



Row spacing studies with cereal grains in Montana
by James L Krall

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Agronomy at Montana State College
Montana State University
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Abstract:

Various problems associated with growing small grains in wide rows, such as cultivation, 2,4-D treatment, varietal response, seeding rates, and date of seeding, were studied at three location in Montana using winter wheat, spring wheat, oats, and barley.

The cultivation of 18, 24, and 30 inch spacings gave substantial increases in yield of winter wheat over the uncultivated 12-inch spacing at Moccasin, Experiments with 2,4-D and cultivation showed nearly identical yields. Applications of 2,4-D after two cultivations gave substantial increases in yield. Seeding rates have little effect on the yield of spring and winter wheat at the wide spacings, No increases in yield were obtained from spaced plantings of spring wheat, oats, and barley. Generally greater reductions in yield due to wide spacings were obtained with spring wheat compared to oats and barley. The reductions in yield of the spring sown grains were, not as great under dry land conditions as they were under irrigation. Comparison of two seeding dates with barley at Bozeman in 1950 indicated that ..wide spacings would respond the same. Trials conducted with half and. full rates of seeding of oats and barley at 6-inch spacings resulted in decreased yields of barley and nearly identical yields of oats.

Variety spacing trials, where several varieties of barley and oats were used, indicated that nursery tests could be grown at 12-inches when normal spacing of 6-inches are used for production. It was found by the analysis of three years of data for Glacier barley and Bridger oats that no years x spacings interactions occurred.

Significant increases in protein and test weights were obtained from wide row spacings and cultivations of winter wheat. No apparent increase in test weight was obtained from spring sown grains, At Havre, no significant increases in protein were found in spring wheat.

It was generally concluded that winter wheat and barley were better adapted to spaced conditions than oats or spring wheat. It was suggested that trials be conducted to study the following possibilities • increasing protein content of wheat by row spacing, possibilities of 2,4-D and cultivation as a method of production and place in crop rotations, ability of varieties under spaced conditions, and the effect of row spacing when used with a companion crop.

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IN MONTANA

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ABSTRACT

Various problems associated with growing small grains in wide rows, such as cultivation, 2,4-D treatment, varietal response, seeding rates, and date of seeding, were studied at three locations in Montana using winter wheat, spring wheat, oats, and barley.

The cultivation of 18, 24, and 30 inch spacings gave substantial increases in yield of winter wheat over the uncultivated 12-inch spacing at Moccasin. Experiments with 2,4-D and cultivation showed nearly identical yields. Applications of 2,4-D after two cultivations gave substantial increases in yield. Seeding rates have little effect on the yield of spring and winter wheat at the wide spacings.

No increases in yield were obtained from spaced plantings of spring wheat, oats, and barley. Generally greater reductions in yield due to wide spacings were obtained with spring wheat compared to oats and barley. The reductions in yield of the spring sown grains were not as great under dry land conditions as they were under irrigation. Comparison of two seeding dates with barley at Bozeman in 1950 indicated that wide spacings would respond the same. Trials conducted with half and full rates of seeding of oats and barley at 6-inch spacings resulted in decreased yields of barley and nearly identical yields of oats.

Variety spacing trials, where several varieties of barley and oats were used, indicated that nursery tests could be grown at 12-inches when normal spacing of 6-inches are used for production. It was found by the analysis of three years of data for Glacier barley and Bridger oats that no years x spacings interactions occurred.

Significant increases in protein and test weights were obtained from wide row spacings and cultivations of winter wheat. No apparent increase in test weight was obtained from spring sown grains. At Havre, no significant increases in protein were found in spring wheat.

It was generally concluded that winter wheat and barley were better adapted to spaced conditions than oats or spring wheat. It was suggested that trials be conducted to study the following possibilities; increasing protein content of wheat by row spacing, possibilities of 2,4-D and cultivation as a method of production and place in crop rotations, ability of varieties under spaced conditions, and the effect of row spacing when used with a companion crop.

INTRODUCTION

Natures ability to space plants differently under varying climatic conditions makes it logical to assume that the methods now used for the production of cereal crops might be modified to obtain maximum plant growth. Such a modification could be wide row spacing and cultivation of the cereal grains. From observations made of border rows in plant breeding nurseries, where the plants remained green in spite of drought conditions, it is apparent the wide spacings might be of some practical value. Why small grain row cultivation was not practiced in the past is probably hinged on the fact that the horse drawn cultivator was a slow tedious process and was not too effective in controlling the weeds within the rows. However, with the advent of motorized equipment and chemical weed killers, such a practice now seems feasible.

Row spacing studies are of interest as the wide rows may have value in; increasing yield and quality of the cereal grains, controlling perennial and other 2,4-D resistant weeds, permitting better establishment of perennial crops when used as a method of companion crop seeding, facilitating roguing of pure seed crops, determining the validity of 12-inch or wider rows in conducting variety trials, and use in rotation sequences, particularly in continuous cropping. It is the purpose of this thesis to study the various aspects of wide row spacing of cereal grains in order to determine what might be expected in the way of yield and quality as influenced by cultivation, seeding rate, varieties, date of planting, 2,4-D sprays, seasons, and locations.

LITERATURE REVIEWED

During the early development of the great plains agriculture the effect of row widths and rate of seeding on the yield of small grains was studied by several investigators to determine the best cultural practice for different soil and climatic conditions, (1), (8). It was generally considered that row spacing of 6 to 10 inches and rates of 50 to 60 pounds per acre would be most efficient.

In the early twenties considerable research was conducted to determine the relative merits of the wide spacing of the furrow drill. McKee and May (15), at the Judith Basin Branch Station, found that the 14-inch furrow drill produced a higher yield of winter wheat than the common 6-inch drill. Salmon at Kansas (18) found little difference in yield until spacing between the rows was greater than 12 to 14 inches. Over a three year period. Kiesselbach, Anderson, and Lyness, at Nebraska, (11) found that lower yields of wheat were obtained in 14-inch rows as compared with 7-inch rows when the same quantity of seed was used. Stephans and McCall, in Oregon, (21) planted winter wheat in 7 and 14-inch rows and spring wheat in 4, 6, 8, and 12-inch spacings over a five year period. It was found that the 7-inch spacing produced the highest yield of winter wheat and the 4-inch spacing the highest yield of spring wheat.

Sprague, at New Jersey in 1931, (10) went into considerable detail in the spacing of barley in rows and within rows. It was found that barley yields were nearly alike as long as the plant populations were in reasonable limits. He concluded that; (1) Thickly populated areas draw from the soil

resources of neighboring sparsely populated areas. (2) Root zones were not confined to the vertical zones occupied by aerial portions. (3) Crops such as wheat, oats and rye were more capable in drawing soil resources from adjacent areas than barley.

Engledow, at Cambridge, (5), studied spacing of two spring wheat varieties in relation to the factors contributing to yield, namely, tillering, ear size, and kernel weight. It was found that as the individual plant spacing was increased from 2-inches on up to 18-inches the amount of tillering increased proportionately so that the final ear populations were nearly alike. Furthermore, it was found that the two varieties did not tiller alike at the closer spacings. The ear size and kernel weight increased as the distance increased. However, this was not reflected in the yield at the extreme spacing due to a slight decrease in number of ears. He concluded that the most efficient spacing was at the 12 to 14-inch or at the point where the ears per unit area, kernels per ear, and kernel size were at their maximum.

The cultivation of wheat has been tested by both cultivation of the rows and harrowing. It has been found that harrowing or rolling generally reduces yields (2), (6), (12). Montgomery, at Nebraska in 1899 (16), spaced oats in 24, 18, 12, and 6-inch rows. The results indicated that a reduction in yield was obtained from the 24-inch spacing cultivated four times. The 18-inch spacing yielded the same as the 6-inch check, and the 12 and 6-inch rows when cultivated produced higher yields. Champlin, at Saskatchewan (3), grew several crops in a double 36-inch row and triple 30-inch row as a

summer fallow substitute in Canada in the early twenties. The yields obtained from such a system of spacing were reduced. However, the following crop gave satisfactory yields. Cole and Hallsted at Kansas, 1922 (4) reported six year results from a single plot of intertilled wheat, where 30-inches were sown solid and 30-inches fallowed. Such a practice not only was difficult to maintain but produced lower yields than fall plowing. McClelland (14) studied the effect of border rows in Arkansas in 1934. He received a 26 per cent increase in yield of oats from 16-inch border rows over 8-inch rows.

Russel (17) discusses the merits of cultivation for weed control and stated quite emphatically that weeds are usually most harmful to the crop in the early stages and particularly the very early stages of growth. He suggested cultivation of row crops as soon as possible. Kiesselbach (10) stated that the development of the wheat spike was determined by favorable growing conditions in the early stages of growth.

The effect of row spacing on the yield of small grain nurse crops was determined by Harper (7) at several locations in Oklahoma. It was found that wide spacing was an insurance against loss of legume stands during drought periods. Yields of wheat were lowered by spacings up to 14-inches, however, oats and barley were about the same.

Varietal interactions were found in barley, by Immer (9), when spaced planted 5-inches apart and in drill rows of 600 seeds per rod row.

MATERIALS AND METHODS

Central Montana Branch Station, Moccasin

Except for 1951, growing conditions were favorable for small grain production for the five year period in which these tests were conducted. The 43 year average seasonal precipitation (April 1st to September 30th) is 11.20 inches. During 1947, 1948, and 1950 above normal seasonal precipitations were recorded with 12.17, 13.51, and 12.59 inches, respectively. The below normal precipitation of 9.3 inches for 1949 was not reflected in yields because of the timely normal rainfall received in months of May and June. Low yields were obtained in 1951 as the seasonal rainfall recorded was only 8.52 inches. Due to drought conditions in the fall of 1948 poor germination of winter wheat occurred. However, by the 1st of May the following spring good stands were evident.

The first experiment to determine whether increase in yields could be obtained from wide row spacing and cultivation was started at Moccasin in 1947 with spring wheat. This test we conducted on fallowed ground using a row spacing of 6-inches for a check and cultivated spacings of 12, 18, 24, 30, and 36-inches. Each spacing was sown at 30, 40, 50, and 60 lbs. per acre. The experimental design was a modified split plot with two replications. The plot size was 18 by 80 feet. One cultivation was given with a corn cultivator when the wheat was from 4 to 6-inches high.

In 1948 experiments were started with winter wheat. The change from spring wheat was made primarily because weeds were not a serious problem in spring sown grains. Due to the difficulty encountered in the cultivation

of the narrow 12-inch spacing of spring wheat and due to the low yields obtained from the 30 and 36-inch row widths the following spacings were used for winter wheat from 1948 to 1951: (1.) 12-inch un-cultivated spacing as a check, (2.) 18-inch rows cultivated once in the fall and once in the spring, (3.) 24-inch rows with fall and spring cultivation, (4.) Two 6-inch rows spaced 30 inches apart with fall and spring cultivation. The same type of experimental design and plot size was used as with spring wheat except that the 30 lb. rate of seeding was dropped and a third replicate was added. Each year the grain was sown on fallowed ground.

Two varieties of winter wheat were used. Karmont was sown in the fall of 1947 and 1949, and Yogo in the fall of 1948 and 1950. The winter wheat was sown with a six foot single disk grain drill. The row spacings were obtained by covering the appropriate feeds in the drill. The winter wheat was cultivated during the middle of October and around the 1st of May with a duckfoot type row cultivator. The depth of cultivation was from 1 to 2 inches or just deep enough to control the weeds. In 1949 and 1951 the wheat plant population for each spacing was determined by counting at three locations the number of mature heads in a yard long row in each plot and then converting the data to heads per square foot. At harvest, sixteen feet of row was cut from the center of each plot and threshed in a Vogel Thresher. The threshed grain was then weighed in grams and later converted to bushels per acre. The grain of each treatment, from the three replicates, was bulked for test weight and protein determinations. The protein determinations were made by the Montana State Grain Laboratory, Bozeman, Montana.

During each of the five years heavy infestations of winter and summer annual weeds of the mustard and amaranth families occurred in all plots. No grassy weeds were observed.

During the period 1948 to 1951 several other aspects of wide row spacing of winter wheat were tested in conjunction with the experiment previously described. These tests were as follows:

1. A one year test conducted in 1948 to determine the effectiveness of fall and spring cultivation vs only spring cultivation. The method used was to divide each cultivated plot in half, one half being cultivated twice and the other half being cultivated once. Yield data were obtained from both halves.

2. A cultivation vs 2,4-D experiment was conducted from 1949 to 1951 to test the merits of cultivation as compared to chemical weed control. This test was a triplicated randomized block with the following treatments: (1) 12-inch uncultivated check, (2) 12-inch rows sprayed with 1/3 lb. of 2,4-D at tillering, (3) 24-inch rows sprayed with 1/3 lb. of 2,4-D at tillering, (4) 24-inch spacing cultivated in the fall and spring.

3. A cultivation plus 2,4-D experiment was conducted in 1951. This was accomplished by spraying a 16-foot swath with 1/3 lb. of 2,4-D per acre across the row spacings previously cultivated.

In 1951 spacing studies were conducted with eight barley varieties to determine if any variety x spacing interaction would occur. The barley was sown in 6 and 12-inch spacings. No cultivations were given, however, the plots were treated with 1/3 lb. of 2,4-D per acre when the barley was well tillered. The experimental design was a randomized block with three

replications. The plot size was 1/50 acre. Harvesting was accomplished by cutting a 7 foot swath from the center of the plot with a self-propelled combined.

A homogeneity of variance test as given by Snedecor (19) was run on the winter wheat data to determine if the 12-inch uncultivated spacing should be analyzed with the cultivated plots. It was found that the populations were alike so the data was analyzed by use of the analysis of variance and appropriate F-test as given by Leonard and Clark (13). The analysis of co-variance was used to study the relationship between yield, test weight, protein, and head populations.

North Montana Branch Station, Havre

A wide row spacing experiment with spring wheat was started at Havre in 1950. The test was conducted on dry land on an alternate fallow crop basis. The long time average seasonal precipitation for the station was 11.54 inches. The rainfall for 1950 was 1.17 inches above normal. However, a hot dry period during the latter part of July generally reduced yields. During 1951 the seasonal rainfall was 12.68 inches and the season was generally favorable for crop production.

The same experimental procedure was followed during each of the two years in which tests were conducted. Rescue spring wheat was sown with a common drill in rows spaced 6, 12, 18, 24, and 30 inches apart. All spacings were sown at rates of 20, 40, and 60 lbs. per acre. The design was a triplicated randomized block. The plots were 132 feet long and after the border rows were removed exactly 1/50 of an acre was left to harvest.

The row spacing plots were not cultivated. Instead, they were harrowed

to control small Russian thistles when the wheat was in the seedling stage. Later 4/10 of a pound per acre of 2,4-D was applied when the wheat was well tillered. Weeds were not a serious problem.

Harvesting was accomplished by a self-propelled combine. The harvested grain was weighed in pounds and later converted to bushels per acre. Test weight and protein determinations were made for each plot. The two years data were combined and analyzed by the appropriate statistical methods.

Montana Agricultural Experiment Station, Bozeman

Irrigated growing conditions were generally more favorable for crop production at Bozeman than under dry land conditions. Except in 1950 when late August rains delayed maturity and in 1951 when 3 weeks of hot weather in July caused premature ripening, crop conditions were ideal for the years that spacing experiments were conducted.

In addition to yield and quality of small grains when grown in wide row spacings, studies were made on other aspects of spacing such as: (1) The validity of testing small grain varieties in 12-inch rows when most farmers use a 6-inch drill for field production, (2) Date of seeding in relation to varieties and spacings, (3) The value of wide row spacings for nurse crops, (4) The possibility of growing pure seed blocks in wide rows so rouging would be less difficult.

The first test on row spacing was conducted in 1944 on dry land at Fort Ellis and under irrigation at Bozeman. During that year Compana and Glacier barley were grown in five randomized replications spaced at 6 and 12 inches to determine if any variety x spacing interaction would occur.

In 1947 row spacing studies were conducted with spring wheat and oats. The spring wheat test was similar to the 1947 Moccasin spring wheat experiment except that the seeding rates were increased to 45, 60, 75, and 90 lbs. per acre. In order to gain more precision, the oat experiment was sown as a latin square split plot design. Overland, Bridger, and Gopher were seeded in rows spaced 6, 12, 18, and 24 inches apart.

No spacing studies were conducted in 1948. To obtain information on spacing x crop interaction two varieties of oats, Bridger and Gopher, and one variety of spring wheat and barley, Thatcher and Glacier, were grown in separate latin square blocks in 1949. The spacings were slightly modified to include a 6-inch spacing which was sown at half the regular rate so as to gather more information on such a rate of seeding for companion crops.

In 1950, oat tests were continued on the same basis as the previous year except that V-R x Bannock (CI4283) was added. The barley experiment was modified to include three varieties, Glacier, Compana, and Titan. These three varieties were grown in a triplicated randomized block with the same spacings as used in 1949. In addition, Glacier and Compana were grown in a latin square split plot design using two dates of seeding in 6, 12, and 18 inch rows.

During 1951 the oat and barley tests were continued. The varieties of oats were changed to include Bridger, Mission, and Clinton x Overland² (CI6611). In the barley test the latin square design was changed to a triplicated randomized block and the 24-inch spacing dropped for Titan and Compana. The 24-inch spacing was maintained with Glacier so that a three

year comparison could be made with one variety.

The general experimental procedure at Bozeman was to plant rod rows with a nursery planter. The plot size varied with the width of spacing so that there would always be a border row on each side and two border rows on the 6-inch spaced plots. Except for the 6-inch spacings, all plots were cultivated once with a wheel hoe. Weeds were not a factor in any spacing. At harvest 16-feet of the center row of each plot, except for 6-inch spacing when two were cut, was cut by hand and threshed with a Vogel thresher. The grain was weighed in grams and converted to bushels per acre. Test weights were obtained.

The data for each of the yearly tests were analyzed by use of the analysis of variance and appropriate F test. Three years data for Bridger oats and Glacier barley were taken out of the yearly test and analyzed for year x spacing interaction. The 1949 data for oats, barley, and spring wheat were tested for crop x spacing interaction.

EXPERIMENTAL RESULTS

Winter Wheat

The winter wheat data presented are from the tests conducted at Moccasin from 1948 to 1951. The detailed data collected are reported in the appendix A, Table I. For the continuous four year spacing and cultivation study, the data for yield and test weight are based on four years results. The data for protein and head populations are for the years 1949 and 1950.

Yields obtained

The annual average yield obtained from the four spacings along with the seasonal precipitation for the 1948-51 period is presented in Fig. 1.

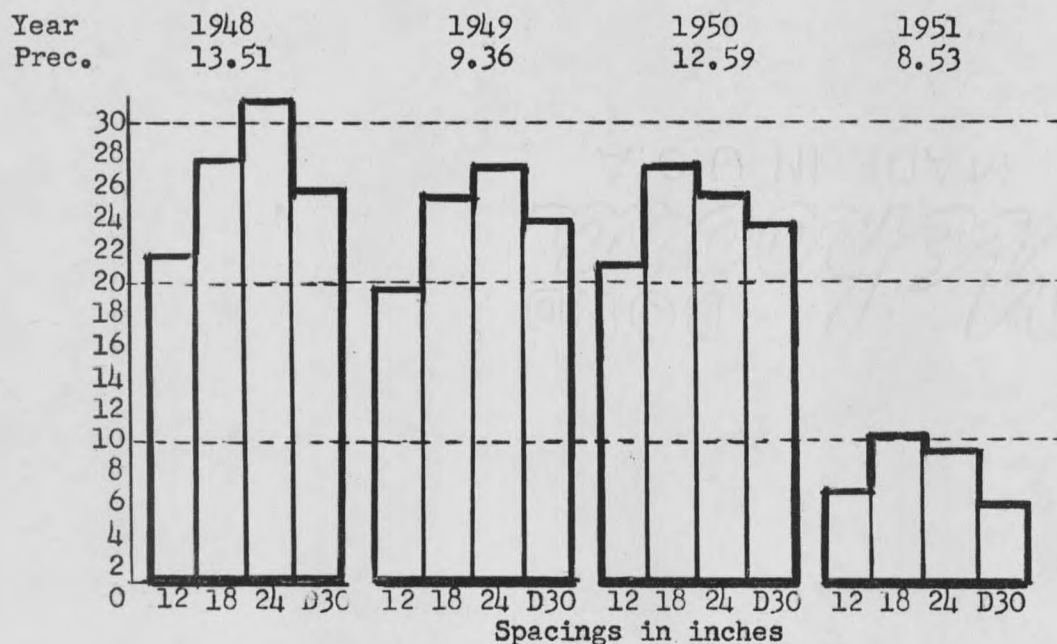


Figure 1. Annual average yield in bushels per acre obtained from spaced plantings of winter wheat, showing yield of 12-inch spacing and 18, 24, and 30 inch spacing cultivated twice, Moccasin, 1948 to 1951.

Yield differences in favor of the 18 and 24 inch cultivated spacings were obtained during each of the four year periods. The low precipitation and high yield for 1949 can be attributed to the favorable seasonal distribution of the rainfall in May and June. It is of interest to note that in 1948 and 1949 the 24 inch spacing had the highest average yield, while in 1950 and 1951 the 18 inch spacing was the highest. This interaction of years and spacings was significant when analyzed statistically, Table I and appendix A, Table II. Except for 1951 the 12-inch uncultivated spacing had the lowest average yield.

Table I. Summary of analysis of variance for yield, test weight, protein, and head counts of the 4 year wide row spacing and cultivation experiment, Moccasin, Montana, 1948-51.

Source of Variation	Yield		Test Weight		Protein		Head counts	
	DF	Variance	DF	Variance	DF	Variance	DF	Variance
Rates	2	54.22**	2	.10	2	35.53	2	9.53
Error	8	2.16	33	.23	22	47.36	22	4.24
Spacing	3	308.94**	3	.71*	3	314.41**	3	65.35**
Error	24	5.96	33	.23	22	47.36	22	4.24
Rates x Spac.	6	11.75	6	.08	6	25.94	6	4.14
Error	48	7.74	33	.23	22	47.36	22	4.24
Yrs. x Spac.	9	23.86	9	.27	6	79.77	6	7.27
Error	24	5.96	33	.23	22	47.36	22	4.24

For the four year period the 24-inch spacing cultivated twice annually had the highest average yield of 23.1 bushels per acre, followed by the 18-inch spacing with a 22.8 bu. average. The double 30 inch spacing did not yield as well as the 18 and 24, as the yield dropped to 19.0 bu. The uncultivated 12-inch spacing had an average yield of 17.1 bu. for the four

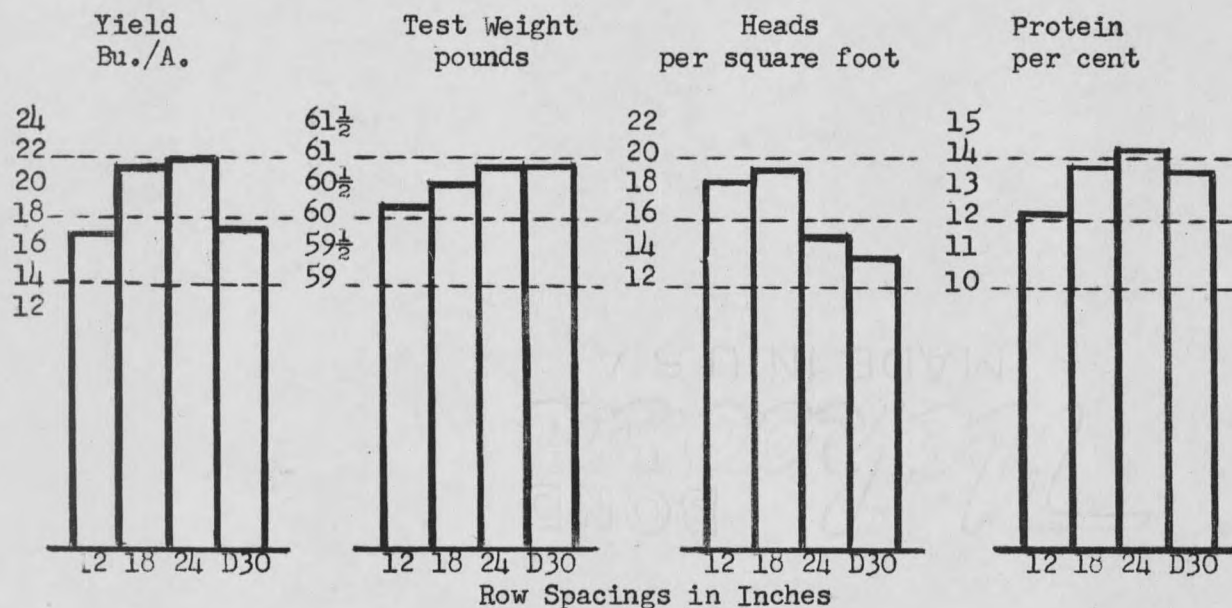


Figure 2. Effects of row spacing and cultivation on the yield, test weight, number of heads per square foot, and per cent protein. Data for yield and test weight are an average of four years, 1948-51. Data for heads per sq. ft. and protein are an average of 1949 and 1951. Moccasin, Montana.

years. The averages of the various spacings are represented graphically in figure 2. These averages were statistically significant, Table I.

The effect of seeding rates on yield for the four spacings is shown in figure 3. In spite of the initial thick stands obtained from the heavier rates of seeding at row spacings greater than 12-inches the 60 pound rate produced the most grain. However, this increase in yield was not significant for the rates x spacing interaction, Table I. The over-all average for all spacings of 19.4, 20.7, and 21.5 bu./a. for 40, 50, and 60 pound rates was significant, Table I.

Test weight and protein

Significant differences in test weight for the four year period, Table I., were obtained from the various spacings. However, the differences were

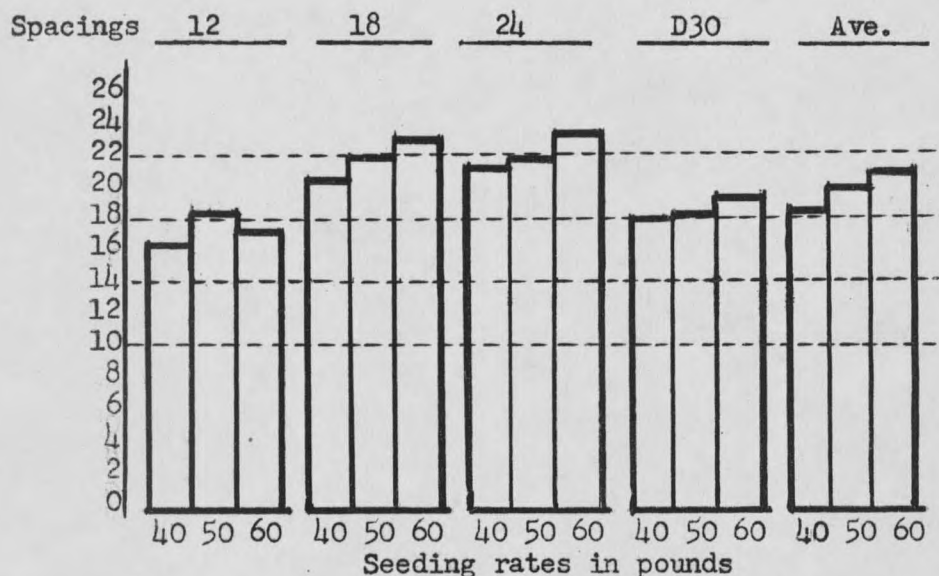


Figure 3. The effects of three seeding rates on yield of winter wheat when grown in four widths of rows and the wider spacings cultivated. Central Montana Branch Station, Moccasin, Montana, 1948-51.

were slight as the 24 and double 30 inch spacings had identical averages of 60.9 lbs/bu., followed closely by the 18-inch spacing with 60.6 and the 12-inch spacing with a 60.3. The four year averages are presented in figure 2. The complete analysis of variance is given in appendix Table 3.

Protein determinations made from the wheat samples in 1949 and 1951 indicated that there was an increase in protein content for the cultivated spacings over the uncultivated 12-inch check. The 24, double 30, and 18-inch spacings had averages of 14.1, 13.7, and 13.6 per cent protein respectively, while the per cent of protein for the 12-inch check was 12.3. When analyzed statistically, Table 1., these differences were found to be significant. The per cent of protein was not effected by the rates of seeding. The two years data is represented graphically in figure 2. The complete analysis of variance is given in appendix A Table 4.

Heading, maturity and head populations.

No difference in heading date for the row spacings was observed. Some delay in maturity occurred in the wider spacings. This was mostly due to the continuous growth of the outside tillers which remained green after the bulk of the grain was mature. Observations made on the wheat spikes of the various spacings indicated that the wider cultivated spacings had longer and larger heads. Some lodging occurred in the 24 and 30-inch spaced wheat as the wide spacings did not support themselves as readily as the narrow spaced rows.

The average number of mature heads per square foot of land area occupied by the various row spacings is given in figure 2 for the data collected in 1949 and 1950. The 18-inch cultivated spacing had the highest number of heads per unit area with 19 heads per square foot. The 12-inch uncultivated spacing had one less head per square foot. For the wider cultivated spacings the number of heads per unit area dropped off quite rapidly, as the 24 and double 30-inch spacing had 15 and 14 heads respectively. The data collected for the two years was analyzed statistically and it was found the differences due to spacings were significant, Table 1. Some differences in heads per square foot due to the rates of seeding were obtained, however, when analyzed these were not significant. The differences obtained for the 40, 50, and 60 pound rates were 15.5, 17.0, and 17.5 heads respectively. See appendix A Table 5 for complete analysis.

It was of interest to note the thickness of the germinating stands due to the heavy rate of seeding within the rows of the wider spacings. The initial stands were comparable to the amount of seed deposited in the row,

or the 18-inch rows were one and one half times as thick as the 12-inch spacings, the 24-inch rows twice as thick, and each of the two 30-inch rows one and one half times as thick.

In order to determine what effect the thick germinating stands had on the production of mature heads, the number of kernels sown by the drill per foot of row were calculated and compared to the number of mature heads per foot of the same row. The calculations were based on wheat weighing 60 pounds per bushel or the equivalent of 19 seeds per foot of row when sown at 12-inch spacing. The number of mature heads and the number of seeds per foot of row plus the ratio of heads at harvest to seeds planted are given in Table II. for 1949 and 1951.

Table II. Average number of mature winter wheat heads and the number of kernels sown per foot of drill row when spaced at 12, 18, 24, and D30-inches apart and sown at 40, 50, and 60 pounds per acre. The three wider spacings received two cultivations annually, Moccasin, Montana, 1949 and 1951.

Spac. in inch.	40 lbs. per acre			50 lbs. per acre			60 lbs. per acre		
	Heads*	Seeds	Ratio**	Heads	Seeds	Ratio	Heads	Seeds	Ratio
<u>1949</u>									
12	18	12.6	143	17	15.8	107	17	19.0	89
18	26	18.9	138	31	23.7	131	32	28.5	112
24	30	25.2	119	32	31.6	101	38	38.0	100
D30***	44	37.8	116	48	47.7	101	58	57.0	102
<u>1951</u>									
12	17	12.6	135	19	15.8	120	18	19.0	95
18	23	18.9	122	30	23.7	127	27	28.5	95
24	28	25.2	111	29	31.6	92	26	38.0	68
D30	28	37.8	74	32	47.7	67	34	57.0	60

*Head and seeds are for one foot of drill row.

**Ratio of heads at harvest to seeds planted.

***Two six inch rows spaced 30 inches apart.

In 1949 there was a general increase in mature heads in proportion to the seeds sown. The 18-inch cultivated spacing had the highest increase in heads, with a 27 per cent increase for all the rates of seeding. The double 30-inch cultivated spacing, which actually had the same amount of seed coming from each of the two seed spouts as the 18-inch spacing, had the lowest proportional increase of 6 per cent for all rates. The uncultivated 12-inch and cultivated 24-inch spacings had increases in heads over seed sown of 13 and 7 per cent respectively. Figure 4 is a graphic representation of the two year average proportions.

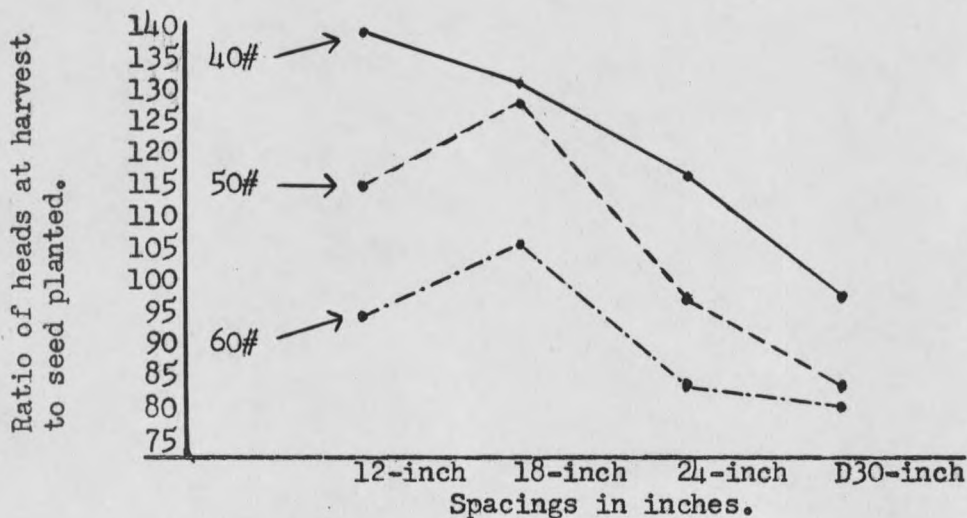


Figure 4. Showing the increase or decrease in heads in proportion to the seeds sown for the various spacings and rates of seeding, Moccasin, Montana, 1949 and 1951.

The seeding rates also effected the proportional increase of heads to seeds deposited. The light seeding rate of 40 pounds had an average increase of 29 per cent for all spacings, the 50 pound rate an increase of 10 per cent, and the heavy 60 pound rate only a 1 per cent increase, Table II.

Due to dryer growing conditions in 1951, the proportion of mature heads to seeds deposited was more severely effected, Table II. This was especially true for the wider spacings and heavier rates of seeding. The double 30-inch cultivated spacing was effected the most as it had a 33 percent decrease for all the seeding rates. The 24-inch cultivated spacing had a 10 percent decrease. The 18-inch cultivated and 12-inch uncultivated spacings had a 15 and 17 percent increase. The rates of seeding for all spacings had a 10 percent increase for 40 lbs., 1 percent increase for 50 lbs., and 20 percent decrease for 60 lbs.

Relationships between yield, test weight, protein and heads per unit area.

There is some evidence that the row spacings and cultivation caused abnormal relationships. This can be observed in figure 5 where the 1949-51 averages for yield, test weight, protein, and heads per sq. ft. are compared with the 12-inch uncultivated check on a percentage basis.

Per cent of
check

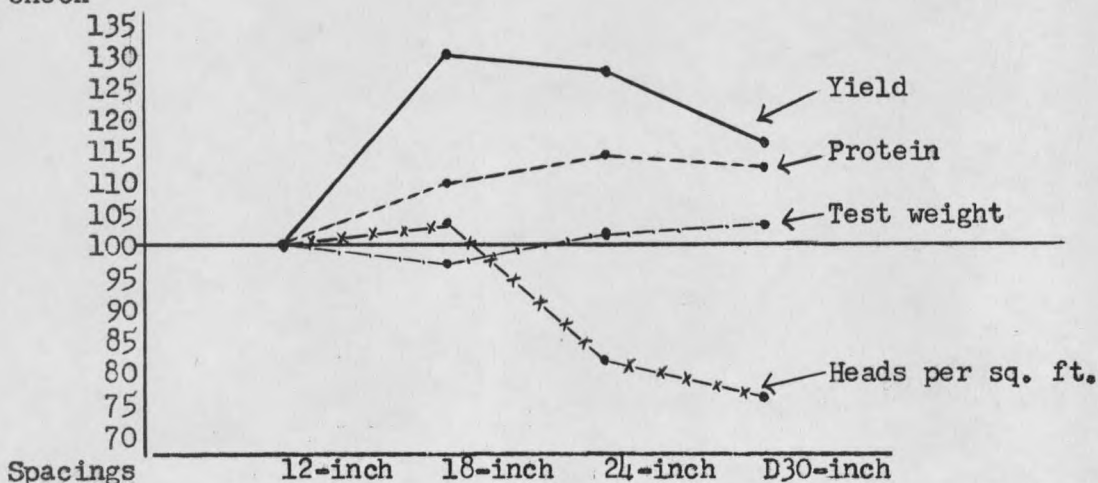


Figure 5. Comparison of yield, test weight, protein, and heads per sq. ft. of the various spacings. The 12-inch is considered as 100 percent. Moccasin, Montana, 1949-1951.

A summary of the relationships are given as follows:

1. For the 18-inch cultivated rows there was an increase in yield, protein content, and heads per square foot while there was a slight drop in test weight.
2. For the 24-inch spacing there was an increase in yield, test weight, and protein, however, the number of heads per square foot dropped off quite sharply.
3. For the double 30-inch spacing there was not as large an increase in yield and protein, the test weight was high, and the number of heads per square foot was further reduced.
4. The general trend for all spacings was as follows: a/ As the yield increased the protein increased. b/ As the spacing between rows increased the test weight increased. c/ Except for the 18-inch spacing, the number of heads decreased as the width of row increased. d/ As the heads per unit area decreased for the wider row spacings the test weight increased. e/ No general trends are apparent between yield and test weight, yield and heads, protein and test weight, or protein and heads per square foot.

Correlation coefficients were calculated by the analysis of covariance for all of the possible relationships, Table III. It was found that but few of the r values were significant. This was to be expected since each spacing seemed to respond differently to yield, test weight, protein content, and heads per square foot.

The only significant correlations, as effected by spacings, was a negative r value of .98 for test weight and heads per square foot. From figure 5. this negative value is apparent as the test weight increased

Table III. Correlation coefficients of the agronomic data obtained from the row spacing and cultivation of winter wheat experiment. The yield and test weight correlation was obtained from four years data, the remaining from one test in 1949 and two tests in 1951. Central Montana Branch Station, Moccasin, Montana, 1948 to 1951.

Source of Variation	D. F.	Correlation coefficients for:					
		Yield and T. W.	Yield and Heads	Yield and Protein	T. W. and Heads	T. W. and Protein	Heads and Protein
Test or yrs.	3-2	.31	.85	-.01	.83	-.88	-.10
Rates	2	-.69	.02	-.08	-.62	-.10	.02
Spacings	3	.31	.15	.23	-.98*	.44	-.03
Rate x Spac.	6	-.77	.28	-.06	-.68	-.16	-.02
Error	35-22	-.08	.42	-.07	-.11	-.11	-.16
Total	47-35	.27	.46**	-.07	.13	-.78**	-.09

for each wider spacing, while the number of heads decreased in the 24 and double 30-inch rows.

Significant total correlations of .46 and -.78 were obtained for yield and heads, and test weight and protein. The positive correlation between yield and heads is apparent for the 18 and double 30-inch spacings, however, the 24-inch spacings had a high yield and comparatively low number of heads per unit area. The total negative r value for test weight and protein indicates that as the test weight increased the protein went down. However, this was not the case for the spacing effect as a positive value was obtained, indicating a reversal in the trend occurred or as the test weight, due to spacing, increased the protein increased. A similar trend can be noted in the relationships between yield and test weight where a positive value was obtained for the spacings. This can be noted in figure 5 where there is a general increase in protein along with the increase in yield.

Effects of cultivation

Cultivation was fairly effective in controlling weeds between the rows of the cultivated wheat. From observations it was apparent that the fall cultivations were effective in controlling the winter annuals, while the spring cultivations controlled the spring germinated weeds. During the years of high rainfall the weeds within the row were quite large, however, during the dryer seasons the weeds were suppressed by the competition of the wheat.

In 1948 the fall and spring cultivated plots produced more winter wheat than just the spring cultivated plots, Table IV. The average yield for all spacing receiving two cultivations was 27.4 bu/a. compared to 24.4 bu/a. for only spring cultivations. These means were significantly different when analyzed statistically, Table V.

Table IV. Average yield of winter wheat in bushels per acre obtained from one and two cultivations of 18, 24, and double 30-inch row spacings, Moccasin, Montana, 1948.

Number of Cultivations	Yield for Spacing			Average
	18	24	D30	
1	25.2	26.0	22.0	24.4
2	27.8	31.4	22.9	27.4

Table V. Analysis of variance of yield for one and two cultivations.

Source of Variation	Degree of Freedom	Sums of Squares	Mean Square	F. Value
Replications	2	86.26		
Cultivations	1	366.30	366.30	7.85*
Spacings	2	1094.33	547.16	11.72**
Cultivations x Spac.	2	134.06	67.03	1.44
Error	10	466.93	46.69	
Total	17	2147.88		

Chemical weed control vs cultivation

From the three years results obtained it is apparent that 2,4-D was as effective as cultivation. The results as given in Table VI show an average yield of 23.33 bushels for the 12-inch spacing treated with one-third pound of 2,4-D and 22.97 bushels for the 24 inch spacing cultivated twice. During 1950 and 1951, the two cultivation plots produced higher yields than the 2,4-D plots. The 24-inch spacing sprayed with 2,4-D had a 2.63 bushel average increase over the 12-inch check.

Table VI. Yield of winter wheat in bushels per acre obtained from the 2,4-D vs cultivation experiment, grown on fallow in a triplicated randomized block, Moccasin, Montana, 1949 to 1951.

Spacing in Inches	Treatment	Bushels per Acre			Average
		1949	1950	1951	
12 inches	None	22.13	25.50	10.87	19.40
12 inches	1/3 lb. 2,4-D	29.50	25.53	14.97	23.33
24 inches	Two Cultivations	26.36	27.37	15.17	22.97
24 inches	1/3 lb. 2,4-D	24.20	25.33	11.50	20.34

The analysis of variance for the experiment is given in Table VII and shows that the yield differences obtained from various treatments were significant.

Table VII. Analysis of Variance for 2,4-D and Cultivation Experiment.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Value
Years	2	1266.46	633.23	
Replication	2	46.25	23.13	
Treatments	3	101.32	33.77	8.22**
Yrs. x Treatments	6	43.15	7.19	1.75
Error	22	90.52	4.11	
Total	35	1547.70		

Cultivation plus chemical weed control

The 1951 yield test to determine the effectiveness of 2,4-D plus cultivation is reported in Table VIII. From the one years results there is some indication that an application of 2,4-D to control the weeds in the rows may be of some value, as the average yield of the three cultivated plots was 9.3 bushels compared to 13.5 bushels for the same spacings cultivated and sprayed with 2,4-D. The 18-inch spacing responded the most to the double treatment as it had a yield of 15.5 bu. This is an 8.3 bu. increase over the 12-inch check and a 6.0 bu. increase over the 12-inch check treated with 2,4-D. The analysis of variance as given in Table IX shows significance for the spray vs cultivation treatments.

Table VIII. Average yield of winter wheat in bushels per acre obtained from the row spacing and cultivation experiment, when treated with one-third pound of 2,4-D in addition to the two cultivations, Moccasin, Montana, 1951.

Row Spacing	Treatment	Seeding Rate			Average
		40 lbs.	50 lbs.	60 lbs.	
12 inch	None	6.7	9.3	5.6	7.2
" "	2,4-D	8.8	11.3	8.1	9.4
18 inch	2 Cultivations	9.6	12.2	11.6	11.1
" "	2 Cult. + 2,4-D	17.5	14.5	14.0	15.5
24 inch	2 Cultivations	9.5	10.3	10.7	10.2
" "	2 Cult. + 2,4-D	16.1	16.3	13.6	15.4
D30 inch	2 Cultivations	6.7	6.2	7.2	6.7
" "	2 Cult. + 2,4-D	9.5	9.5	9.4	9.5

Table IX. Analysis of Variance for yield of cultivation plus 2,4-D experiment.

Source of Variation	Degree of Freedom	Sums of Squares	Mean Square	F. Value
Replications	2	42.03		
2,4-D vs Cultivation	1	235.80	235.80	58.95**
Error (a)	2	8.00	4.00	
Plots of 2,4-D	5	286.78		

Spring Wheat

The spring wheat row spacing data presented are from tests conducted at Moccasin in 1947, Bozeman in 1947 and 1949, and Havre in 1950 and 1951. The detailed data and complete analysis of variance for all stations are presented in the Appendix B.

Yields obtained

Yield differences in favor of the wide row spacings did not occur for spring wheat as it did for winter wheat. For all tests at all stations it followed practically the same pattern. The wider the spacing the lower the yield. These depressions in yields are shown graphically in figure 6.

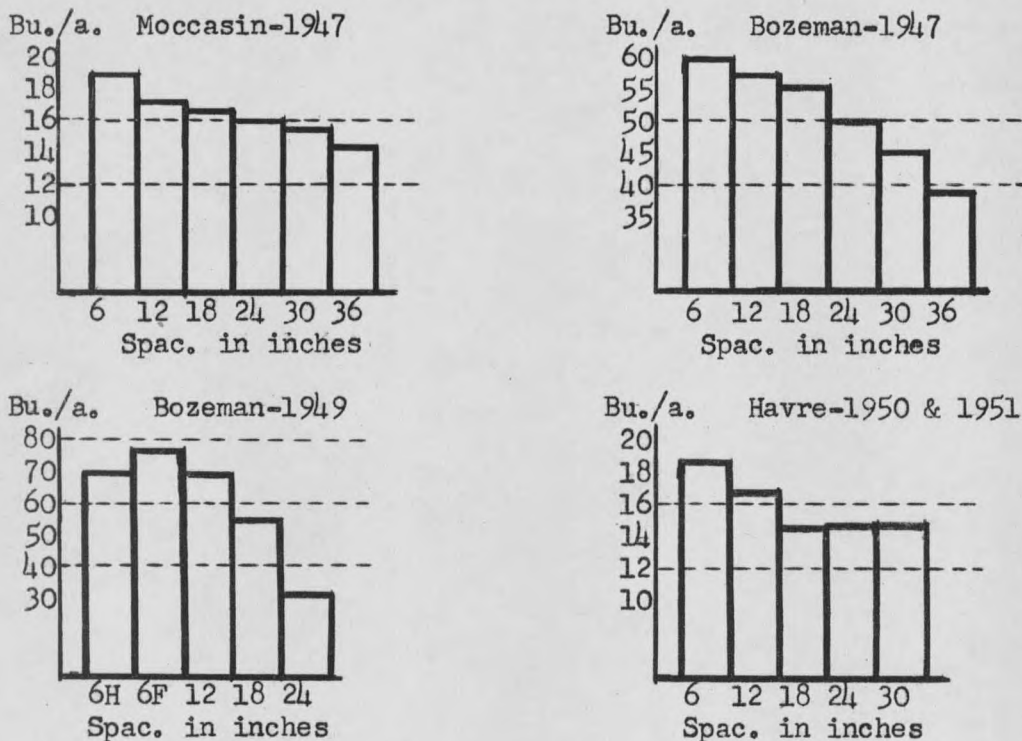


Figure 6. Yield in bushels per acre of spring wheat obtained from various row spacings at three locations in Montana.

At Moccasin in 1947, the yield dropped from 19.1 bu./a. for the 6-inch spacing to 13.8 bu. for the 36-inch. The percentage decrease in yield for each 6-inch increase in row width was 9.5 from the 6 to 12, 12.3 from 6 to 18, 18.5 from 6 to 24, 18.5 from 6 to 30, and 31.0 from 6 to 36 with an average of 6.2 per cent for each 6-inch increase in row spacing. Under irrigation at Bozeman in 1947, the same general trend is apparent except that it is more pronounced at the wider spacing. As the decrease in yield for each 6-inch increase in row width was 7.6, 9.4, 14.4, 28.4, and 41.0 per cent with an average of 8.3 per cent for each 6-inch increase in row spacing.

No significant differences in yield due to spacings were obtained at Moccasin when analyzed, Table X, however, significance was obtained at Bozeman.

Table X. Summary of analysis of variance for spring wheat row spacing studies conducted at Moccasin, Bozeman, and Havre, Montana, 1947 to 1951.

Source of Variation	Moccasin 1947		Bozeman 1947		Havre 1950-51		Bozeman 1949	
	DF	Variance	DF	Variance	DF	Variance	DF	Variance
Rates	3	3.50**	3	40.88	2	.35		
Error	3	.33	3	65.55	58	2.75		
Spacing	5	25.33	5	481.88**	4	35.10**	4	2,102*
Error	5	21.00	5	13.45	58	2.75	24	408
Rates x Spac.	15	3.88	15	4.81	8	1.44		
Error	15	2.42	15	15.83	58	2.75		

At Bozeman in 1949 more pronounced decreases in yield were obtained from the wider rows. In fact, the yield dropped from 79.8 bu./a. for the 6-inch spacing to 28.9 bu. for the 24-inch spacing, figure 6. The decrease in yield was 9.9 per cent from the 6 to 12 inch rows, 34.0 per cent from 6 to 18, and 63.8 per cent from 18 to 24, with an average decrease of 28.0 per cent for each 6-inch increase in row width.

At Havre, a different trend in decrease in yield was obtained, figure 6. General decreases of 6.6 per cent occurred from the 6 to 12 and 21.6 per cent from 6 to 18-inch rows. However, after the row width reached 18 inches the yield tapered off, as identical percentage decreases of 21.3 per cent occurred from the 6 to the 18, 24, and 30 inch spacings. Significant differences in yield were obtained when analyzed, Table X. The relative yields of the various row spacings were not constant for the two years at Havre as indicated by a significant years x row spacing interaction, appendix B, Table V.

Seeding rates in relation to yield.

The amount of seed sown did not affect the yields for any of the spacings, as no significant rate x spacing interactions were obtained, Table X. The yield for each seeding rate used at the three locations is given in Table XI.

At Moccasin, the 50 and 30 lb. seeding rate produced the highest yield of 16.8 and 17.0 bu./a., respectively. The 60 and 40 lb. rates were about a bushel per acre lower. These differences were significant when analyzed, Table X. At Bozeman the 90, 75, 60 and 45 lb. rates had nearly identical yields of 58.7 bu. The 60, 40 and 20 lb. rates for the two years at Havre

Table XI. Average yield in bushels per acre of spring wheat obtained from various rates of seeding at three locations. Averages are for all spacings used.

Moccasin - 1947				
Seeding rate	60	50	40	30
Bushels per acre	16.1	16.8	15.9	17.0
Bozeman - 1947				
Seeding rate	90	75	60	45
Bushels per acre	58.7	58.7	58.6	58.7
Havre 1950 to 1951				
Seeding rate	60	40	20	
Bushels per acre	16.2	16.4	16.2	

had averages of 16.2, 16.4 and 16.2 bu./a. At Bozeman in 1949, when Thatcher was sown in 6-inch rows at half and full rates of seeding, the half rate of seeding yielded 9.6 per cent less grain.

Test weight and protein.

The bushel weights obtained from each location for the various spacings of spring wheat are given in Table XII. No apparent differences in test weight are apparent for Moccasin. Slightly heavier test weights for the wider spacing were obtained at Bozeman and Havre. For the three station average, there appears to be a decrease in test weight as the spacing is increased up to 18-inches. However, beyond that width the test weight again increased.

Table XII. Weight of spring wheat in pounds per bushel due to various spacings at three locations.

Location	Spacings in inches					
	6	12	18	24	30	36
Moccasin	60.8	60.6	61.0	60.8	61.0	60.9
Bozeman	58.9	58.6	58.2	58.5	59.1	58.9
Havre	53.6	53.3	52.8	53.2	54.8	(53.8)*
Average	57.8	57.5	57.3	57.5	58.3	57.9

* Calculated by Yates missing value formula

Barley

Except for one test at Moccasin in 1951, all of the row spacing studies with barley were conducted at Bozeman. The detailed data collected along with the individual analysis of variance tables for tests conducted in 1944 and 1949 through 1951 for Bozeman and Moccasin are given in Appendix C.

Yields obtained for spacings

As compared to spring wheat, the yields of barley were not decreased as sharply at the wider spacings. Comparisons of the 6 and 12 inch spacings for all barley varieties in six trials over a four year period are given in figure 7.

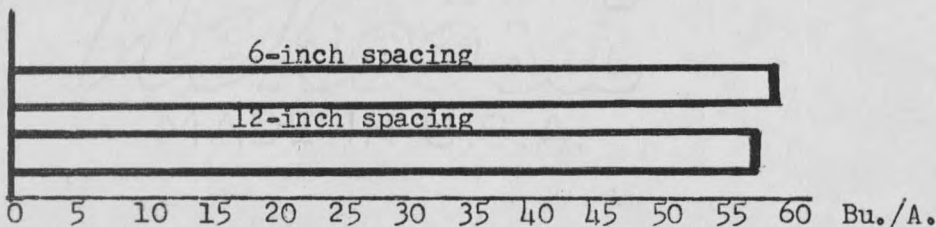


Figure 7. Average yield of barley in bu./a. grown at 6 and 12 inch spacings. Averages are from six trials conducted over a four year period.

Only an eight-tenths bushel difference in yield in favor of the 6-inch spacing was obtained. The eight-tenths bushels difference is actually based on 84 individual comparisons.

Figure 8 represents the average yield of four spacings used at Bozeman from 1949 to 1951, when row widths of 6-inch at a half rate seeding, 6, 12, 18, and 24 inches at a full rate seeding were used. The 6-inch full rate of seeding produced the highest yield of 78.1 bu./a. Only a one bushel loss in yield was obtained from both the 12 and 18 inch spacings. The yield of

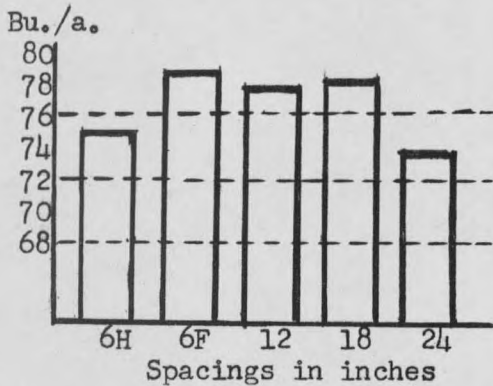


Figure 8. Average bushels per acre of barley obtained from four widths of rows grown at Bozeman, Montana 1949-51.

Table XIII. Summary of analysis of variance for yield of barley grown at Bozeman and Moccasin, 1944, 1949-51.

Source of Variation	Ft. Ellis-1944		Bozeman-1944		Bozeman-1949		Bozeman-1950	
	D.F.	Variance	D.F.	Variance	D.F.	Variance	D.F.	Variance
Varieties	1	13.45	1	872.52**			1	5,041
Error	12	71.49	12	56.93			2	558
Spacings	1	505.60*	1	194.07	4	236.25	2	7,895
Error	12	71.49	12	56.93	12	77.07	4	42,551
Var. x Spac.	1	284.29	1	235.98			2	26,245
Error	12	71.49	12	56.93			14	5,820
Date x Spac.							2	2,955
Error							14	5,819

Source of Variation	Bozeman-1951		Moccasin-1951		Glacier 1949-50-51	
	D.F.	Variance	D.F.	Variance	D.F.	Variance
Varieties	2	28,265**	7	43.54*		
Error	16	2,842	30	18.41		
Spacings	3	10,644	1	.01	4	16,126
Error	6	16,656	30	18.41	28	9,644
					Yrs. x Spac.	
Var. x Spac.	6	6,291	7	6.99	8	7,107
Error	16	2,843	30	18.41	28	9,644

rows spaced 24-inches apart dropped to 70.0 bu. Comparing the 6-inch half rate of seeding with the full rate, figure 8, it is apparent that such a rate and spacing reduces yield more than a 12 or 18 inch spacing at a full rate of seeding. From the standpoint of yield it would seem that a full rate of seeding in 12 or 18 inch rows would be more practical than a half rate of seeding in 6 inch rows.

Except for the trial at Fort Ellis, when the 6 and 12 inch spacings were used, no significant differences in yield of the spacings were obtained, Table XIII. This may indicate that barley is capable of producing average yields regardless of the width of rows up to 18-inches. This is further brought out in the three year comparison of 4 spacings for Glacier from 1949 to 1951, when the average yields were 63.9, 65.0, 67.4 and 56.4 bu./a. for the 6, 12, 18, and 24-inch rows, respectively. With a range in average yields of 62.8 to 96.2 bu./a. in the various years of this test the spacing x year interaction was significant.

The 1950 comparison showing the effect of seeding dates on yield of three spacings are given in Table XIV.

Table XIV. Average yield in bushels per acre of two varieties of barley sown at two dates of seeding in 6, 12, and 18 inch rows, Bozeman, 1950.

Seeding Date	Spacing in inches			Average
	6	12	30	
Normal	62.2	69.8	64.4	65.5
Late	63.2	72.3	67.6	67.4

Other than an increase in yield for the late seeding date, the date of seeding had little effect on yields obtained from each of the row widths.

This is further substantiated by the lack of significant date x spacing interaction Table XIII.

This one trial would seem to indicate that the general findings concerning row spacings would be applicable, regardless of the date of seeding, for the two varieties used, Glacier and Compana.

Varieties x spacing interaction.

The only significant spacing x variety interaction obtained was in the 1951 trial at Bozeman, Table XIII. This interaction can be noted in figure 9. where Compana does not yield proportionately the same at each row width as does Glacier and Titan. Compana apparently being better adapted for use at the wider row spacings.

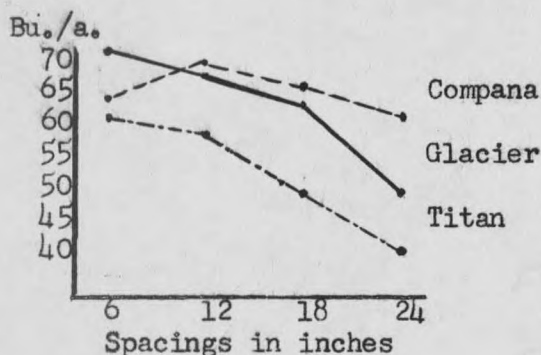


Figure 9. Average yield in bu./a. of three barley varieties grown in four row widths, Bozeman, 1951.

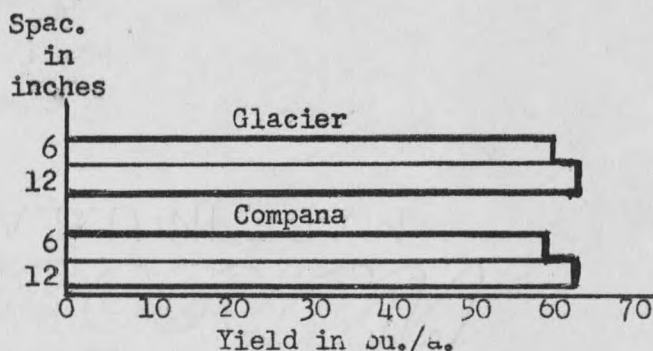


Figure 10. Average yield in bu./a. of Glacier and Compana grown in five separate trials at 6 and 12-inch spacings.

The average yield of Glacier and Compana planted in 6 and 12-inch spacings in five separate trials is given in figure 10. Both varieties reacted the same to the two spacings, as the 6-inch spacing had lower yields in both cases. This should substantiate the validity of planting

barley variety nurseries in 12-inch rows when the normal seeding distance is 6-inches.

The yield results from the variety x spacing interaction study at Moccasin in 1951, when eight varieties were grown at 6 and 12 inch spacings, are given in Table XV.. There is some indication that the different varieties responded differently to yield for the different spacings. However, the spacing x variety interaction was not significant when analyzed, Table XIII.

Table XV. Yield in bushels per acre obtained from eight barley varieties grown in 1/20th acre plots and planted at 6 and 12 inch intervals in a triplicated randomized block, Moccasin, 1951.

Spac. inch.	Variety							
	Gem	Titan	Can.Hyb.	Moore	Compana	G.xC.I*	G.xC.V*	G.xC.X*
6	12.8	13.8	14.7	10.7	19.3	11.7	13.5	14.3
12	15.3	15.8	13.1	10.8	20.1	13.5	10.7	11.5

* Glacier x Compana 2-row selections.

Test weight

The bushel weights obtained from 1949-51 from the various barley spacing experiments are given in Table XVI. Slightly heavier test weights were obtained in 1949 and 1950 for the 18 and 24 inch spacings. However, for the three year average there is very little difference in bushel weight due to spacings. The 6-inch full rate of seeding was 1.5 lbs. heavier than the 6-inch half rate. It would appear that barley may be grown in rows without any appreciable effect on quality as measured by test weight.

Table XVI. Weight of barley in pounds per bushel due to various spacings at Bozeman, 1949-51.

Year	Spacing in inches				
	6 half	6 full	12	18	24
1949	47.0	47.3	46.9	47.5	48.0
1950	48.8	48.8	48.2	49.4	49.5
1951	45.8	46.1	44.9	47.5	45.1
Average	45.9	47.4	46.7	48.1	47.5

Oats

All of the row spacing studies presented for oats were conducted at Bozeman in 1947, and 1949-51. The detailed data collected along with the individual analysis of variance tables are given in Appendix D.

Yields obtained for spacings.

The average yield of all oat varieties used for the four years in which 6, 12, 18, and 24 row spacings were used is presented graphically in figure 10. As the row width increased, there occurred a progressive decrease in yield. In figure 6, a similar decline in yield has been noted for spring wheat.

The sharpest decrease in yield was obtained in 1947 when a 27.7 bushel drop in yield occurred between the 6 and 24 inch rows. This large difference was significant when analyzed statistically, Table XVII. Although a decline in yield of 12, 14, and 10 percent was obtained between the 24-inch spacing and the 6-inch spacing in 1949, 1950, and 1951, respectively, these differences were not significant. The average yield for each spacing over the four year period was 115.9, 109.3, 106.3, and 100.5 bu./a. for the 6,

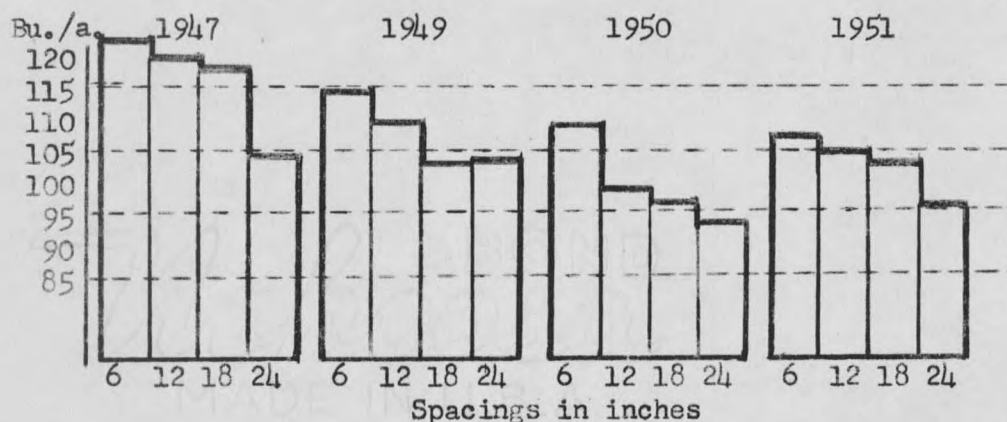


Figure 11. Average yield in bu./a. of oats obtained from four row widths, Bozeman, 1947, 1949-51.

Table XVII. Summary of analysis of variance for yield of oats grown at various row widths, Bozeman, 1947, 1949-51.

Source of Variation	1947		1949		1950		1951	
	D.F.	Variance	D.F.	Variance	D.F.	Variance	D.F.	Variance
Varieties	2	15,793	1	194	2	63	2	1,678**
Error	2	8,830	4	812	8	87	8	140
Spacing	3	27,450**	4	511	4	749	4	213
Error	6	3,881	12	311	12	259	12	72
Var. x Spac.	6	1,550	4	164	8	59	8	93
Error	12	7,163	16	175	32	116	32	84

12, 18, and 24 inch spacings, respectively. In the comparison of the half and full rate of seeding for the 6-inch spacing from 1949 to 1951, the full rate of seeding averaged a 5.7 bushel increase in yield. The 12, 18, and 24 inch spacings in the same studies showed a decrease in yield of greater than 5.7 bushels.

Varieties x spacing interaction

No significant variety x spacing interactions for oats were obtained

during any of the years with the six varieties included in the various tests. The three year average yield of Bridger and Gopher for the four spacings is given in Table XVIII. Although the two varieties yielded differently at various spacings, the spread in yields was slight.

Table XVIII. Average yield in bu./a. of Bridger and Gopher oats grown in 6, 12, 18, and 24 inch rows, Bozeman, 1947, 1949, and 1950.

Variety	6	Spacing in inches		24
		12	18	
Gopher	120.6	109.9	107.4	102.4
Bridger	119.2	114.7	108.8	106.3

It is concluded that varieties recommended for Montana are equally suited to growing in wide row spacings.

An analysis of three years data, when the average yearly yields ranged from 99.9 to 111.9 bushels per acre, showed the four row spacing treatments and the half rate of planting in 6-inch rows to yield in the same order as indicated by a non-significant spacing x year interaction.

Test weight

The various spacings used had practically no effect on the bushel weight of oats, as only a range of four tenths of a pound occurred. For the comparison of the full and half rate of seeding for the 6-inch rows, the test weights were nearly identical. This is of particular interest because oats test weights are generally considered to be quite sensitive to environmental factors. The test weights obtained for each of the four years from the 6 half, 6 full, 12, 18, and 24 inch rows are given in Table XIX.

Table XIX. Weight of oats in pounds per bushel due to various spacings, Bozeman, 1947, 1949-51.

Year	Spacing in inches				
	6-half	6-full	12	18	24
1947		36.0	35.3	35.2	35.5
1948	41.9	42.0	42.0	42.1	42.1
1949	37.5	37.2	36.9	37.2	37.3
1950	36.6	36.2	36.4	36.2	36.9
Average		37.9	37.7	37.8	38.0

Lodging

Lodging data collected in 1947 on three oat varieties are presented in Table XX. From this data, it is apparent that the wider rows caused an increase in lodging in varieties that were susceptible.

Table XX. Per cent lodging of three oat varieties grown at 6, 12, 18, and 24 inch rows, Bozeman, 1947.

Variety	Spacing in inches			
	6	12	18	24
Overland	0	4	6	4
Bridger	47	32	63	92
Gopher	88	85	99	97
Average	45.0	40.3	56.0	64.3

Spring Wheat - Oats - Barley

The results of the 1949 crop row spacing test at Bozeman, when one variety of wheat, oats, and barley were grown in a latin square split plot design, are given in pounds of grain produced per acre in Table XXI, and represented graphically in figure 12.

Table XXI. Pounds of grain produced per acre of spring wheat, oats, and barley grown at various spacings in a latin square split plot design, Bozeman, 1949.

Crop	Spacing in inches				
	6H*	6F	12	18	24
Wheat	4332	4764	4308	3156	1734
Oats	3782	3680	3466	3302	3293
Barley	4780	4997	4488	4603	4118

*Half and full rate of seeding

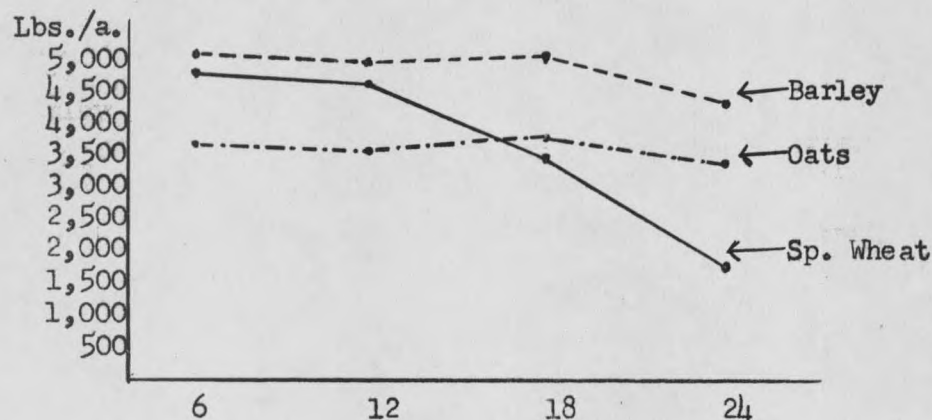


Figure 12. Average yield in lbs. per acre of spring wheat, oats, and barley when grown in 6, 12, 18, and 24 inch rows, Bozeman, 1949.

From figure 12, it is apparent that spring wheat is not as adaptable to the wide row spacings as barley or oats, because the spring wheat yields dropped much more at the 18 and 24 inch spacings than did oats and barley yields. The crop spacing interaction, along with differences due to spacing and cropping were, significant when analyzed, Table XXII.

From Table XXI it can be noted that spring wheat and barley responded the same to half and full rates of seeding in that they both produced higher yields at the full rate. However, with oats the reverse was true this one year. It produced more pounds of grain at the half rate than the full rate.

Table XXII. Analysis of variance for yield of spring wheat, oats, and barley grown at five spacings in a latin square split plot design, Bozeman, 1949.

Source of Variation	Degrees of Freedom	Variance
Crops	2	241,627**
Spacing	4	136,200**
Crop x Spacing	8	48,368**
Error	56	16,310

DISCUSSION

The results of this study indicates that by increasing the distance between rows of winter wheat from 12 to 18 or 24 inches and controlling the weeds by cultivation or 2,4-D a substantial yield increase will result. However, with use of similar practices, spring sown grains did not respond as favorably. The reasons why winter wheat is better adapted to row spacing conditions is undoubtedly based on many factors.

Perhaps it would be desirable to discuss several aspects and ramifications of spaced cereal plants before any attempts are made to give reasons for differences in yield from wider spacings. Engledow (5), in his studies with spacing of spring wheat, brought to light several basic facts on wheat plant development under different spaced conditions. His findings indicated that regardless of the spacing up to a certain point, the wheat plant was very sensitive to the three factors contributing to yield, namely; heads per unit area, kernels per head, and size of the kernels. It was found as the distance between the wheat plants increase tillering would increase up to a point where the plant was incapable of producing tillers. From that point the other two factors, spike and kernel size, would develop in proportion to compensate for the lack of tillers. Hence, the plant would produce average yields, regardless of the number of plants, until the distance was increased to a point where it was unable to utilize all of the resources in its immediate environment. Sprague (10), working with spacing of wheat, oats, rye, and barley found that barley did not produce as extensive a root system as other crops. Basing his conclusions on these findings and other experimental evidence, he implied that barley would be the least desirable

for growing in wide rows.

Coupled with the above conclusions, there are other soil and plant spacing relationships that may be postulated. Soil feeding zones under solid and spaced plantings are changed considerably. It has been generally accepted that soil moisture moves slowly from wet to dry areas. In fact, the plant roots reach out after the moisture instead of the moisture moving to the plant. Consequently, under row spacing conditions there remains an area of reserve soil moisture and soil nutrients between the rows which are not utilized until the plants are fairly well established. Soil temperatures are undoubtedly affected. Whether the temperatures would influence the amount of soil moisture and available plant nutrients has not been generally established. Although experimental evidence has shown that cultivation is of no practical value, except to control weeds, this field of research has not been entirely explored. Such aspects as water infiltration, release of plant nutrients, effects on soil organisms, and evaporation under cultivated row spacing conditions cannot be overlooked.

In view of the foregoing assumptions and facts, some of the reasons why differences in yield and quality occurred between the spaced plantings of the cereal grains grown under different environmental conditions in Montana may be more readily understood. It is quite evident in the results that winter wheat, spring wheat, oats and barley have different inherent characteristics for adapting themselves to wide spacing. Winter wheat and barley appear to give the best response in this respect. Evidently they are either more capable of utilizing the soil resources between the rows or they are more adapted to thick growing conditions or competition within the

heavily seeded rows.

There is some evidence that the reserve moisture and plant nutrient feeding zone theory caused by row spacing conditions has some merit. This is evident in the winter wheat results when increases in yield, test weight and protein were obtained at the 18, 24, and 30 inch spacings. In accounting for the increase in protein along with yield there must have been an available supply of nitrogen and/or moisture at the critical stage of plant growth or fruit development. Postulating on where the nitrogen came from is difficult. One possibility is that the plant roots must have spread out into the area between the rows in search of moisture and encountered nitrogen and other elements. In other words, the area between the rows acts as a store house for moisture and elements for kernel development. The reason for spring wheat not reacting in a similar manner probably lies in the development of the root system.

From the results, it is apparent that seeding rates had little effect on the yields of the wider row. Evidently a balance between tillers, size of spike, and kernel size occurred. Such conclusions were made by Engledow. This balance is quite evident in the winter wheat results when head populations were determined. It was found that the number of heads per unit area decreased as the spacing increased. The increase in test weight was not large enough to compensate for the increase in yield. Consequently, the number of kernels per spike must have increased as it is the only remaining factor that could have contributed to the increase in yield.

The question of whether 2,4-D or cultivation is the better means of weed control has not been fully answered. Both appeared to have distinct

advantages as nearly identical yield results were obtained. Perhaps a combination of the two would be desirable. This was evident where cultivation plus 2,4-D sprays gave an appreciable increase in yield of winter wheat in 1951. The advantage is undoubtedly in favor of 2,4-D as far as costs are concerned. However, 2,4-D has certain limitations. It cannot be applied until the crop has reached a safe stage of development, giving the weeds an additional opportunity to deplete the soil moisture. Furthermore, recent investigations have shown that 2,4-D is capable of reducing yields under weed free conditions. However, from the standpoint of 2,4-D vs cultivation, the yield decrease caused by 2,4-D is offset by the damage caused by the weeds within the row under cultivated conditions. Grass and perennial weeds were not present in any of the trials conducted. Under such conditions, cultivation would be more advantageous.

The value of fall cultivation of winter wheat merits some attention, as significant increases in yield were obtained in 1948 from fall and spring cultivation vs only spring cultivation. Whether the increase in yield was due primarily to the control of winter annual weeds, better soil conditions, or a combination of both is hard to ascertain. Evidently, it must have created better sowing conditions as indicated by yields. Russel (17) indicates that weed control at the early stages of crop growth is very important. In the development of the young wheat spike, Kiesselbach (10), suggested ideal growing conditions were necessary for maximum development. It is difficult to imagine that the control of winter annual weeds during the period October 15 to May 1 would increase yields to the extent noted here.

The spring varieties did not react differently to the row spacing as originally expected. In seven trials, when different varieties of oats and barley were tested under spaced conditions, only one significant variety x spacing interaction occurred. This should be sufficient evidence to validate the culture of variety nursery trials in 12-inch or wider rows when normal field planting distances are only 6 inches. It should be remembered that all of the variety spacing testing was conducted under irrigation with oats and barley. Perhaps variety x spacing interactions might occur under dry land conditions.

From the results and previous discussion it is apparent that many of the problems and various aspects connected with wide row spacing of cereal grains have not been solved. Further research should be conducted to determine the possibilities of obtaining increases in protein under dry land conditions, or establish the validity of a source of nitrogen during the later stages of wheat plant development. The merits of chemical weed control and cultivation should be given considerable attention. Trials should be conducted to determine if wide row spacing coupled with cultivation and 2,4-D could not replace the alternate fallow system of cropping commonly used on dry land. Crop varieties should be screened under spaced conditions in order to obtain a variety that will produce maximum yields in the event row spacing practices should become of some value in cultural practice. In the selection of such a variety consideration should be given to its ability to tiller and withstand lodging. The value of row spacing for the establishment of companion crops appears practical. Trials conducted along these lines should be profitable.

SUMMARY

Winter wheat was grown in 12, 18, 24, and double 30 inch rows on an alternate fallow basis from 1948 to 1951. The three wider spacings were cultivated twice annually, the 12-inch spacing was left intact as a check. All spacings were sown at comparable rates of 40, 50, and 60 lbs./a. Yield and test weights were obtained for the four year period. Protein and mature head populations were determined in 1949 and 1950.

Significant increases in yield were obtained from the 18 and 24 inch cultivated spacings over the 12 inch spacing and cultivated double 30 inch spacing. Increases in test weight resulted from the 24 and double 30 inch rows. The per cent of protein was increased by the cultivation treatments. A three year test where 2,4-D was tested against cultivation showed that 2,4-D yield increases were comparable to cultivation increases. By spraying with normal rates of 2,4-D across the cultivated spacings, additional increases in yield were obtained in 1951. Seeding rates had little effect on yield, test weight, and protein due to spacings.

Spring wheat row spacing studies were conducted at three locations in the state. In 1947, spacings of 6, 12, 18, 24, 30, and 36 inches of Thatcher were sown at rates of 30, 40, 50, and 60 lbs./a. at Moccasin and 45, 60, 75, and 90 lbs./a. at Bozeman. Significant reductions in yield were obtained from the wide spacings as compared to the 6 inch rows at Bozeman. The spacing yield differences were not significant at Moccasin although in the same direction. In 1949, Thatcher was grown in a latin square design at Bozeman. Spacings of 6, 12, 18, and 24 inches were sown at normal rates of seeding. Significant reductions in yield were obtained

from the wide spacings. In 1950 and 1951, Rescue was sown at 20, 40, and 60 lbs./a. in 6, 12, 18, 24, and 30 inch rows at Havre. Distinct reductions in yield were obtained from the 6 to 12 and from the 12 to 18, after the 18 inch distance was reached no further reductions in yield occurred. Seeding rates had little effect on yields at any of the locations. Protein determinations made with spring wheat at Havre indicated that the content was not materially affected at any of the spacings.

Barley spacing trials were conducted at Bozeman in 1944, 1947, 1949, 1950, and 1951. Spacings of 6, 12, 18, and 24 inches were sown at normal rates of seeding. During the five year period, three varieties, Compana, Titan, and Glacier were used. Yields of barley were not materially depressed for the wide spacings as few significant yield differences were noted. Compana was better adapted than Glacier and Titan for growing in widely spaced rows in 1950. Testing of half and full rate of seeding of the 6 inch spacing gave reductions in yield for the half rate as compared to the full rate of the 6, 12, and 18 inch rows. Spacing yields were not affected by dates of seeding in 1950. Test weights of barley were not changed by row spacings. Eight varieties of barley were grown in 6 and 12 inch drill rows at Moccasin in 1951. No variety x spacings interactions were noted. The yield of all varieties at 6 and 12 inches were nearly identical.

Oat spacings tests were conducted at Bozeman in 1947, 1949, 1950, and 1951 in latin square designs. Oats was sown at normal rates in rows of 6, 12, 18, and 24 inches. Half and normal rates of seeding were tested with the 6 inch spacing. Over the four year period, six varieties were compared.

Oat yields were depressed more by wide spacing than were barley yields. Test weights were not affected by spacing. Significant variety x spacing interactions were not obtained. The half rate of seeding was lower in yield than the 6 inch full rate and equal in yield to the 12 and 18 inch full rate.

It was found by analysis of the data for Glacier and Bridger over a three year period that no spacing x year interactions occurred. During 1949, when oats, barley, and spring wheat were grown in a latin square design in 6, 12, 18, and 24 inch rows, it was found that depressions in yields due to wide row spacing were greater for spring wheat than were yield depressions for barley or oats.

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APPENDIX A

Table 1. Agronomic data for winter wheat, showing yield, test weight, protein, and head populations from continuous four year row spacing study, Bozeman, 1948 to 1951.

Seeding Rate	12-inch no cultivations					18-inch two cultivations			
	Year	Yield	T.W.	Heads*	Protein	Yield	T.W.	Heads	Protein
40 lbs.	1948	16.7	61.5			23.4	62.0		
	1949	20.3	61.0	18	10.3	23.6	60.5	17	11.6
	1950	20.1	61.5			26.8	61.5		
	1951	6.7	58.5	18	14.5	9.6	58.0	15	15.1
	Average	15.9	60.6	18	12.4	20.9	60.5	16	13.4
50 lbs.	1948	21.1	61.5			29.9	61.5		
	1949	21.1	61.5	17	8.6	25.2	61.0	21	11.1
	1950	22.6	61.0			27.1	61.5		
	1951	9.3	58.0	19	14.4	12.2	57.5	20	15.9
	Average	18.5	60.4	18	11.5	23.5	60.4	21	13.5
60 lbs.	1948	25.3	61.0			30.5	61.5		
	1949	17.4	61.5	17	11.4	27.4	61.0	21	12.0
	1950	19.9	62.0			27.0	61.5		
	1951	5.6	57.0	18	14.5	11.6	58.5	18	15.9
	Average	17.1	60.3	18	13.0	24.1	60.6	20	14.0
Grand Average		17.2	60.4	18	12.3	22.8	60.5	19	13.6

Seeding Rate	24-inch two cultivations					D30-inch two cultivations**			
	Year	Yield	T.W.	Heads	Protein	Yield	T.W.	Heads	Protein
40 lbs.	1948	27.4	62.0			20.2	61.5		
	1949	26.7	61.0	15	12.0	23.3	61.0	15	12.5
	1950	23.4	62.0			22.7	61.5		
	1951	9.5	59.0	15	15.1	6.7	60.0	10	14.9
	Average	22.5	60.9	15	14.6	18.2	61.0	13	13.7
50 lbs.	1948	29.7	62.0			22.0	62.0		
	1949	25.4	61.0	14	12.1	23.1	61.0	16	12.5
	1950	23.5	61.5			22.8	61.0		
	1951	10.3	58.5	15	15.3	6.2	59.5	11	14.8
	Average	22.2	60.8	15	14.2	18.5	60.9	14	13.7
60 lbs.	1948	27.1	62.0			26.6	62.0		
	1949	26.1	61.0	19	11.7	23.7	61.0	19	12.1
	1950	24.7	62.0			23.0	62.0		
	1951	10.7	59.0	13	15.2	7.2	58.0	12	15.2
	Average	24.7	61.0	16	13.5	20.1	60.8	16	13.7
Grand Average		23.1	60.9	15	14.1	19.0	60.9	14	13.7

* Heads per square foot.

** Two six inch rows space thirty inches apart.

Table II. Analysis of variance for winter wheat yield, four year row spacing and cultivation experiment, Moccasin, 1948 to 1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Years	3	6702.26	2234.08	16.24**
Replications	2	37.75	18.86	
Error (a)	6	825.34	137.56	
Plots of Yrs. & Repl.	11	7565.35		
Rows + Rows x Yrs.	8	209.17		
Rates	2	108.43	54.22	25.10**
Years x Rates	6	287.55	47.92	22.19**
Error (b)	8	17.24	2.16	
Plots of Rates	35	8187.74		
Spacings	3	926.82	308.94	51.84**
Years x Spacings	9	214.74	23.86	4.00**
Error (c)	24	143.16	5.96	
Plots of Spacings	47	8850.07		
Rates x Spacings	6	70.52	11.75	1.52
Yrs. x Rate x Spac.	18	67.35	4.74	
Error (d)	48	370.87	7.73	
Total	143	9931.62		

Table III. Analysis of variance for winter wheat test weight, four year row spacing and cultivation experiment, Moccasin, 1948-1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Years	3	81.63	21.10	-
Rates	2	.20	.10	-
Spacing	3	2.12	.71	3.09*
Rates x Spacings	6	.48	.08	-
Years x Rates	6	1.84	.31	
Years x Spacings	9	2.42	.27	
Yrs. x Rates x Spac.	18	3.48	.19	
Error	33	7.74	.23	
Total	47	92.17		

Table IV. Analysis of variance for winter wheat protein, four year row spacing and cultivation, experiment, Moccasin, 1948-1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Tests	2	10,305.39	5,152.69	
Rates	2	71.05	35.53	---
Spacings	3	940.22	313.41	6.62**
Rates x Spacings	6	155.62	25.94	---
Test x Rates	4	141.78	35.39	
Test x Spacings	6	478.61	79.77	
Test x Rates x Spac.	12	421.55	35.13	
Error	22	1,041.94	47.36	
Total	35	12,514.22		

Table V. Analysis of variance for winter wheat head counts, four year row spacing and cultivation, experiment, Moccasin, 1948-1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Tests	2	107.39	53.70	
Rates	2	19.06	9.53	2.24
Spacings	3	196.09	65.36	15.42**
Rates x Spacings	6	26.49	4.44	---
Test x Rates	4	14.91	3.73	
Test x Spacings	6	43.65	7.27	
Test x Rates x Spac.	12	34.72	2.89	
Error	22	93.28	4.24	
Total	35	442.31		

APPENDIX B

Table I. Agronomic data for row spacing studies with spring wheat, showing average yield, test weight, and protein collected for the years and stations as listed.

Moccasin--1947--Thatcher--Duplicated Randomized blocks.

	Seeding rate lbs.	Spacing in inches					
		6	12	18	24	30	36
Bu./A.	60	21.1	18.2	16.5	12.9	14.9	12.6
	50	19.9	17.1	15.6	17.0	16.3	14.7
	40	16.1	16.4	17.1	16.8	15.6	13.2
	30	19.1	17.4	18.2	16.2	16.3	14.6
Test weight		60.8	60.6	61.0	60.8	61.0	60.9

Bozeman--1947--Thatcher--Duplicated Randomized Blocks.

	Seeding rate lbs.	Spacing in inches					
		6	12	18	24	30	36
Bu./A.	90	60.4	58.9	65.2	50.3	45.8	41.1
	75	63.2	55.2	54.2	52.0	43.8	35.3
	60	59.7	54.5	33.3	53.6	44.4	41.6
	45	56.2	51.9	52.8	50.1	43.4	36.8
Test weight		58.9	58.6	58.2	58.5	59.1	58.9

Bozeman--1949--Thatcher--Latin square.

	Seeding rate lbs.	Spacing in inches				
		6-half	6-full	12	18	24
Bu./A.	(Normal)	72.2	79.8	71.9	52.7	28.9
Test weight		61.6	61.8	61.6	51.7	61.8

Havre-1950-51--Rescue--Triplicated Randomized Blocks.

	Seeding rate lbs.	Spacing in inches				
		6	12	18	24	30
Bu./A.	60	19.4	16.5	15.4	14.6	15.0
	40	18.4	16.9	14.5	16.2	15.9
	20	17.3	17.7	15.6	15.3	15.2
Test weight		53.6	53.3	52.8	53.2	54.8
Protein		18.5	18.4	18.6	17.9	17.6

Table II. Analysis of variance for spring wheat yield row spacing study, Moccasin, 1947.

Variation Due:	Degrees of Freedom	Sum of Square	Mean Square	F. Value
Blocks	1	12.61	12.61	
Spacings	5	126.65	25.33	1.16
Error (a)	5	109.52	21.90	
Plots of Spac.	11	248.78		
Blocks	1	12.61	12.61	
Rates	3	10.49	3.50	10.67**
Error (b)	3	.98	.33	
Plots of rates	7	24.08		
Plots of Spac.	11	248.78		
Dev. or rate plots from block	6	11.47		
Rates x Spac.	15	58.25	3.88	1.60
Error (c)	15	30.81	2.42	
Total	47	354.81		

Table III. Analysis of variance for spring wheat yield, row spacing study, Bozeman, 1947.

Variation Due:	Degrees of Freedom	Sum of Squares	Mean Square	Standard Error	F. Value
Blocks	1	.04	.04		
Spacings	5	2,409.40	481.88		35.83**
Error (a)	5	65.26	13.45	3.667	
Plots of Spac.	11	2,476.70			
Blocks	1	.04	.04		
Rates	3	122.64	40.88		Not sig.
Error (b)	3	196.64	65.55		
Plots of rates	7	319.32			
Plots of Spac.	11	2,476.70			
Dev. of rate plots from blocks	6	319.28			
Rates x Spac.	15	72.16	4.81		Not sig.
Error (c)	15	237.43	15.83		
Total	47	3,105.57			

Table IV. Analysis of variance for spring wheat yield, row spacing studies, Bozeman, 1949.

Variation Due:	Degrees of Freedom	Sum of Square	Mean Square	F. Value
Columns	4	112.41		
Rows	4	415.88		
Spacing	4	8,409.76	2,102.44	5.15*
Error	12	4,894.39	407.87	
Total	24	13,932.44		

Table V. Analysis of variance for spring wheat yield, row spacing studies, Havre, 1950-1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Years	1	2.81		
Reps	2	1.38		
Rates	2	.69	.35	
Spacings	4	140.40	35.10	12.76**
Years x Rates	2	24.55	12.28	2.47
Years x Spac.	4	105.87	26.47	9.62**
Rates x Spac.	8	31.74	3.97	1.44
R. x S. x Y.	8	29.98	3.75	1.36
Error	58	159.44	2.75	
Total	89	496.86		

APPENDIX C

Table I. Agronomic data for row spacing studies with barley, showing average yield and test weight, collected at Bozeman for the years as listed.

1944--Ft. Ellis--Five Randomized Reps.				1944--Boz.--Five Randomized Reps.			
		Spacings in inches				Spacings in inches	
Variety		6	12	Variety		6	12
Glacier	Bu./a.	52.1	65.2	Glacier	Bu./a.	34.9	43.9
Compana	Bu./a.	72.2	71.6	Compana	Bu./a.	48.7	33.4

1949--Bozeman--Latin Square

		Spacings in inches				
Variety		6-half	6-full	12	18	24
Glacier	Bu./a.	99.7	104.2	93.6	95.9	85.8
	T. W.	47.4	45.9	46.9	48.1	47.5

1950--Bozeman--Latin Square Split Plot--Normal Date of Seeding.

		Spacings in inches				
Variety		6-half	6-full	12	18	24
Glacier	Bu./a.	63.6	72.3	67.8	61.5	48.7
	T. W.	46.1	48.6	45.4	46.9	46.5
Compana	Bu./a.	75.8	62.0	71.8	67.3	53.7
	T. W.	50.0	50.0	50.4	50.5	50.2
Titan	Bu./a.	41.5	57.5	54.0	48.0	42.1
	T. W.	50.3	50.2	51.1	51.9	51.8

1950--Bozeman--Latin Square Split Plot--Late Date of Seeding

		Spacing in inches		
Variety		6	12	18
Glacier	Bu./a.	74.5	70.5	66.8
	T. W.	45.0	44.1	46.9
Compana	Bu./a.	51.9	74.2	68.5
	T. W.	50.4	50.0	51.0

1951--Bozeman--Triplicated Randomized Blocks

		Spacin in inches				
Variety		6-half	6-full	12	18	24
Glacier	Bu./a.	80.5	72.5	82.0	86.3	76.8
	T. W.	43.0	41.0	42.0	44.0	45.1
Compana	Bu./a.	67.5	61.6	63.9	73.0	
	T. W.	48.7	49.2	48.5	50.0	
Titan	Bu./a.	69.0	64.3	69.6	69.3	
	T. W.	46.6	47.1	44.4	48.5	

Table II. Analysis of variance for yield of barley, row spacing studies, Ft. Ellis, 1944.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Reps.	4	559		
Variety	1	13	13	
Spacings	1	506	506	7.07*
Var. x Spac.	1	284	284	3.98
Error	12	858	71	
Total	19	2,212		

Table III. Analysis of variance for yield of barley, row spacing studies, Bozeman, 1944.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Reps.	4	193		
Variety	1	873	873	15.33**
Spacings	1	194	194	3.41
Var. x Spac.	1	236	236	4.14
Error	12	683	57	
Total	19	2,179		

Table IV. Analysis of variance for barley yield, row spacing studies, Bozeman, 1949.

Glacier Barley				
Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Columns	4	336		
Rows	4	323		
Spacings	4	945	236	3.07
Error	12	925	77	
Total	20	2,530		

Table V. Analysis of variance for barley yield, row spacing studies, two dates, three varieties, five spacings, Bozeman, 1950.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Reps.	2	14,520		
Spacings	2	15,791	7,895	.19
Error (a)	4	170,206	42,552	
Plots of Spac.	8	200,517		
Reps.	2	14,520		
Varieties	1	5,041	5,041	9.03
Error (b)	2	1,116	558	
Plots of Var.	5	20,677		
Reps.	2	14,520		
Dates	1	235	235	.04
Error (c)	2	11,431	5,715	
Plots of Dates	5	26,186		
Spac. x Var.	2	52,490	26,245	4.51*
Spac. x Dates	2	5,911	2,955	.51
Dates x Var.	1	4,444	4,444	.77
Spac. x Var. x Dates	2	3,616	1,808	.31
Error (d)	14	81,478	5,820	
Total	35	366,279		

Table VI. Analysis of variance for barley yield, row spacing studies, normal date of seeding, Bozeman, 1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Reps.	2	5,422		
Spacings	4	100,304	25,076	1.81
Error (a)	8	111,007	13,876	
Plots of Spac.	14	216,733		
Varieties	2	165,272	82,636	17.08**
Var. x Spac.	8	56,480	7,060	1.46
Error (b)	20	96,781	4,839	
Total	44	535,266		

Table VII. Analysis of variance for barley yield, row spacing studies, Bozeman, 1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Reps.	2	126,100		
Spacings	3	31,932	10,644	
Error (a)	6	99,935	16,656	
Plots of Spac.	11	257,967		
Varieties	2	56,531	28,266	9.95**
Var. x Spac.	6	37,745	6,291	2.21
Error (b)	16	45,482	2,843	
Total	35	297,732		

Table VIII. Analysis of variance for three years of Glacier barley yield, Bozeman, 1949-1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Reps.	2	3,641		
Years	2	536,559	268,280	27.81**
Spacings	4	64,505	16,126	1.67
Yrs. x Spac.	8	56,860	7,108	---
Error	28	270,045	9,644	
Total	44	931,610		

APPENDIX D

Table 1. Agronomic data for row spacing studies conducted with oats at Bozeman, showing yield and test weights of varieties used for the years as listed.

1947--Tripllicated Randomized Blocks.

Varieties		Spacings in inches			
		6	12	18	24
Bridger	Bu./a.	140.3	136.5	128.0	115.6
	T. W.	36.1	35.8	35.0	34.9
Gopher	Bu./a.	132.7	125.9	121.8	101.0
	T. W.	36.4	35.7	35.4	36.1
Overland	Bu./a.	121.2	118.8	121.4	106.6
	T. W.	35.5	34.6	35.3	35.6

1949--Latin Square Split Plot Design.

Varieties		Spacings in inches				
		6-half	6-full	12	18	24
Bridger	Bu./a.	124.6	110.7	113.1	102.6	108.0
	T. W.	42.2	42.5	42.4	42.5	42.4
Gopher	Bu./a.	112.4	120.4	106.0	102.1	99.1
	T. W.	41.6	41.5	41.5	41.7	41.7

1950--Latin Square Split Plot Design.

Varieties		Spacings in inches				
		6-half	6-full	12	18	24
Bridger	Bu./a.	107.0	106.6	94.5	95.9	95.4
	T. W.	38.7	38.4	37.8	37.9	38.0
Gopher	Bu./a.	111.6	108.6	97.8	98.1	98.0
	T. W.	36.9	36.5	36.3	37.4	36.9
V-R x Ban.	Bu./a.	108.2	113.4	102.6	98.9	88.9
	T. W.	37.0	36.8	36.7	36.2	37.0

1951--Latin Square Split Plot Design.

Varieties		Spacings in inches				
		6-half	6-full	12	18	24
Bridger	Bu./a.	114.1	116.2	111.4	112.0	103.9
	T. W.	36.6	36.2	36.3	36.2	36.7
Mission	Bu./a.	94.4	93.5	102.3	96.1	90.5
	T. W.	36.6	36.7	37.2	36.2	37.3
C. I. 6611	Bu./a.	101.5	111.5	99.1	96.6	96.3
	T. W.	36.6	35.8	35.6	36.1	36.6

Table II. Analysis of variance for yield of oats, row spacing studies, Bozeman, 1947.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Replications	2	3,568		
Columns	2	12,924		
Varieties	2	31,586	15,793	1.79
Error (a)	2	17,659	8,830	
Plots of Var.	8	65,737		
Replications	2	3,568		
Spacings	3	82,349	27,450	7.07**
Error (b)	6	23,286	3,881	
Plots of Spac.	11	109,203		
Plots of Var.	8	65,737		
Error (b) + Spac.	9	105,635		
Var. x Spac.	6	9,299	1,550	---
Error (c)	12	85,959	7,163	
Total	35	266,630		

Table III. Analysis of variance for yield of oats, row spacing studies, Bozeman, 1949.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Replications	4	14,829		
Varieties	1	194	194	---
Error (a)	4	3,249	812	
Plots of Var.	9	18,272		
Replications	4	14,829		
Columns	4	617		
Spacings	4	2,045	511	1.65
Error (b)	12	3,728	311	
Plots of Spac.	24	21,219		
Plots of Var.	9	18,272		
Col. + Spac. + Error (b)	20	6,390		
Var. x Spac.	4	766	164	---
Error (c)	16	2,789	175	
Total	49	28,226		

Table IV. Analysis of variance for yield of oats, row spacing studies, Bozeman, 1950.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Replications	4	1,460		
Columns	4	2,207		
Spacings	4	2,994	749	2.89
Error (a)	12	3,103	259	
Plots of Spac.	24	9,764		
Replications	4	1,460		
Varieties	2	125	63	---
Error (b)	8	700	87	
Plots of Var.	14	2,285		
Plots of Spac.	24	9,764		
Var. + Error (b)	10	825		
Var. x Spac.	8	471	60	---
Error (c)	32	3,705	116	
Total	74	14,765		

Table V. Analysis of variance for yield of oats, row spacing studies, Bozeman, 1951.

Variation Due:	Degrees of Freedom	Sums of Squares	Mean Square	F. Value
Replications	4	1,253		
Columns	4	1,495		
Spacings	4	853	213	2.95
Error (a)	12	868	72	
Plots of Spac.	24	4,470		
Replications	4	1,253		
Varieties	2	3,357	1,679	11.99**
Error (b)	8	1,125	141	
Plots of Var.	14	5,735		
Plots of Spac.	24	4,470		
Var. + Error (b)	10	4,482		
Var. x Spac.	8	745	93	1.10
Error (c)	32	2,705	85	
Total	74	12,401		

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