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Fieldbean (Phaseolus vulgaris L.) and adzuki [Vigna angularis (Willd.) Ohwi & Ohashi] are harvested as mature, dry seed and used for human food in either canned or dry form. Farmers rarely retain seed to plant the next year's crop. Instead, they purchase seed from Minnesota growers of certified seed or from seed conditioners who buy the commercial crop. Most of the seed sold by seed conditioners is produced in Idaho, Wyoming, or California. Consequently, bean seed is expensive and a significant cash cost of bean production.

Planting rate refers to the number of seeds or pounds of seed planted per acre. Recommended planting rates for most nonhybrid field crops are higher than necessary for optimum production if most seeds produce plants, if plants are uniformly spaced, and if weeds are controlled. Excess seed is recommended as insurance against uneven seed distribution, low plant emergence, and weeds. Planting excess bean seed is not low cost insurance so there is interest in using minimum but adequate amounts.

There are 15 market classes of fieldbean and each class is composed of a few to many varieties. Varieties vary from large prostrate vines to small or large upright plants (bush-type). Even the best of the large, upright varieties is inferior to common soybean [Glycine max (L.) Merr.] varieties in erectness of growth or in the clearance between soil surface and lowest pod. Adzuki plants are medium size, upright plants with lowest pods close to the ground.

The objectives of this research were to develop recommendations for planting rates and row spacings. Fieldbean varieties used were representative of three growth habits--prostrate vine (UI-114 and Wyo 166 pinto), small upright bush (Seafarer and Upland navy), and large upright bush (Montcalm kidney). One or more trials were conducted at Rosemount, Elk River, Becker, Crookston, Morris, Lamberton, and Waseca, Minnesota. Planting rates given in the tables and text of this report are based on seed of 95 percent or higher germination. "LSD" figures given in the tables are statistical measures of variability and are based on odds of 19 to 1 that data differing by the amount of the LSD were truly different.

FIELDBEAN PLANTING RATE

Considering yield per se, the optimum planting rate is the minimum rate that produces maximum yield. Research in 1972-73 at Morris, Lamberton, Elk River, and Rosemount showed that navy, pinto, and kidney bean planted at rates of 105,000 and 157,000 seeds per acre in rows 30 inches apart did not differ significantly in yield at any location. Consequently, with 30-inch row spacings, there is no need to plant more than six seeds per foot of row (105,000/acre). Additional trials at six locations show that maximum yield may be maintained with 78,000 seeds per acre (Table 1).

[1]University of Minnesota agronomists at St. Paul, Lamberton, Waseca, Morris, and Crookston, respectively.

Table 1. Planting rates and yields of fieldbean at six locations

Rate	Lamberton		Morris		Waseca	Elk River	Rosemount	Crookston	Average	
seeds/acre	1972-75	1974-75	1972-75	1974-75	1975	1972-73	1972	1981-82	1972-75	1974-75
(thousands)	(pounds/acre)									
Seafarer or Upland navy										
52	1500	1450	1590	1590	1790	1680	1830	--	1610	1570
78	--	1530	--	1720	1790	--	--	--	--	1660
105	1730	1510	1680	1680	1700	1770	2280	--	1760	1610
UI-114 or Wyo 166 pinto										
52	2060	1740	2250	2270	2440	2070	2800	2440	2250	2090
78	--	1730	--	2360	2480	--	--	2590	--	2130
105	2040	1630	2390	2290	2520	2120	2470	2540	2290	2070
Montcalm kidney										
52	1320	1170	--	1700	1300	1660	--	--	1480	1410
78	--	1230	--	1750	1280	--	--	--	--	1450
105	1580	1310	--	1760	1390	1560	--	--	1590	1510
Average three varieties										
52	1630	1450	1920	1850	1840	1810	2320	--	--	1690
78	--	1500	--	1940	1850	--	--	--	--	1750
105	1780	1480	2040	1910	1870	1820	2370	--	--	1730
LSD 5% average	70	70	70	90	140	160	350	--	--	50
LSD within varieties	110	120	130	160	250	250	500	130	55	90

In most of the trials, planting rates of the large vine, pinto varieties could be reduced to 52,000 seeds per acre without significant loss of yield.

Planting rate is almost always greater than plants per acre (plant population) at harvest time because of less than 100 percent seed germination and plant mortality. From 77 to 100 percent of the seeds planted in the 1974-75 trials produced mature plants, and average survival from 52,000, 78,000, and 105,000 seeds per acre was 93, 89, and 88 percent, respectively (Table 2). Seeds planted at the lowest planting rate had the greatest percentage survival; this advantage was evident at emergence, because there was little loss of plants during the growing season. Navy seed had greater percentage survival than kidney or pinto seed, because it is smaller and had less difficulty penetrating crusted soil.

The three components of bean yield are number of plants per acre, number of seeds per plant, and average seed weight. The product of these three components is yield per acre:

yield/acre = plants/acre X seeds/plant X weight/seed

Planting rates greatly affected number of seeds per plant but had no effect on weight per seed (Table 3). Despite the wide range (47,000 to 97,000 plants per acre) of plant populations derived from planting rates of 52,000 to 105,000 seeds per acre, bean plants adjusted numbers of seeds per plant to maintain yields from the various populations at similar levels.

Table 2. Plants per acre at harvest expressed in percentage of planting rate of fieldbean at three locations

Rate seeds/acre (thousands)	Lamberton 1974-75	Morris 1974-75	Waseca 1975	Average 5 trials
		(percent)		
Seafarer navy				
52	93	100	98	97
78	91	100	91	95
105	94	97	82	93
UI-114 pinto				
52	91	98	86	93
78	82	93	80	86
105	81	94	77	85
Montcalm kidney				
52	85	95	87	89
78	85	91	77	86
105	86	92	80	87
Average three varieties				
52	90	98	90	93
78	86	95	82	89
105	87	94	79	88
LSD 5% average	3	2	5	2
LSD within varieties	5	4	8	3

Table 3. Fieldbean planting rates with associated plants per acre, numbers of seeds per plant, and weights per seed; average Lamberton, Morris, and Waseca

Seeds/acre (thousands)	Plants/acre (thousands)	Seeds/plant (numbers)	Weight/seed (grams)
Seafarer navy			
52	51	69	.21
78	74	50	.21
105	97	38	.21
UI-114 pinto			
52	49	53	.38
78	67	38	.38
105	89	28	.38
Montcalm kidney			
52	47	27	.51
78	67	20	.51
105	91	16	.50
Average three varieties			
52	49	50	.36
78	70	36	.36
105	92	27	.36

ADZUKI PLANTING RATE

Some growers of fieldbean also raise adzuki, and some production practices are similar for both crops. Since 1980, research plots and some commercial fields of adzuki have been devastated by a new disease caused by bacteria. The plant population trial in 1979 (Table 4) was not affected, but disease was the overriding factor affecting yields in the 1980 trials (Table 5). Percentage survival of the seed planted was high except on the dryland sandy soil at Becker. Adzuki plants maintained about the same yield throughout the range of populations in both high and low yield environments (Tables 4, 5).

FIELDBEAN ROW SPACING

Uniform distribution of seed and plants favors

Table 4. Effect of plant population on leaf retention and yield of adzuki at Rosemount, 1979

Plants/acre (thousands)	Leaf retention[1] (percent)	Yield/acre (pounds)
52	38	3150
70	33	3190
93	21	3200
120	22	3050
166	16	3010
LSD 5%	15	350

[1]Adzuki tends to retain leaves after maturity if the plants are healthy and growing conditions are favorable.

weed control, uniform maturity, and high yield. Seed distribution is improved by reducing row spacing and by using planting machinery designed for precise placement of seed. At equal planting rates per acre, seeds within the row are closer together in wide than in narrow row spacings. The relationship between seeds per acre and seed spacing in rows 6, 7, 18, 22, 30 and 38 inches apart is shown in Table 6.

Yields of all three varieties at four planting rates (52,000, 78,000, 105,000 and 157,000 seeds per acre) increased as row spacing decreased from 38 to 22 inches (Table 7). Interactions between row spacings and planting rates and between row spacings and varieties were not significant. Consequently, the averages at the bottom of the table accurately summarize the research.

Plant populations at harvest ranged from 72 to 100 percent of the seed planted (Table 8). Survival was greater in narrow than in wide rows which is in agreement with the planting rate trials in which seeds close together in the row had greater mortality. Interactions between row spacings and planting rates and between row spacings and varieties were not significant, so the averages at the bottom of the table accurately depict the results. Navy bean had greater percentage survival than pinto or kidney, but differences were not significant in all trials.

The major effect of row spacing on components of yield was the increase in plants per acre with

Table 7. Row spacings and yields of fieldbean at three locations

Row spacing (inches)	Lamberton 1973-75	Morris 1973-75	Waseca 1975	Average 7 trials
		(pounds per acre)		
Seafarer navy				
22	1800	2210	2000	2010
30	1650	2050	1790	1840
38	1610	1820	1490	1680
UI-114 pinto				
22	2210	2700	2700	2490
30	2130	2570	2520	2370
38	1970	2610	2240	2280
Montcalm kidney				
22	1660	2320	1620	1940
30	1490	2130	1220	1730
38	1370	2060	1130	1630
Average three varieties				
22	1890	2410	2110	2140
30	1760	2250	1840	1980
38	1650	2160	1620	1870
LSD 5% average	110	100	210	90
LSD within varieties	190	180	370	150

Spacings X planting rates - not significant

Table 5. Effect of planting rate on plant establishment and yield of adzuki at Becker and Rosemount, 1980

Rate seeds/acre (thousands)	Plant establishment (percent)			Yield/acre (pounds)			
	Becker irrigated	Becker dryland	Rosemount dryland	Becker irrigated	Becker dryland	Rosemount dryland	Average
70	97	69	90	770	230	600	530
105	94	77	89	950	200	530	560
139	98	76	91	820	190	710	570
174	98	80	93	1060	160	710	650
LSD 5%	6	9	9	370	140	150	200

Table 6. Seed spacings for six planting rates in various row spacings

Planting rate seeds/acre (thousands)	Row spacing						
	6 inches	7 inches	18 inches	22 inches	30 inches	38 inches	Other[1] inches (number)
	within-row seed spacing (inches)						
26	40.2	34.4	13.4	11.0	8.0	6.3	241.26
52	20.1	17.2	6.7	5.5	4.0	3.2	120.63
78	13.4	11.5	4.5	3.7	2.7	2.1	80.42
105	10.0	8.5	3.3	2.7	2.0	1.6	59.74
131	8.0	6.8	2.7	2.2	1.6	1.3	47.88
157	6.7	5.7	2.2	1.8	1.3	1.1	39.95

[1]For seed spacing in any row spacing, divide the number given by the row spacing in inches.

Table 8. Fieldbean plants per acre at harvest expressed in percentage of planting rate at three locations

Row spacing (inches)	Lamberton 1973-75	Morris 1973-75	Waseca 1975	Average 7 trials
		(percent)		
Seafarer navy				
22	95	100	93	97
30	92	99	90	95
38	88	94	82	90
UI-114 pinto				
22	84	94	87	89
30	82	91	79	86
38	78	90	73	82
Montcalm kidney				
22	93	91	88	92
30	80	92	82	85
38	79	84	72	80
Average three varieties				
22	91	97	90	93
30	85	94	83	89
38	82	89	76	84
LSD 5% average	7	8	6	2
LSD within varieties	12	14	10	3

Spacings X planting rates - not significant

Table 9. Fieldbean row spacings with associated plants per acre, numbers of seeds per plant, and weights per seed; average of four planting rates, Lamberton, Morris, Waseca

Row spacing (inches)	Plants/acre (thousands)	Seeds/plant (number)	Weight/seed (grams)
Seafarer navy			
22	86	51	.21
30	81	50	.21
38	76	48	.21
UI-114 pinto			
22	76	38	.39
30	73	38	.39
38	70	38	.39
Montcalm kidney			
22	79	21	.53
30	73	20	.53
38	68	20	.53
Average three varieties			
22	80	37	.38
30	76	36	.38
38	71	35	.38

decreasing row spacing (Table 9). The greater number of plants per acre accounts for the higher yields from narrow than from wide rows. Row spacing had no effect on weight per seed and only a small or no effect on seeds per plant.

Fieldbean had been grown solely as a cultivated row crop in the United States. Improved grain drills and greater confidence in herbicides have caused many Minnesota farmers to grow navy bean in noncultivated rows 6, 7, 12, or 14 inches apart. This practice is generally restricted to varieties of upright growth and to small-seeded classes like navy. The major advantages are no cultivation expense and a level undisturbed soil surface for combine-harvest of the standing crop. Very narrow (6- or 7-inch) rows are the only spacings to approach equidistant plant spacing at practical planting rates (Table 6). Equidistant plant spacing may offer a potential yield advantage because it provides an earlier and more complete soil cover than other spacings. As a result, more sunlight is intercepted by bean foliage. The greater interception of light increases photosynthesis per acre and reduces evaporation of water from the soil. The more complete vegetative cover also intercepts more rainfall and may reduce runoff and soil erosion.

At optimum planting rates, many grain drills crack bean seed and distribute it unevenly. The problem may be reduced by mixing the seed with an equal amount (or other ratio) of cracked corn to increase the total volume. Then the drill can be calibrated and set with wider openings for the seed to pass through. Another way of increasing openings without increasing the planting rate is to block off every other entrance to the furrow openers but this practice results in rows 12 or 14 inches apart.

Trials comparing noncultivated rows 6 inches apart with cultivated rows 18-22 and 30 inches apart at Rosemount and Morris were planted with a fluted feed grain drill (Table 10). Plant establishment was only fair as indicated by the differences between seeds planted (column 2) and plants at harvest (column 3). Weed species present were susceptible to trifluralin (Treflan) and chloramben (Amiben). Consequently, weeds were not an important variable, but cultivation was needed for most complete control. Differences in maturity were not important, but bean in 30-inch rows was earliest. The trials at Morris were harvested by hand and those at Rosemount with a standard grain combine. Bean in 18- or 22-inch cultivated rows and at the two higher planting rates in noncultivated 6-inch rows produced the highest yields.

Trials at Crookston involved row spacings of 6, 18, and 30 inches and various plant populations of Wyo 166 pinto and Upland navy varieties under weedfree conditions. The plant populations given in Tables 11 and 12 are at harvest and are higher than usually recommended for navy bean in

Table 10. Effect of row spacing and planting rate on performance of Seafarer navy bean at Morris, 1977-78, and at Rosemount, 1976-78

Row spacing (inches)	Planting rate seeds/acre (thousands)	Plants/acre (thousands)	Weed control (percent)	Planting to maturity (days)[1]	Yield/acre Morris	Yield/acre Rosemount	Yield/acre Average
					(pounds)		
6	100	74	80	86	1480	1350	1420
6	150	96	86	86	1580	1510	1550
6	200	110	92	85	1560	1560	1560
18-22	100	82	97	85	1820	1380[2]	1600
30	100	83	95	83	1520	1260	1390
LSD 5%		13	6	2	190	210	150

[1]Rosemount. [2]1977-78 adjusted to be comparable with 1976-78 data.

Table 11. Effect of row spacing and plants per acre on performance of Wyoming 166 pinto bean at Crookston, 1981-82

Row spacing (inches)	Plants/acre (thousands)	Planting to: soil cover (days)	Planting to: maturity (days)	Yield/acre (pounds)
6	67	70	121	2650
6	86	68	120	2860
6	103	66	120	2670
18	55	72	120	2520
18	72	71	120	2480
18	93	69	120	2540
30	48	80	120	2140
30	72	78	119	2430
30	78	74	120	2420
LSD 5% for populations within spacings				220
Row spacing averages				
6	85	68	120	2730
18	73	71	120	2510
30	66	77	120	2330
LSD 5% for spacing averages				520

Table 12. Effect of row spacing and plants per acre on performance of Upland navy bean at Crookston, 1981-82

Row spacing (inches)	Plants/acre (thousands)	Planting to: soil cover (days)	Planting to: maturity (days)	Yield/acre (pounds)
6	120	70	118	2610
6	156	68	118	2830
6	161	67	116	2790
18	94	82	115	2870
18	120	81	113	2820
18	156	80	116	2890
30	98	never	118	2540
30	114	never	114	2750
30	130	never	114	2670
LSD 5% for populations within spacings				220
Row spacing averages				
6	146	68	117	2740
18	123	81	115	2860
30	114	never	115	2650
LSD 5% for spacing averages				230

cultivated rows. The major effect of plant population and row spacing was the earlier soil cover resulting from high populations and narrow rows. Navy bean in rows 30 inches apart never achieved complete soil cover. Neither plant population nor row spacing affected lodging or plant height except that pinto vines were 3 inches longer in 6-inch rows than in wider rows.

Yields from the three row spacings at Crookston did not differ significantly, but the lowest average yields were in rows 30 inches apart. Within the 30-inch row spacing, the 48,000 plant population produced lower yields than 72,000 or 78,000 plant populations of pinto bean (Table 11). Yields of navy bean at these high populations were not affected significantly by either row spacing or plant population (Table 12). The 2-year average data indicate that seed yields were greater from 156,000 plants per acre than from 120,000 plants per acre in rows 6 inches apart.

SEED QUALITY

Fieldbean seed is more prone to mechanical damage than that of most field crops. Splits and cracks can be easily seen, but damage is often internal. Some internal damage appears after emergence (Figure 1). A broken cotyledon may not be serious, but plants with broken hypocotyls will die. Plants broken in the first internode--called baldheads--may develop branches from axillary buds, but these plants will be late and weak. Baldheads and other damage might be counted as good seed in some germination tests, so it is wise to watch closely for mechanical damage when testing germination.

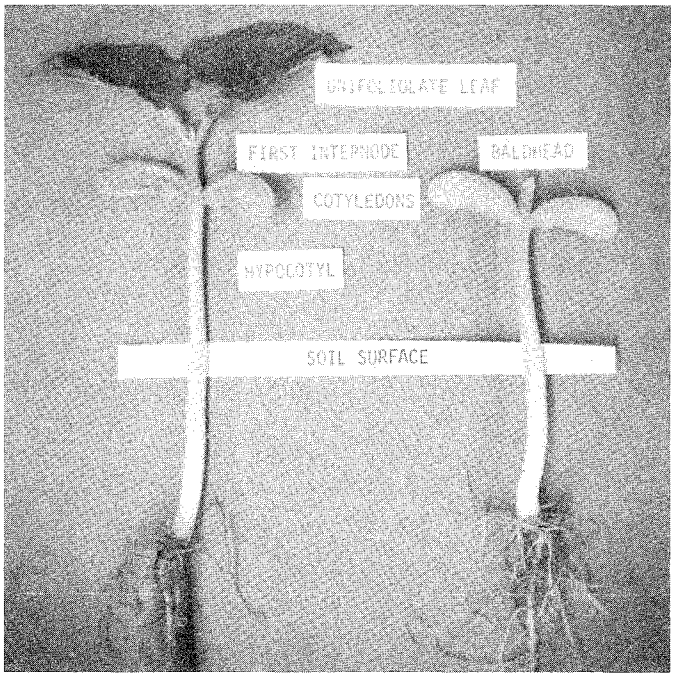

Figure 1. The aboveground parts of these fieldbean seedlings were very small but already formed in the ungerminated seed. Internal seed injury suffered during threshing and handling of the dry seed often results in broken cotyledons and baldheads.

Observations based on germination and variety testing indicate that seed quality differences among seedlots within a variety may affect performance as much as some varietal differences within a fieldbean class. A 4-year study of certified seedlots of Seafarer navy bean at Rosemount supports this viewpoint. Thirty-five seedlots in 1975, 13 in 1976, 11 in 1977, and 9 in 1978 were compared in stand establishment and yields. All seedlots were planted at a rate of 100,000 seeds per acre in rows 30 inches apart unless the seed tag stated that germination was less than 95 percent. For seedlots of less than 95 percent germination, planting rate was increased to 95,000 viable seeds per acre.

Seedlots were planted in triplicate (three replications), and data from the seedlots were analyzed statistically. Since the only variable was different seedlots of the Seafarer variety grown in the same environment, there should be no statistically significant difference in performance.[1] However, the seedlots did differ significantly in performance (Table 13). Seed quality improved from 1975 to 1978 as indicated by the percentage decline in seedlots of poor establishment (plants per acre). Seed quality has continued to improve as Minnesota seed growers gain experience, and much of the seed imported from western states is under close control and inspection by Minnesota seed conditioners.

DISCUSSION AND SUMMARY

Good seed is needed to allow minimum planting rates and low seed costs per acre. Bean seed grown under good conditions and harvested and conditioned at proper moisture levels should produce 95 to 100 percent undamaged seedlings in a germination test. Each conditioning operation may injure bean seed, so germination tests should be made on treated seed that is ready to plant. Seed treatment with fungicide and insecticide protects against seed rots and seed corn maggots which can reduce potential bean stands. Bean emergence percentage usually exceeds 90 percent when good seed is planted in a good seedbed after mid-May. Large-seeded varieties may average about 5 percent lower emergence than small-seeded varieties.

A base planting rate of 78,000 seeds per acre is suggested for all classes of fieldbean and adzuki in cultivated rows 18 to 38 inches apart if good seed is planted in a good seedbed after mid-May. However, when planting rates are ex-

[1]The average of the best three seedlots in each variety in each trial was used for comparison, because one seedlot out of 20 could be expected to perform differently than the others based on chance.

Table 13. Stand establishment and seed yields obtained from all certified seedlots of Seafarer navy bean at Rosemount, 1975-78

Year	Plants/acre Range (thousands)	Plants/acre Low[1] (percent)	Yield/acre Range (pounds)	Yield/acre Low[1] (percent)
1975	9-72	83	407-1100	23
1976	44-85	46	1578-2110	8
1977	67-86	45	1158-1547	27
1978	52-89	22	734-943	11

[1]Percent of seedlots significantly lower (poorer) than the average of the three best seedlots in each trial.

pressed in pounds per acre, varieties with large seed (fewer seeds per pound) require higher planting rates (Table 14). Consequently, seed cost per acre is higher for large-seeded varieties. A reduction in planting rate to 60,000 seeds per acre for varieties with large vines will reduce seed cost. An increase in planting rate to 85,000 seeds per acre may be justified for very large-seeded varieties that have difficulty emerging through crusted soil. When seed is cheap, an increase in planting rate to 105,000 seeds per acre for small-seeded varieties where the increased rate amounts to no more than 10 pounds per acre is low cost insurance against poor stands. When seed is expensive, a reduction in planting rate of large-seeded varieties to about 52,000 seeds may be considered.

A base planting rate of 157,000 seeds per acre is suggested for fieldbean and adzuki grown in noncultivated rows 6 or 7 inches apart. Good seed must be planted in a good seedbed with a planter capable of even seed distribution. Noncultivated, narrow-row plantings are usually practical for only certain small-seeded varieties of erect growth. Seed distribution of large-seeded varieties with a grain drill may not be satisfactory. Planting rates for large vine varieties could be as low as 105,000 seeds per acre. But prostrate vines may not mature evenly and may be difficult to combine harvest. The potential for increased seed yield, smoother soil surface for harvesting, and elimination of cultivation costs in narrow rows should be balanced against greater seed cost per acre and risk of poor weed control.

These planting rates are much lower than those for soybean. Fieldbean should not be planted on fields with weed species that cannot be controlled with recommended herbicides. Herbicides should be used for fieldbean production in either cultivated or noncultivated rows. However, if herbicides are not used, postemergence harrowing with the coil spring harrow, rotary hoe, weeder, or spike tooth harrow will kill small and emerging weeds. Planting rates should be increased to allow for loss of stand from harrowing. The loss of pinto bean plants grown in rows 30 inches apart was 4 percent from cross harrowing at the full unifoliolate leaf stage and 5 percent at slightly beyond the first trifoliolate leaf stage. However, the loss was considerably greater in the wheel tracks, so unless severe wheel track damage can be tolerated, postemergence tillage should be parallel to rather than across rows. A coil spring harrow was used in this trial. The same amount of damage would be expected with a rotary hoe or weeder but more would occur with a spike tooth harrow.

Table 14. Market classes and planting rates based on average number of seeds per pound

Market class and seeds/pound	Planting rate (seeds/acre) 26,000	52,000	60,000	78,000	105,000	131,000	157,000
	planting rate (pounds/acre)						
Navy, 2600	10	20	23	30	40	50	60
Pinto, 1250	21	42	48	62	84	105	126
Pinto, 1450[1]	18	36	41	54	72	90	108
Kidney, 950	27	55	63	82	111	138	165
Pink, 1700	15	31	35	46	62	77	92
Small White, 3000	9	17	20	26	35	44	52
Great Northern, 1350	19	39	44	58	78	97	116
Great Northern, 1000[2]	26	52	60	78	105	131	157
Small Red, 1450	18	36	41	54	72	90	108
Black Turtle Soup, 2300	11	23	26	34	46	57	68
Cranberry, 1000	26	52	60	78	105	131	157
Yelloweye, 1050	25	50	57	74	100	125	150
Marrow, 1000	26	52	60	78	105	131	157
Brown, 1200[3]	22	43	50	65	88	109	131
Adzuki, 2700[4]	10	19	22	30	39	49	58
Adzuki, 3800[5]	7	14	16	21	28	34	41

[1]Holberg and Pindak varieties. [2]Emerson variety. [3]Not a market class. [4]Not a fieldbean. Minoka variety. [5]Not a fieldbean. Takara variety.