering	Hulled Yield	Lodging	FBS disease	Plant height	Panicle length
	lb/A[1]	%[2]	%[3]	lb/A[4]	score[5]	score[6]	in.	in.
96F-111	585	40	25	196	2.8	6.8	68.9	7.2
FSP5-C4	810	44	26	255	2.0	4.5	72.3	7.9
FY-C7	913	35	32	362	1.5	4.5	73.3	7.2
Franklin	555	40	31	152	3.0	6.2	74.4	7.4
GIB-C9	865	36	38	322	2.3	4.9	71.3	8.2
K2-C10	714	44	27	221	2.3	5.0	72.1	7.1
K2EF-C2	369	42	29	121	3.3	5.0	67.5	7.4
K2F-C10	873	42	22	266	1.7	4.2	71.1	7.6
K2	686	43	29	213	2.0	5.5	72.1	7.7
NACH-B	541	39	22	190	3.0	6.0	67.9	7.7
NEBR-C1	538	41	15	184	1.9	4.4	72.6	8.3
PBM-C6	1200	37	28	439	1.2	3.5	73.8	7.9
PLAR-C6	1194	39	30	381	2.0	4.5	73.6	8.5
PM3E-C10	1252	38	33	406	2.0	4.1	72.6	8.6
PS-C6	811	43	23	254	2.2	6.0	72.2	8.7
PeB-2	492	41	30	171	2.0	4.8	70.3	7.1
PeB-3	1048	39	15	402	3.0	5.0	73.1	8.2
Petr. BB	496	41	29	170	2.7	5.2	71.1	7.7
Petr. Purple	736	37	42	263	2.5	5.0	70.5	7.8
Voyager	361	44	27	107	3.0	6.3	72.9	7.3
Mean	752	40	27	254	2.3	5.1	71.7	7.8
LSD.05	247	3	7	90	0.6	1.3	3.1	0.7
CV	23%	4%	19%	25%	18%	18%	3%	7%

[1] Adjusted to 40% moisture.

[2] Percent moisture in grain at harvest, fresh weight basis.

[3] Expressed as a percentage of shattered seed plus grain yield per unit area.

[4] Yield of seeds that were left after drying and hulling.

[5] Using a 1-5 scale where 1 = stems completely erect, 3 = stems averaging 45° angle, 5 = stems prostrate.

[6] Fungal Brown Spot disease rating on a 1-9 scale where 1 = no significant disease lesions and 9= completely susceptible (dead)

Table 3 **Yield and other varietal characteristics for 2000 variety trials 3 locations combined.**

Entry	Yield	Hulled yield	FBS disease	Average seed length	100-seed weight	Hydration
	lb/A[1]	lb/A[2]	score[3]	64ths in.[4]	g	%[5]
NACH-B	1478	630	6.3	24.0	1.88	60.2
Voyager	1072	388	5.2	24.1	1.70	65.3
FSSR-C10	1907	780	3.5	23.8	1.94	59.4
FY-C6	2026	825	4.0	22.9	1.89	57.4
Franklin	1602	613	4.2	23.7	1.87	61.1
K2-C9	1968	806	3.9	24.4	1.85	61.8
K2F-C9	1989	811	3.8	23.3	1.90	59.0
K2	1612	622	4.0	22.8	1.71	64.0
P2BR-C4	1530	577	3.7	23.2	1.82	61.1
PS-C5	1452	558	4.7	23.9	1.81	61.6
Petr. BB	1424	588	5.7	23.3	1.80	64.3
Petr. Purple	1663	645	3.3	22.6	1.65	63.9
GIB-C9	2372	990	3.5	23.1	1.76	63.3
PM3E-C9	2230	828	3.3	23.7	1.89	62.8
FSP5-C3	1903	817	4.5	22.4	1.73	62.2
K2PiH-C2	2017	694	4.1	23.3	1.74	65.8
K2PiP-C3	2038	758	4.9	23.6	1.75	61.5
PBM-C6	2443	1044	3.8	22.5	1.75	63.2
PBM-F4	2022	830	3.9	22.2	1.74	62.6
PLAR-C5	2131	729	4.6	23.3	1.73	62.9
Mean	1844	727	4.2	23.3	1.80	62.2
LSD.05	448	182	1.1	0.6	0.14	3.5
CV	29%	30%	32%	3%	9%	7%

[1] Adjusted to 40% moisture.

[2] Yield of seeds that were left after drying and hulling.

[3] Fungal Brown Spot disease rating on a 1-9 scale where 1 = no significant disease lesions and 9= completely susceptible (dead)

[4] As measured with WinSeedle© software on samples of approx. 200 hulled seeds x 4 reps x 3 locations.

[5] Amount of water absorbed (as a percentage of seed dry weight) by oven-dried, hulled, unscarified whole seeds during 25 minutes in boiling water.

Hydration tests were only done for 2000-season plot samples. The results shown in Table 3 indicate varietal differences for the trait, ranging from 57.4 to 65.8%. When correlations were calculated between hydration and several seed size parameters, the best correlation was found with surface area to volume ratio (r^2=0.56). This means that 56% of the varietal variation in hydration can be attributed to differences in seed shape. Seeds that are round (short and fat), tend to take up water slower than seeds that are long and skinny, a fact already known by processors. Varieties with high hydration rates may be ones that have more of a tendency to produce "B" or "C" grade seeds. This idea is somewhat borne out by the similar correlation between hydration and the sum of B and C grade percentages (r^2=0.52). The number of seeds of this size and shape may be more affected by maturity than by genetic differences. There is still a lot of room for hydration to be affected by factors that might be more heritable, such as seed coat characteristics, which were not measurable with these methods. Seed size will be discussed further later.

Long-term performance in variety trials

When averaged with the previous three seasons, the 2001 season generally brought down the overall performance, as expected (Table 4). However, PBM-C6 still yielded highest (both raw yield and hulled yield), shattered least, and had the lowest lodging and FBS disease scores. Although it was not significantly higher yielding than GIB-C9, PBM-C6 statistically outperformed it in the other characteristics mentioned. PBM-C6 is significantly taller than all but two other varieties, FY-C7 and GIB-C9. Its panicle length, however, is only significantly greater than three others: K2, NACH-B, and Petrowske Purple.

In the 4-year averages, Petrowske Purple was more moderate in yield and shattering, but maintained good lodging resistance and disease resistance. Franklin was slightly below Petrowske Purple in yield, similar in shattering, and suffered more disease and lodging damage. The 2001 shattering data for Petrowske Purple raised its overall average shattering to a much higher level relative to other varieties. Whether this reflects its true shattering resistance can be confirmed with the addition of future data.

Seed size analyses in 2000 and 2001

Tables 5 and 6 give the results of digital image analysis of seed size in 2001 and 2000, respectively. Overall, seeds were smaller in 2001 than in 2000, by 1/64 inch. Width was also slightly lower in 2001. Seed volume in 2001 (data not shown) was 16% less than in 2000. Seed volume was shown to be well correlated to kernel weight in 2000. These all imply that kernels did not fill as well in 2001 as in 2000, for the possible reasons discussed earlier.

Although the differences between varieties in these trials was not great, some were significant. However, for the 16 entries that appeared in both years, average length in 2001 did not correlate well to length in 2000 trials (r^2=0.32). All averaged above the minimum for long-grain (20/64 in), but that did not mean that there were no seeds in each variety that fell below the long-grain category.

Table 4 **Yield and other varietal characteristics for variety trials at 3 locations, 1998-2001.**

Entry	Yield	Seed shattering	Hulled yield	Lodging	FBS disease	Plant height	Panicle length
	lb/A[1]	%[2]	lb/A[3]	score[4]	score[5]	in.	in.
	acefghi[6]	*achi*	*efg*	*ALL*	*ALL*	*ALL*	*ALL*
FSP5-C3	1440	16	522	1.8	4.4	77	8.2
FY-C7	1529	20	563	1.5	4.1	79	7.7
Franklin	1182	21	380	2.2	4.7	77	8.1
GIB-C9	1677	22	614	1.8	4.2	79	7.7
K2-C9	1452	18	526	1.5	4.2	77	7.7
K2F-C9	1455	18	512	1.7	4.2	78	7.6
K2	1166	19	433	1.8	4.6	77	7.5
NACH-B	1249	21	469	2.3	6.6	72	7.4
P2BR-C4	1229	16	452	1.4	3.8	78	7.7
PBM-C6	1757	16	644	1.2	3.6	80	7.8
PLAR-C6	1571	20	489	2.2	4.7	77	8.2
Petr. BB	1075	27	374	2.3	5.9	74	7.7
Petr. Purple	1274	23	443	1.5	3.8	76	7.5
Voyager	889	28	310	2.1	5.4	77	7.8
Mean	1358	21	474	1.8	4.5	76	7.8
LSD.05	157	5	74	0.3	0.5	2	0.3
CV	22%	36%	27%	30%	23%	4%	9%

1 Adjusted to 40% moisture.

2 Expressed as a percentage of shattered seed plus grain yield per unit area.

3 Yield of seeds that were left after drying and hulling.

4 Using a 1-5 scale where 1 = stems completely erect, 3 = stems averaging 45° angle, 5 = stems prostrate.

5 Using a 1-9 scale where 1 = no significant disease lesions and 9= completely susceptible (dead)

6 Environments included in means: a=Waskish 98; b=Clearbrook 98; c=Waskish 99; d=Aitkin 99; e=Aitkin 00; f=Clearbrook 00; g=Waskish 00; h=Aitkin 01; i=Waskish 01.

Table 5 **Seed size characteristics for 2001 variety trials (average of Aitkin and Waskish), as estimated by Winseedle® software, Regent Instruments.**

Entry	Seed length	Seed width	A Long	A Medium	Long in A	B Long	B Medium	Length ≥24/64
	64ths in.[1]	64ths in.[1]	%[2]	%[2]	%[3]	%[2]	%[2]	%[4]
96F-111	22.7	3.9	49.2	4.0	92.3	22.3	5.7	33.0
FSP5-C4	22.0	4.0	48.8	8.6	84.6	18.2	9.0	22.2
FY-C7	21.7	4.2	57.3	16.4	77.7	10.6	7.1	20.6
Franklin	22.5	4.0	53.5	5.7	90.3	20.5	7.7	27.5
GIB-C9	22.2	4.2	56.7	11.4	83.1	15.6	7.2	27.8
K2-C10	22.3	3.9	48.3	7.2	86.4	22.2	6.3	27.2
K2EF-C2	22.8	4.0	54.8	8.3	85.8	15.6	7.5	38.0
K2F-C10	21.5	4.1	50.2	13.4	78.8	14.2	9.7	18.5
K2	21.8	4.0	47.9	11.0	81.0	17.1	9.0	23.0
NACH-B	22.4	4.0	55.9	8.4	87.2	20.1	5.0	27.2
NEBR-C1	22.6	3.9	47.6	5.9	88.6	21.9	7.9	34.8
P2BR-C5	22.9	3.9	51.9	3.9	92.9	22.7	6.8	36.1
PBM-C6	21.4	4.0	49.8	15.2	76.3	13.8	10.9	18.6
PLAR-C6	22.4	4.0	53.0	8.6	86.0	17.0	7.5	28.5
PM3E-C10	22.1	4.0	50.9	9.6	84.3	16.4	7.9	26.0
PS-C6	22.8	3.8	45.8	3.4	93.3	25.0	5.8	37.7
PeB-2	23.1	4.0	56.9	7.3	87.9	18.5	5.7	39.6
PeB-3	22.8	4.1	57.7	6.7	88.6	17.9	6.7	33.0
Petr. BB	22.1	3.9	47.2	7.5	86.0	21.1	8.1	27.7
Petr. Purple	21.5	4.0	46.2	13.8	76.4	15.8	11.1	19.4
Voyager	22.0	3.8	47.7	4.5	91.2	22.3	8.7	23.0
Mean	22.3	4.0	51.3	8.6	85.7	18.3	7.7	28.1
LSD.05	0.7	0.3	12.8	4.5	6.8	6.7	3.0	8.2
CV	3%	7%	25%	52%	8%	36%	38%	29%

[1] Average of approx. 200 seeds x 4 reps x 2 locations.

[2] Percentage of sample falling into each width and length category: widths A (>3.75/64th"), B (3.00-3.75/64"); long (>20/64"), medium (12-20/64").

[3] Long-grain A-grade seeds as a percentage of all A-grade seeds.

[4] Seeds longer than 24/64 in as a percentage of total seeds measured, regardless of width.

Table 6 **Seed size characteristics for 2000 variety trials (average of Aitkin, Clearbrook, and Waskish) , as estimated by Winseedle© software, Regent Instruments.**

Entry	Seed length	Seed width	A Long	A Medium	Long in A	B Long	B Medium	Length ≥24/64
	64ths in.[1]	64ths in.[1]	%[2]	%[2]	%[3]	%[2]	%[2]	%[4]
NACH-B	24.0	4.3	72.9	6.0	92.3	12.7	3.1	52.7
Voyager	24.1	4.0	62.1	3.0	95.4	21.0	3.1	49.5
FSSR-C10	23.8	4.3	69.6	7.2	91.1	15.1	2.9	47.1
FY-C6	22.9	4.4	70.4	9.0	88.5	10.3	4.4	34.5
Franklin	23.7	4.2	69.1	4.4	94.1	14.8	3.9	44.7
K2-C9	24.4	4.2	72.4	4.1	94.8	13.8	3.0	51.1
K2F-C9	23.3	4.3	71.5	8.2	89.5	12.4	3.5	40.3
K2	22.8	4.2	61.9	10.1	86.0	12.7	5.1	36.6
P2BR-C4	23.2	4.3	70.2	6.5	91.3	12.5	4.4	38.0
PS-C5	23.9	4.2	66.7	4.3	93.8	17.2	4.4	47.5
Petr. BB	23.3	4.2	68.7	6.0	91.9	15.1	4.5	40.2
Petr. Purple	22.6	4.1	60.5	8.4	87.7	16.0	4.9	28.7
GIB-C9	23.1	4.3	67.1	7.1	90.5	13.5	4.8	38.3
PM3E-C9	23.7	4.2	68.6	6.2	91.5	14.5	4.1	45.7
FSP5-C3	22.4	4.3	63.6	12.6	83.2	10.2	6.8	26.6
K2PiH-C2	23.3	4.1	62.0	6.5	90.3	16.8	4.7	41.7
K2PiP-C3	23.6	4.1	65.3	5.9	91.5	16.2	4.1	44.2
PBM-C6	22.5	4.3	64.9	11.9	84.0	12.2	5.2	29.2
PBM-F4	22.2	4.3	63.2	13.7	81.6	10.9	6.9	27.5
PLAR-C5	23.3	4.1	62.0	5.9	91.4	17.5	4.2	40.4
Mean	23.3	4.2	66.6	7.3	90.0	14.0	4.5	39.0
LSD.05	0.6	0.1	6.5	3.1	4.3	4.2	2.0	7.5
CV	3%	3%	12%	50%	6%	36%	52%	23%

[1] Average of approx. 200 seeds x 4 reps x 2 locations.

[2] Percentage of sample falling into each width and length category: widths A (>3.75/64th"), B (3.00-3.75/64"); long (>20/64"), medium (12-20/64").

[3] Long-grain A-grade seeds as a percentage of all A-grade seeds.

[4] Seeds longer than 24/64 in as a percentage of total seeds measured, regardless of width.

The percentages of seeds in several width-length categories (A-long, A-medium, B-long, and B-medium) are also reported in Tables 5 and 6. In many entries, there were no seeds in the short category (A, B, or C width), preventing meaningful comparisons. C-long and C-medium were analyzed, but the results were not presented here. The significance of these category percentages for individual varieties may be the subject for speculation and debate. However, less than 85% long-grain in A-grade seeds is cause for concern for some processors (Steve Wraa, personal communication). There were a number of entries that fell below that mark in 2001, including several currently grown varieties (GIB-C9, K2, and Petrowske Purple), as well as PBM-C6. Of these, only PBM-C6 fell below 85% in 2000.

The percentage of seeds (regardless of width) that were longer than 28/64 in. was analyzed, but the values were low, averaging 3.6% in 2001 trials and 5.6% in 2000 trials. These numbers were statistically too variable to make meaningful comparisons. However, the analysis of seeds longer than 24/64 in. did reveal some differences in keeping with the overall length averages. In fact, there was a very strong positive correlation between the percentage of seeds longer than 24/64 in and overall seed length (r^2=0.93 in 2001 and r^2=0.96 in 2000). The influence of medium-length seeds (12 to 20/64 in) on this average is in inverse proportion—that is, the more medium length seeds, the shorter the overall average, as would be expected. However that relationship is not quite as strong (r^2=0.79 in 2001 and r^2=0.89 in 2000).

Heritability of seed size.

When the data from the variety trials in both years is approached from the standpoint of analyzing and estimating genetic variability, the variety means are not the key information. If we assume that these variety trial entries (or genotypes) represent the overall genetic variability availability for breeding stock, we can calculate the broad-sense heritabilities of seed size variables. When this was done for 2001 data, average seed length and "Length ≥24/64" were 80% heritable, and "Long in A" was 70% heritable—moderately high, considering that all the environmental and Genotype x Environment variability for these seed size parameters only amounted to 20-30% of the total variability. Similarly, in 2000 the heritabilities were 86%, 89%, and 84%, respectively for the same three parameters. However, as was pointed out earlier, the correlation between varieties' seed length in 2000 to the same varieties in 2001 was low (r^2=0.32). It could be that 2001 was such a unique season that long-seeded genotypes in that year may not be genotypes that would produce long seeds in other years.

These types of heritabilities (broad-sense) are, as the name implies, more general than narrow-sense heritabilities, which estimate only that part of genetic variability (additive genetic variance) that can produce direct gains in selection for the trait. Narrow-sense heritabilities, therefore, are more informative than broad-sense heritabilities in determining gain from selection. Our next step will be to measure and analyze seeds from half-sib families at two locations in 2001 to estimate narrow-sense heritabilities for seed size. In the meantime, we are proceeding, on the basis of the high broad-sense heritabilities, to select for increased seed size in a number of short-seeded elite breeding populations, using both individual plant selection and half-sib family selection.

Seed Size Estimation of Selected Commercial Plant Samples

In order to translate our findings on seed size in experimental plots to actual production fields, we undertook a small study using seed samples from commercial paddies.

Materials and Methods

Seed samples from the Gourmet House (Riviana Foods) Clearbrook plant were collected from a total of 35 different loads from 4 farms (designated A, B, C, and D). Loads were selected which could be traced to individual fields of known varieties. In most cases, there were at least four samples of each variety from each farm. The only exceptions were Petrowske Purple from farm B (1 sample), and Petrowske Bottlebrush from farm A (2 samples). Results were averaged for each variety on each farm.

The samples were placed in quart-size freezer bags and kept frozen at –4°F until just before analysis. One 100 g subsample was weighed out from each sample, dried at 130°F for at least one week, then weighed again to determine percent moisture. The dried sample was then run through a McGill sample huller twice and weighed to obtain a crude estimate of recovery. A one-teaspoon subsample was then taken for image analysis, using the methods as described in the variety trials section.

Results and Discussion

Table 7 shows the results of the seed size analysis. Statistical analysis were not carried out on these samples. The means of the same varieties in the variety trials were included for comparison.

There were differences between the characteristics of seeds from different farms, most notably for Franklin. Farm D was in California, and the Franklin from there had much longer and wider seeds (and plumper, as shown by the lower surface area to volume ratio) than any of the other samples, all of which were from Clearbrook area farms. Practically all of the A-width seed was long-grain, and 4 out of 5 seeds were longer than 24/64 in. The exact reason for the difference is unknown; speculations about environmental differences will have to suffice.

Surprisingly, Petrowske Purple grown commercially had longer seeds, and more long-grain and 24/64 in seeds than the other Minnesota-grown varieties, except Petrowske Bottlebrush. It was 1.5/64 in longer than Petrowske Purple in the variety trials. The reasons for this discrepancy are unknown, but may have something to do with the variety trials being located in other growing areas (Aitkin and Waskish). However, the shorter length compared to California Franklin is cause for concern about marketing. It is possible that under more ideal *Minnesota* growing conditions (i.e., in better years), Franklin and other varieties may produce longer grains. Regardless, more breeding work to increase seed size of Minnesota-adapted varieties is needed.

Table 7 **Seed size characteristics of commercial processing plant samples of known varieties, compared to variety trial samples, 2001.**

Source	Variety	Recovery	Seed length	Seed width(64)	Surf. area / volume	Long in A	Length ≥24/64
		%[1]	64th in[2]	64th in[2]	ratio	%[3]	%[4]
Farm A	Franklin	43	21.9	4.1	2.72	76	26
Farm A	Petr. BB	39	22.9	4.2	2.69	83	33
Farm A	Petr. Purple	41	22.8	4.1	2.78	84	35
Farm B	Franklin	41	21.8	4.1	2.76	79	24
Farm B	GIB	42	21.8	4.1	2.75	77	25
Farm B	Petr. Purple	42	23.2	4.4	2.57	87	40
Farm C	Franklin	33	21.3	4.1	2.77	70	19
Farm D	Franklin	52	27.5	4.8	2.38	99	81
VT-01	Franklin	-	22.5	4.0	2.78	90	28
VT-01	GIB	-	22.2	4.2	2.70	83	28
VT-01	Petr. BB	-	22.1	4.0	2.91	86	28
VT-01	Petr. Purple	-	21.5	3.9	2.90	76	19

[1] Weight of dried hulled seeds as a percentage of fresh weight.

[2] Average of approx. 200 seeds x 4 reps x 2 locations.

[3] Long-grain A-grade seeds as a percentage of all A-grade seeds.

[4] Seeds longer than 24/64 in as a percentage of total seeds measured, regardless of width.

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Don says 51–52 day after first ~~first~~ 10 heads