AN ABSTRACT OF THE THESIS OF

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(Name) (Degree) (Major)

Date thesis is presented May 13, 1969

Title THE EFFECT OF SEEDING RATE ON YIELD AND YIELD COMPONENTS OF TWO WINTER WHEAT VARIETIES

Redacted for Privacy

Abstract approved
(Major professor)

Wheat is an important cereal crop in the Willamette Valley of Oregon and the stiff-strawed, high-yielding varieties are the predominant types grown. Observation of the effect of seeding rates on the yield and yield components are useful in determining which of the components contributes most to the yield of a winter wheat variety and in developing optimum seeding rate recommendations.

The experiments were conducted in 1963-1964, 1964-1965, and 1965-1966. The purpose of these studies was to determine the effect of various seeding rates on the yield and yield components of two winter wheat varieties and to find the optimum seeding rates for these varieties. A further objective was to determine if reasonable yields could be obtained from low rates of seeding for both varieties. The yield was measured in terms of bushels per acre. The yield components studied were (1) the number of spikes per unit area, (2) number of spikelets per spike, (3) number of kernels per

spike, and (4) the weight of 100 kernels. The results were obtained and comparisons were made between the two varieties and their performance over a three-year period.

There was considerable fluctuation in the yields involving both varieties for all seeding rates in the different seasons. The 1966 season was most favorable for Gaines and the 1964 season for Druchamp. Druchamp gave higher yields than Gaines for all seeding rates.

The number of spikes per unit area for both varieties was most effected by differences in seeding rate in each year, while the other components showed no response.

High yield of Druchamp was due to the result of more spikes per unit area, heavy kernels, and resistance to stripe rust. The yield of Gaines was the result of more kernels per spike.

The higher seeding rates for both varieties produced the highest yields.

THE EFFECT OF SEEDING RATE ON YIELD AND YIELD COMPONENTS OF TWO WINTER WHEAT VARIETIES

by

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A Thesis

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1967

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Typed by Gloria M. Foster

ACKNOWLEDGMENTS

I wish to express my sincere appreciation and thanks to the following:

Dr. Wilson H. Foote, my Major Professor, who in spite of all his other heavy responsibilities found time to inspire and guide me in a friendly manner throughout the course of my graduate program.

Dr. Warren E. Kronstad for his friendly advice and constant inspiration throughout the course of my graduate program.

Col. Indu. S. J. B. Rana and Mrs. Manju Rani Rana, my parents, and Mrs. Jaya S. Rana, my wife, for their firm, never-failing support and inspiration throughout my studies in America.

Mrs. Kamal Shah, Rt. Honorable Member of the National Panchayat of Nepal, my aunt, who not only encouraged me to complete my studies, but made it possible for me to be here.

Mr. Garry Smith for his help in statistical work.

Mrs. Gloria Foster, who so kindly agreed to type this manuscript at the eleventh hour.

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INTRODUCTION

Farmers are constantly striving to produce more grain per unit area of land. Plant scientists are endeavoring to find better yielding crop varieties and better rotations and cultural methods which will help the farmers produce more grain. These workers have made great progress in the improvement of wheat production, and in recent years wheat growers have had the opportunity to choose a variety from several different types. Some of the varieties differ considerably in plant characteristics and yielding ability. These differences in plant characteristics and yield ability often raises questions relative to certain cultural practices. One question could well be: what is the optimum seeding rate for a particular variety?

Investigations have been conducted to determine what characters of the plant are most closely associated with yield. It was realized that yield was the final result of a large number of interacting environmental and plant factors. As the wheat plant stands in the field at harvest time, some of the more important characters determining yield are reported to be the number of spikes per unit area, number of kernels per spike, number of spikelets per spike, and weight per 100 kernels. These are commonly referred to as the yield components. Studies have determined the influence of seeding rate on yield but have generally ignored the influence of seeding rate on the yield components. Conversely, determinations of the yield components have not been based on planned variations in plant density. Any increase in yields that may be gained by varying the rate of seeding is a relatively inexpensive advantage to the grower.

The objectives of these experiments were to find out how the different rates of seeding influenced yield and the yield components of Gaines and Druchamp (*Triticum aestivum* L.) winter wheat varieties during three seasons. Other objectives were to determine the optimum seeding rates for both varieties and to see if low seeding rates of these varieties could give satisfactory yields.

REVIEW OF LITERATURE

The majority of the experiments regarding the effect of seeding rate on the yield of wheat, barley, and oats were conducted during the period of 1909 to 1936. In recent years, several experiments have been conducted to determine the influence of seeding rate on the components of yield of wheat, barley, and oats.

Relation of seeding rate and yield

The results of experiments conducted with different rates of seeding of both winter and spring wheats have shown that as seeding rates increased, there was a corresponding increase in yield. Seeding rates ranging from 10 to 50 pounds per acre in these studies were regarded as low and above that as high. The experimental results of Atkinson (1917), Bergh (1915), Brown and Down (1957), Dowling (1908), Coffman (1925), Georgeson, Burtis and Shelton (1892), Georgeson (1896), Goldel (1935), Guitard, Newman and Hoyt (1961), Hickman (1897-1901), Hutchison (1936), Kirna *et al*. (1963), Martin (1926), Martin and Leonard (1962), Pitt (1916), Salmon and Taylor (1939), Voelker (1904), and Woodcock (1933), supported this conclusion.

Bracken (1930), experimenting with varying seeding rates of winter wheat, showed that between two and three pecks there was a yield difference of two bushels and between seeding rates of three and four pecks and four to eight pecks, the increase in yield was smaller.

However, Coffman (1925) found from experiments in 1915 with white spring wheat and in 1916 with hard red spring wheat sown at rates ranging from two to six pecks to the acre, that rates of seeding within reasonable limits affected the yields very slightly. Fikry (1937) found that difference in rates of seeding per unit area did not result in a significant difference in yields of wheat. Similar results were also reported by Hudson (1941), Jain et al. (1963), Kiesselbach, Anderson and Lyness (1934), and Nelson and Osborn (1915).

In contrast to the results of the previous authors, Forster and Vasey (1930), in experiments with 45, 60, 75, 90, 120, and 180 pounds of wheat per acre, found that 45 pounds per acre gave the highest yield, the yield of 60 and 75 pounds per acre rate seeding was the same, and there was a decrease in yield from 90 to 160 pounds per acre rates of seeding. The difference between 120 and 180 pounds per acre was large. Similar results were reported by Dowling (1908), Hays (1893). Curtis and Haus (1967) reported that in cool areas at high altitudes, such as central Colorado, wide rows with low seeding rates gave the higher yield of wheat.

Guitard, Newman and Hoyt (1961) found from experiments conducted with wheat, barley, and oats over several seasons, that variety and season did not alter appreciably the influence of seeding rate on yield. Martin (1926) concluded from experiments with wheat at 14 experiment stations during three or more years with varying rates of seeding, that the optimum rate of seeding for wheat was practically independent of soil type, moisture, locality, date of seeding, cultural treatment, and variety.

Downing (1911), in experiments with two varieties of wheat and three seeding rates of 20, 30 and 40 pounds per acre, and with mid-season and late planting, found that for the mid-season planting, the 40 pounds per acre seeding gave the highest yield and yield increased as the seeding rate increased. The late planting yield of both varieties were reduced as compared to mid-season planting, but there was not much difference between the different rates of planting. Jardine (1916) observed from three years of trials at Manhattan, Kansas with 2, 4, 6, and 8 pecks per acre rate of seeding, and different dates of seeding winter wheat that there was a distinct relation between rate and date of seeding on the yield of winter wheat. Martin (1926), in experiments with wheat conducted over a period of years, found that early seeding of spring wheat and medium seeding of winter wheat were most favorable. Stevens (1965) recommended seeding rates for normal sowings (May-June) and late sowing (July), for Queensland conditions of 40-50 and 60-70 pounds per acre, respectively, for wheat. He also found that differences in sowing rate had little effect on yields when compared with the effect of differences in sowing date.

Leighty and Taylor (1927), in experiments with the Purplestraw variety of winter wheat at Arlington, Virginia for a six-year period (1919-1924), with seeding rates of 2, 3, 4, 5, 6, 7, and 8 pecks per acre sown at three different dates (September 15, October 5, and October 30) with different seedbed preparations, found that no significant differences in bushel weight of grain resulted from the different rates of seeding or from the different seedbed preparations. The rate of 6 pecks per acre returned the highest net grain yield. Seeding rates of 2 and 3 pecks per acre produced significantly less grain than the 6 pecks per acre rate, and yield from 4 pecks per acre produced slightly less net yields of grain than the 6 pecks per acre rate. Slightly greater increase in yields were obtained from sowing larger quantities of seed per acre when the seeding was early than when late.

The effect of location and seeding rate was demonstrated by the experimental results of Williams (1920) who conducted trials with several rates of seeding of wheat ranging from 3 to 10 pecks per acre for several years at four locations in Ohio. When all other factors were kept uniform, he found that at two locations, 8 pecks per acre rate gave the largest yield. At the other two locations, 7 pecks per acre rate gave the largest yield. While Stephen, Wanser and Bracken (1932), from experiments with wheat under dryland conditions in the Pacific Northwest, found no great differences in yield from rates of seeding of 2 to 8 pecks per acre, they came to the conclusion that 5 pecks per acre was the optimum rate. In contrast, Thatcher, working in Ohio, has summarized considerable data on the rates of seeding wheat under more humid conditions. He obtained very little difference in yields from all rates of 60 pounds or over per acre. He concluded 90 pounds to be the optimum rate.

The results of experiments reported by Atkinson (1917), Guitard, Newman and Hoyt (1961), Robertson _et al._ (1936), and

Olsen et al. (1940) with different rates of seeding barley, indicated that high seeding rates ranging from 90 to 120 pounds per acre rates gave higher yields. Guitard, Newman and Hoyt (1961) found that the optimum seeding rates for barley varied with location. But Harlan (1925) stated that the best rate of seeding for barley varied widely with the season and maximum yields were obtained at rates covering a wide range. A single plant accomodated itself to its individual conditions. If it was crowded by other plants, it produced only one or two tillers, but in an open space it may produce several. The best seeding rates were usually heavy enough to insure that the thinnest spots on the field would have enough plants for a maximum yield. Thayer (1938) used four varieties of barley and 1/2, 1, 1-1/2, 2, 2-1/2, and 3 bushels per acre seedings and found that for all varieties of barley, 1/2 bushel per acre was too light and 3 bushels per acre was too heavy to obtain maximum yields. The test indicated that seeding small seeded varieties of barley at more than 1-1/2 bushels per acre was wasteful of seed and reduced yield, and that seeding large seeded strains below 2 bushels per acre was lessening the chances of obtaining maximum net yields. Similarly, Thayer and Rather (1937) conducted studies involving six rates of sowing, eg. 1/2, 1, 1-1/2, 2, 2-1/2, and 3 bushels of barley per acre with Spartan, Michigan Two-Row, Glabron, and Wisconsin No. 38 during the seasons of 1932 to 1934. They found that the rates of seeding which gave maximum acre yield was not a single rate (because varieties were inherently different) but a rather wide range. For Glabron and Wisconsin No. 38 barley, it was from 1 to 2-1/2 bushels per acre; for Michigan Two-Row, 1-1/2 to 2-1/2 bushels per acre; and for Spartan, 2 to 3 bushels per acre. These results indicate that the varieties must be considered in recommending seed rates for higher yields of barley.

Sprague and Farris (1931) used two methods of sowing barley in which seeds were sown evenly spaced in such a manner that each foot of row received kernels equivalent in number to a seeding rate of 10 pecks per acre and in the variable method where the average rate of seeding was 10 pecks per acre. Consecutive sections of the row were planted at different seeding rates equivalent to 6, 9, 11, and 14 pecks of seed to the acre and a random distribution of the four rates were provided to determine the relation between uniformity of spacing seed, development, and yield of the crop. The results were that the yield of grain and straw increased with seeding rate when the component rates of the variable method were considered. However, the increase in yield was far from proportional to the plant density because of the reduced development for individual plants at the closer spacing. Unlike the results of the above mentioned experiments, the results of this latter experiment indicates that low seeding rate of barley would give higher yields.

Burnett (1928), Coffman (1925), Nelson and Ruzek (1940), Wiggans and Frey (1957), and Zook and Burr (1923), conducted experiments with oats with varying seeding rates and their results were similar in that yield increased with increasing seeding rates and the highest yields were obtained with seeding rates ranging from 90 to 150 pounds per acre, while McClelland (1931) concluded that slight differences in rates resulted whether seed was counted, weighed or measured. In a test of rate of seeding the fine, medium, and coarse seeded oats with from 100 to 700 seeds per row, the results showed that 400 or more seeds per row gave better yields.

Relation of seeding rate and components of yield

Poehlman (1959) stated that yield was effected by all the environmental conditions influencing the growth of the wheat plant as well as the plant's heredity. The inherent capacity for yield may be expressed through such morphological features of the plant as tillering, length and density of the spike, number of grains per spikelet, or size of the grain. But none of these physical components of yield can by itself be considered as an index to yield. Grafius (1956a) had stated that yield of small grain varieties like wheat and oats could be likened to a box. To represent the three dimensions of the box, one would use (a) number of spikes per unit area, (b) the number of grains per spike, and (c) the average weight per grain. The volume of the box would be the yield of the variety and it was determined by the product of these components. An increase in any one of the three components could result in an increase in the total yield, provided there was no corresponding decrease in the other two components.

Guitard, Newman and Hoyt (1961), McNeal (1960), Quisenberry (1928), Kiesselbach and Sprague (1926), and Waldron (1941), from their experiments with wheat and varying rates of seeding, reported that the yield component number of spikes per unit area had the greatest influence on yield while the number of kernels per spike was of secondary importance. Arny and Garber (1918) concluded that subject to the environmental conditions under which they worked with wheat, kernels per spike was closely associated with yield rather than number of tillers. The average weight of kernels was somewhat less associated with yield. But Hudson and Stafford (1934) concluded that where the rates of seeding of wheat were in excess of the optimum, no appreciable difference in yield and bushel weight occurred. Johnson, et al. (1960), and Kronstad and Foote (1964), in their experiment with wheat, found that yield was increased by more spikelets per spike and more kernels per spikelet in shorter varieties of winter wheat. Grantham and Groff (1961) reported that (a) the number of sterile spikelets per spike in wheat was directly affected by the rate of seeding or the spacing of plants. The more space allowed each plant, the smaller the number of sterile spikelets. (b) The beardless varieties of wheat have a higher percentage of sterile spikelets than bearded varieties. (c) Yield of grain was correlated to a fair degree with low percentage of sterile spikelets. (d) The weight of kernel and the quality of grain was correlated to a considerable degree with a low percentage of sterile spikelets. Similarly, Myers (1910) from his study from a mixed population of the variety of wheat known as Dawsons Golden Chaff, found that (a) there was a slight positive correlation between number of tillers and the average weight of kernels. That is, the majority of the heavier kernels were produced by the plants with larger numbers of tillers. (b) In general, taller plants produced the heavier kernels.

Coffman (1925), Frey (1959), Grafius (1956b), Guitard, Newman and Hoyt (1961), and Leighty (1910), found that increased seeding rate of oats resulted in higher yields, which as in wheat was due chiefly to the production of greater number of spikes per unit area and to a lesser extent the number of kernels per spike. Love and Leighty (1914), from several years of experimentation with oats, found that environmental conditions such as existed in different years, caused changes in the mean. Conditions that generally resulted in reduction of plant yield also resulted in reduction of height, number of kernels, and number of tillers, but increased size of kernel.

Bonnett and Woodworth (1931) experimented on a yield trial analysis of three varieties of barley and observed that (a) yield per unit area was more closely associated with the number of spikes than with the number of plants per unit area. Average yield per plant depended upon the average number of spikes per plant and the average weight of grain produced per spike. (b) Average weight of grain produced per spike varied with variety, number of spikes per plant, class of tillers, and average kernel weight. Guitard, Newman and Hoyt (1961) reported that for barley, although number of spikes per unit area did influence yield most, the second component was number of kernels per spike and not the weight of kernels as above. Thayer (1938) and Thayer and Rather (1926), in trials with barley, reported that (a) as the rate of seeding was increased from 1/2 to 3 bushels per acre, the number of plants per unit area increased, but tillering, length of tiller, length of spike, number of kernels per spike, and weight of 1000 kernels decreased; (b) an increase in the rate of seeding beyond the optimum range caused so great a reduction in growth characteristics, particularly tillering, length of spike, and number of kernels per spike, that acre yields were reduced.

Relation of size and weight of seed to yield

Arny and Garber (1918), Bolley (1900), Cobb (1903), Grantham and Groff (1916), Grenfell (1901), Kiesselbach (1924), Love (1910), Waldron (1941 and 1942), and Zavitz (1912), from their experiments with wheat, were unanimous in their report that large plump seed outyielded small plump seed. Hays, Aamodt and Stevenson (1927) stated that (a) percentage plumpness of grain and yield were correlated to the extent of +0.5101 in spring wheat and +0.6228 in winter wheat, and (b) the bearded selections of wheat produced plumper grain on the average than the awnless ones. Kiesselbach and Helm (1917), from several experiments, found that yields from large seed were higher than yields from small seeds of wheat, but when the individual seeds were space-planted to permit maximum plant development, small seeds outyielded the large seeds in grain and straw by 72 percent. But Quisenberry (1928) and Voelcker (1901) found no difference in yields of wheat between large and small grain.

Fikry (1937) experimented with wheat seeds of varying thickness below 1/2 to 3 mm with weights from 0.75 to 4.9 grams per 100 kernels. He found that (a) tillering capacity gradually increased from plantings in which the seed ranged from thin to thick; (b) the height of plant from the thick seed was 50 percent taller than the thinnest seed; (c) when kernels of a mixed weight were planted in comparison with a fixed number of kernels, yields of the plants from the middle ranges of seed thickness more than offset the yield secured from rows planted with seed of maximum thickness; and (d) kernel weight of harvested seed increased significantly with an increase in size of parent seed.

Kiesselbach (1924) and Zavitz (1912), in their experiments with oats, found that large and plump seeds gave higher yields than smaller seeds. Similarly, heavy seeds outyielded lighter seeds. On the other hand, Grafius (1956b), and Love and Leighty (1910) found that the size of the oat seed did not influence yield.

Bonnett and Woodworth (1931) found in trials with barley that if seeded at the same rate (pounds per acre), a small seeded variety may outyield a large seeded variety on account of the larger number of plants per unit area rather than because of superior plant yield characteristics.

<u>Relation of plant height and yield</u>

Arny and Garber (1918), in their experiments with wheat, found that there was a distinct tendency for greater average height of tillers to be accompanied by greater average length of spike, number of kernels and higher grain yields. Clark and Hooker (1926), Fikry (1937), Grantham and Groff (1916), Grantham (1917), Hays, Aamodt and Stevenson (1927), Love (1910), and Myers (1910), in their trials with wheat, had results which indicated that the plant height did have an influence on yield. But Johnson et al. (1966) found that shorter varieties of wheat yielded more than the taller ones.

Leighty (1910) showed that tall plants of oats were better yielders than shorter ones; that all tillers of tall plants were on the average heavy yielders. Love and Leighty (1914) obtained similar results with oats.

Relation of tillers and yield

Roberts (1910) reported that tillering was, in all probability, the most important vegetative phenomenon in the growth of wheat plants, as far as yield was concerned, since it was extremely highly correlated with the weight of grain per spike. A better growing season reduced variability in pure strains as far as the characters tiller length, spike length, number of grains per spike, number of tillers per plant, and weight of grain per spike. Engledow and Ramiah (1930) found that early tillering of wheat was an important index to yield. Tillering of wheat influencing yield had also been reported by Arny and Garber (1918), Dowling (1908), and Grantham (1917). But Papadakis (1940) proved that varieties of wheat with dense early growth could not attain the high grain yields of varieties with less dense early growth; the first were better adapted to poor soils and poor conditions. A high grain yield necessitated favorable conditions during early growth, but not so favorable as to induce a density exceeding the critical one; it also necessitated very favorable conditions for grain formation. He further proved that moderately high level of fertility during early growth and a very high level during grain formation was needed for high grain yield.

Leighty (1910) showed that as the number of tillers per plant of oats increased, the amount of grain obtained from each tiller increased. Kaukis and Reitz (1955) and Love and Leighty (1914) have indicated that tillering did influence yield. Similar results for barley have been reported by Thayer and Rather (1937).

Smith (1925), from the data obtained from 8,000 observations of 64 varieties of spring wheat, oats, and barley at the Dickson Substation during the years 1909 to 1919, found the following: (a) There was no uniformly close relation between extent of tillering and yield between different varieties of cereals. (b) Durum wheats yielded more but tillered less than varieties of common wheat of the blue stem group. (c) Comparing three crops, oats yielded most and tillered best, and barley slightly exceeded wheat in both tillering and yield. (d) Comparing different years, mean tillering, mean yield, and rainfall from May 16 to July 15, all were closely correlated, showing the close relationship that existed between rainfall and tillering and between tillering and yield.

The influence of seeding rate on yield in wheat is very complex, as indicated by the works of the different authors cited. It was observed that the effect of the seed rate varies from location to location, with varieties and environment. No single rate can be said to be optimum for different regions or from season to season. Yet, on the basis of the seed size, weight and the quality of seed, a general range of seeding rate can be safely recommended to obtain a favorable yield.

MATERIALS AND METHODS

The experiments reported in this study were conducted during the growing seasons of 1963-64, 1964-65, and 1965-66. Plantings were made on the Hyslop Agronomy Farm located about six miles north of Corvallis, Oregon. The soil on the Agronomy Farm is classed as a Woodburn silt loam, which is typical of the valley floor soils of the Willamette Valley.

The experimental areas were summer fallowed before each planting and the planting dates for the three years were October 18, 1963, October 9, 1964, and October 8, 1965. Each of the plots was sprayed with 1.6 pounds of Karmex per acre after seeding for weed control and fertilized in the early spring with 60 pounds of nitrogen per acre.

Two winter wheat varieties, Gaines and Druchamp (*Triticum aestivum* L.), were used in these experiments. These varieties are presently widely grown in the Willamette Valley. A brief description of these varieties follows:

Gaines C.I. 13448 is a short-strawed (semi-dwarf), awned, white winter wheat. Gaines is only moderately resistant to the present races of stripe rust (*Puccinia glumarum*) found in the Willamette Valley.

Druchamp C.I. 13273 is a standard height, stiff-strawed, awnletted, high yielding white winter wheat. Druchamp is highly resistant to the prevalent races of stripe rust in the Pacific Northwest.

The seeding rates were obtained by determining the number of kernels per square foot that would be required to equal the seeding rate of one pound per acre. The number of kernels per square foot was then used as a base for the other rates. The number of kernels per square foot for the various seeding rates were as follows:

Seeding rate pounds per acre	Number of kernels per square foot	Total number of kernels
10	3	48
20	6	96
30	9	144
40	12	192
50	15	240
60	18	288
70	21	336
80	24	384
90	27	432
100	30	480
110	33	528
120	36	576
130	39	624

Seed for the experiments was carefully selected to avoid undersized and cracked kernels. The kernels were counted and packaged separately for each row. The seed was treated with Arasan prior to seeding.

The plots in 1963 and 1964 consisted of three rows per plot with the rows being 16 feet, and with one foot spacing between rows.

The plots in 1965 were four rows, one foot apart and 16 feet long. The three row plots were seeded by hand with a single-row cone type seeder. The four row plots were seeded with a machine-pulled four-row cone seeder. The cone seeders were calibrated to distribute the required number of kernels in each row.

The experiments were designed as a randomized block with the variety and seeding rate treatments randomized within each replication. Five replications were used in 1963-64 and 1964-65, while in 1965-66 four replications were used.

The following observations were obtained on each plot:

Spikes per unit area: A metal U-shaped frame was designed with two-foot spacing between points. A section of the center row of each plot was selected randomly and the frame carefully placed at the base of the plants. By raising the frame up to the spikes, it was then possible to quickly count the number of fully developed spikes between the points. Two counts were made per row and the average obtained. These counts were then recorded as the number of spikes per unit area.

Number of spikelets: A random sample of ten spikes was selected from each plot. The number of fully developed spikelets were counted for each spike and the average determined.

Number of kernels: Each of the ten spikes were hand-threshed and the number of kernels counted and the average number per spike determined.

Kernel weight: Samples of two to five 100-kernel lots were counted and the weights to the nearest milligram obtained.

Yield in bushels per acre: A measured area of each plot was cut by hand and the grain threshed and cleaned. The yields were determined by converting the weights from grams per plot to bushels per acre by the appropriate conversion factor.

Analysis of the data: Analyses of variance were used to determine the differences for yield and the yield components for each year. Least significant differences were used to find the significance between individual seeding rate means.

RESULTS

Trials were conducted in 1964, 1965, and 1966 with two winter wheat varieties, Gaines and Druchamp, and with seeding rates of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, and 130 pounds per acre.

The data were analyzed using the randomized block design analysis of variance method and the mean square values of yield and the yield components of the two winter wheats are given in Tables I, II, and III. The least significant difference values at the 5 percent level for the individual yield components and yield were computed and reported in the respective tables.

Yield components

The results of the three years experiments for the number of spikes per unit area are given in Table IV and the averages of three years are graphically presented in Figure 1. The average of three years for both varieties shows a constant increase of this component with corresponding increase in the seeding rate. Druchamp had a slightly higher number of spikes per unit area than Gaines across all seeding rates, except at 10, 50, and 60 pounds per acre rates where it was slightly less. In the three different years under consideration, there were noticeable fluctuations with both varieties for the number of spikes per unit area.

Table I. Summary of the mean squares for the seeding rate experiment for yield and yield components of two winter wheat varieties in 1964

Gaines

Sources of variation	Yield	No. of spikes/2 ft.	No. of ker/spike	No. of spikelets/spike	Wt. per 100 ker
Replication	127.00	96.75	20.70	1.25	.03
Rates	274.00**	1452.00**	32.00**	1.75*	.05
Rep x Rates	77.46	108.10	8.26	.62	.05

Druchamp

Sources of variation	Yield	No. of spikes/2 ft.	No. of ker/spike	No. of spikelets/spike	Wt. per 100 ker
Replication	226.20	147.50	39.70**	1.25	.06
Rates	1044.80**	4706.50**	35.60**	3.73	.41**
Rep x Rates	106.42	337.96	12.20	1.93	.08

*Significant at the 5 percent level
**Highly significant at the 1 percent level

Table II. Summary of the mean squares for the seeding rate experiment for yield and yield components of two winter wheat varieties in 1965

Gaines

Sources of variation	Yield	No. of spikes/2 ft.	No. of ker/spike	No. of spike-lets/spike	Wt. per 100 ker
Replication	198.35	130.17	38.98*	2.94*	.05
Rates	789.45**	214.18	41.13**	1.66**	.86**
Rep x Rates	115.12	222.19	13.27	.80	.27

Druchamp

Sources of variation	Yield	No. of spikes/2 ft.	No. of ker/spike	No. of spike-lets/spike	Wt. per 100 ker
Replication	2608.30**	1233.97**	29.20	7.12**	.10
Rates	1986.60**	2319.22**	24.34	1.41	.63**
Rep x Rates	227.30	232.64	24.20	1.01	.08

*Significant at the 5 percent level
**Highly significant at the 1 percent level

Table III. Summary of the mean squares for the seeding rate experiment for yield and yield components of two winter wheat varieties in 1966

Gaines

Sources of variation	Yield	No. of spikes/2 ft.	No. of ker/spike	No. of spikelets/spike	Wt. per 100 ker
Replication	153.93	99.82	164.56**	3.10**	.16
Rates	137.18	818.62**	70.24**	2.56**	.09*
Rep x Rates	94.33	96.31	14.18	.54	.04

Druchamp

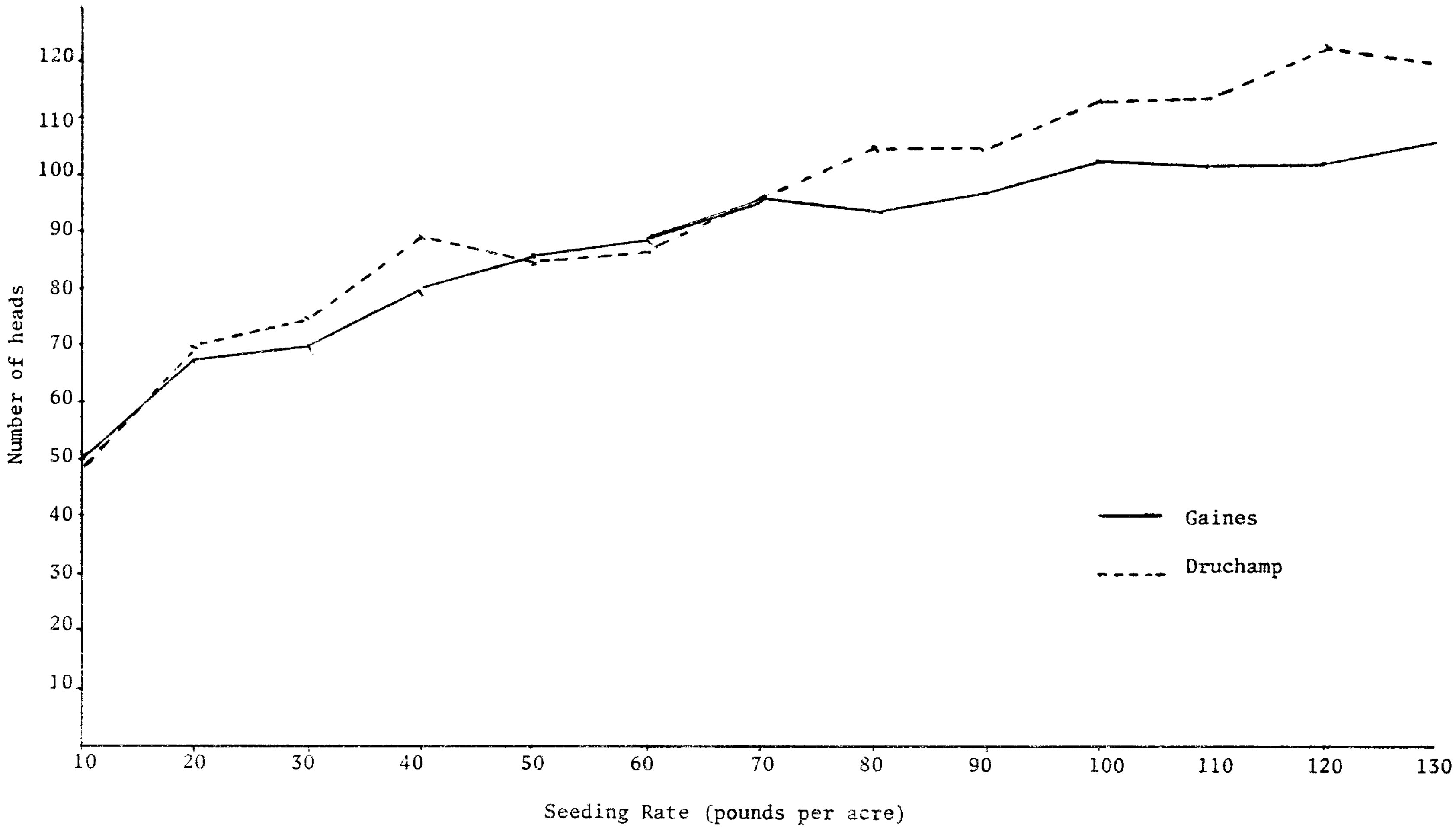
Sources of variation	Yield	No. of spikes/2 ft.	No. of ker/spike	No. of spikelets/spike	Wt. per 100 ker
Replication	108.16*	25.00	12.28	.38	.04
Rates	79.52**	820.04**	61.23*	1.15*	.09
Rep x Rates	24.84	97.06	15.69	.64	.15

*Significant at the 5 percent level
**Highly significant at the 1 percent level

Table IV. Summary of average number of spikes per unit area for Gaines and Druchamp winter wheats at various seeding rates of pounds per acre for three years

Seeding rate	Gaines 1964	Gaines 1965	Gaines 1966	Gaines Av.	Druchamp 1964	Druchamp 1965	Druchamp 1966	Druchamp Av.
10	48	40	61	50	56	26	61	48
20	66	60	79	68	93	48	70	70
30	79	52	78	70	91	60	74	75
40	85	67	87	80	114	64	90	89
50	91	78	88	86	121	56	78	85
60	89	83	95	89	105	74	82	87
70	90	100	97	96	120	73	96	96
80	98	84	99	94	140	83	91	105
90	97	88	106	97	147	72	96	105
100	97	99	113	103	158	81	99	113
110	109	99	98	102	144	90	107	114
120	107	98	102	102	160	98	107	122
130	104	108	107	106	148	106	107	120
LSD(5%)	13	NS	10		17	19	10	

Figure 1. Average number of spikes per unit area for the two winter wheat varieties at various seeding rates



The three-year averages of the number of spikelets per spike are given in Table V and shown graphically in Figure 2. The different rates of seeding for both varieties showed little or no effect except for a slight reduction for the higher rates of seeding. Both varieties produced slightly more spikelets per spike in the 1966 season than in the 1964 and 1965 seasons.

The three-year averages for the number of kernels per spike are given in Table VI and shown graphically in Figure 3. Gaines had consistently higher number of kernels per spike than Druchamp. Generally, both varieties produced more kernels per spike with low seeding rate than with higher seeding rate, with a few exceptions in the different years. In the 1964 and 1965 seasons, the difference between the two varieties in this characteristic was not as pronounced as in the 1966 season. In that year, Gaines had considerably higher number of kernels per spike than Druchamp.

The three-year averages for the weight in grams of one hundred kernels for the two varieties are given in Table VII and shown graphically in Figure 4. The average for three years showed that Druchamp had heavier kernels than Gaines at all seeding rates. Both varieties showed almost no fluctuation in this component for the different rates of seeding. The 1964 and 1966 seasons were favorable for heavier kernel weights for both varieties in contrast to the 1965 season.

Yield

The yield in bushels per acre for the two varieties in the

Table V. Summary of average number of spikelets per spike for Gaines and Druchamp winter wheats at various seeding rate of pounds per acre for three years

Seeding rate	Gaines 1964	1965	1966	Av.	Druchamp 1964	1965	1966	Av.
10	17	17	21	18	19	17	21	19
20	17	16	21	18	18	18	21	19
30	17	16	21	18	18	18	20	19
40	16	15	22	18	18	19	20	19
50	18	15	21	18	17	18	20	18
60	16	15	20	17	17	18	20	18
70	16	15	20	17	17	15	20	17
80	16	15	21	17	16	17	19	17
90	16	15	20	17	16	18	19	18
100	16	15	20	17	18	17	19	18
110	16	15	20	17	17	18	20	18
120	16	15	20	17	17	17	19	18
130	15	15	19	16	16	17	19	17
LSD(5%)	1	1	1		NS	NS	1	

Figure 2. Average number of spikelets per spike for two winter wheat varieties at various seeding rates

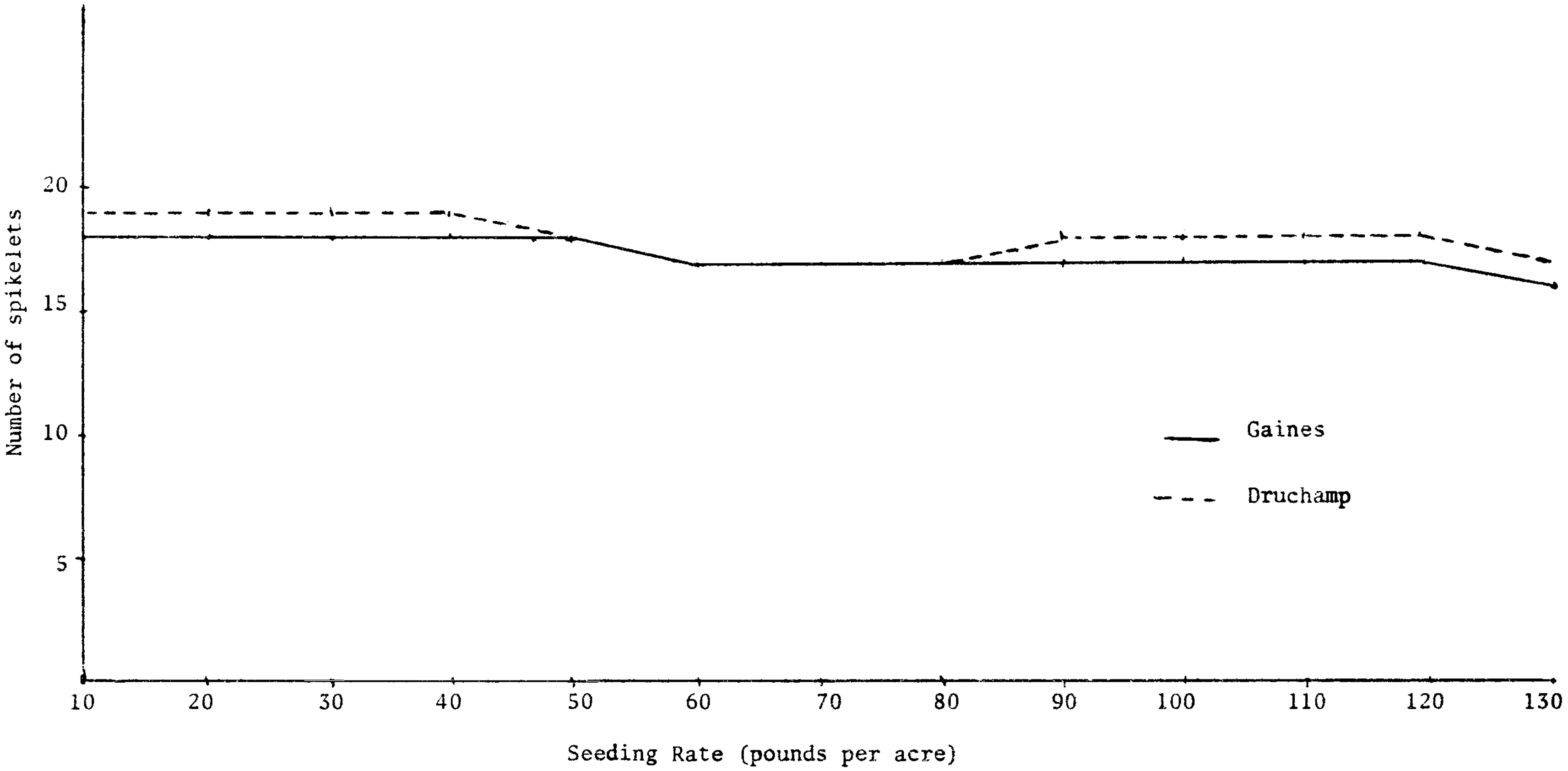


Table VI. Summary of average number of kernels per spike for Gaines and Druchamp winter wheats at various seeding rates of pounds per acre for three years

Seeding rate	Gaines 1964	1965	1966	Av.	Druchamp 1964	1965	1966	Av.
10	42	49	61	51	45	42	49	45
20	41	46	63	50	38	44	48	43
30	39	45	60	48	38	44	46	43
40	37	41	62	47	36	47	41	41
50	43	41	61	48	36	43	40	40
60	38	41	60	46	35	44	40	40
70	38	40	56	45	31	40	38	36
80	37	41	56	45	31	41	39	37
90	37	42	56	45	31	41	37	36
100	37	40	58	45	35	40	37	37
110	36	41	54	44	35	45	40	40
120	38	41	54	44	32	40	37	36
130	34	39	48	40	28	43	43	38
LSD(5%)	4	5	4		4	NS	4	

Figure 3. Average number of kernels per spike for two winter wheat varieties at various seeding rates

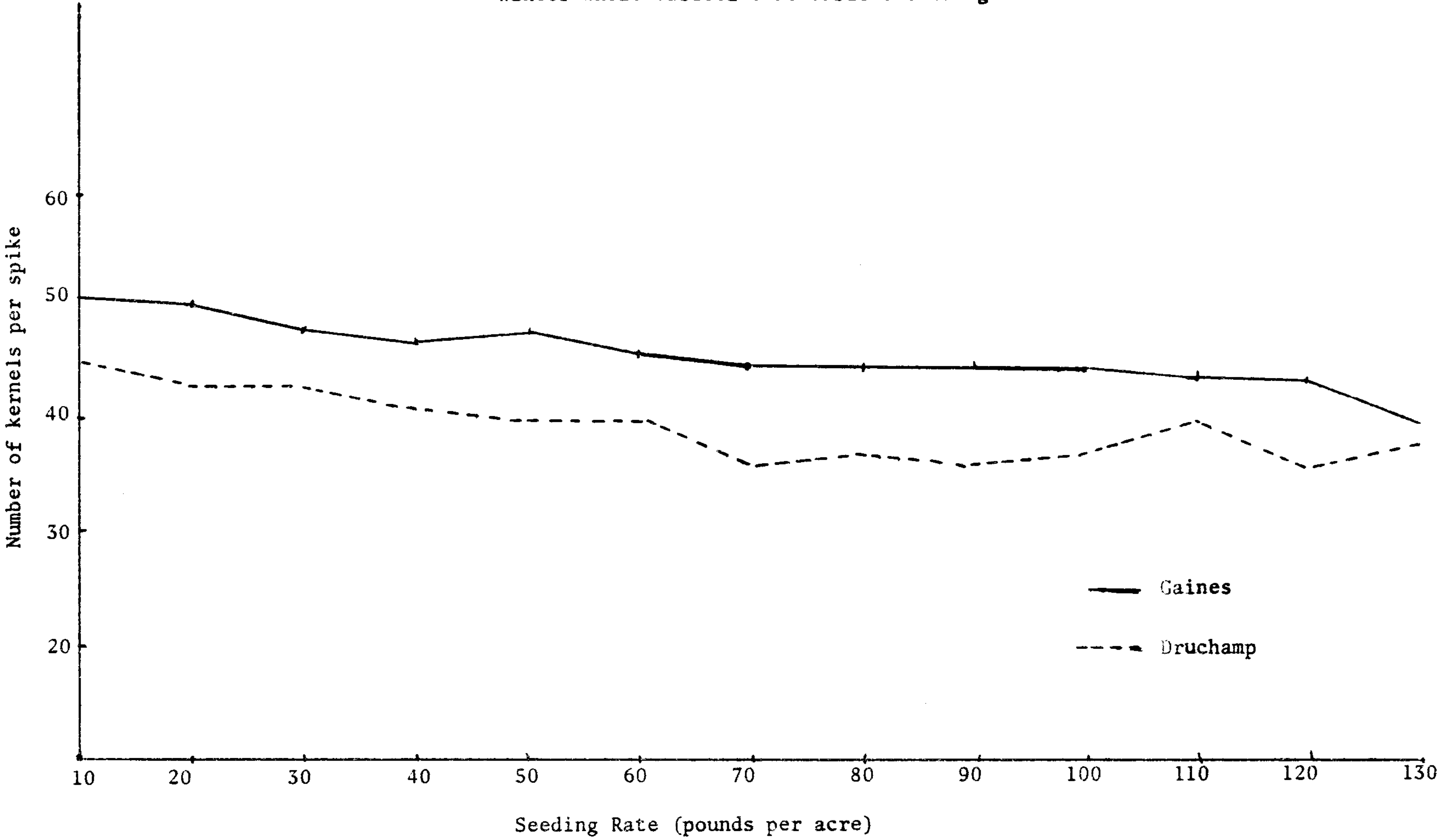
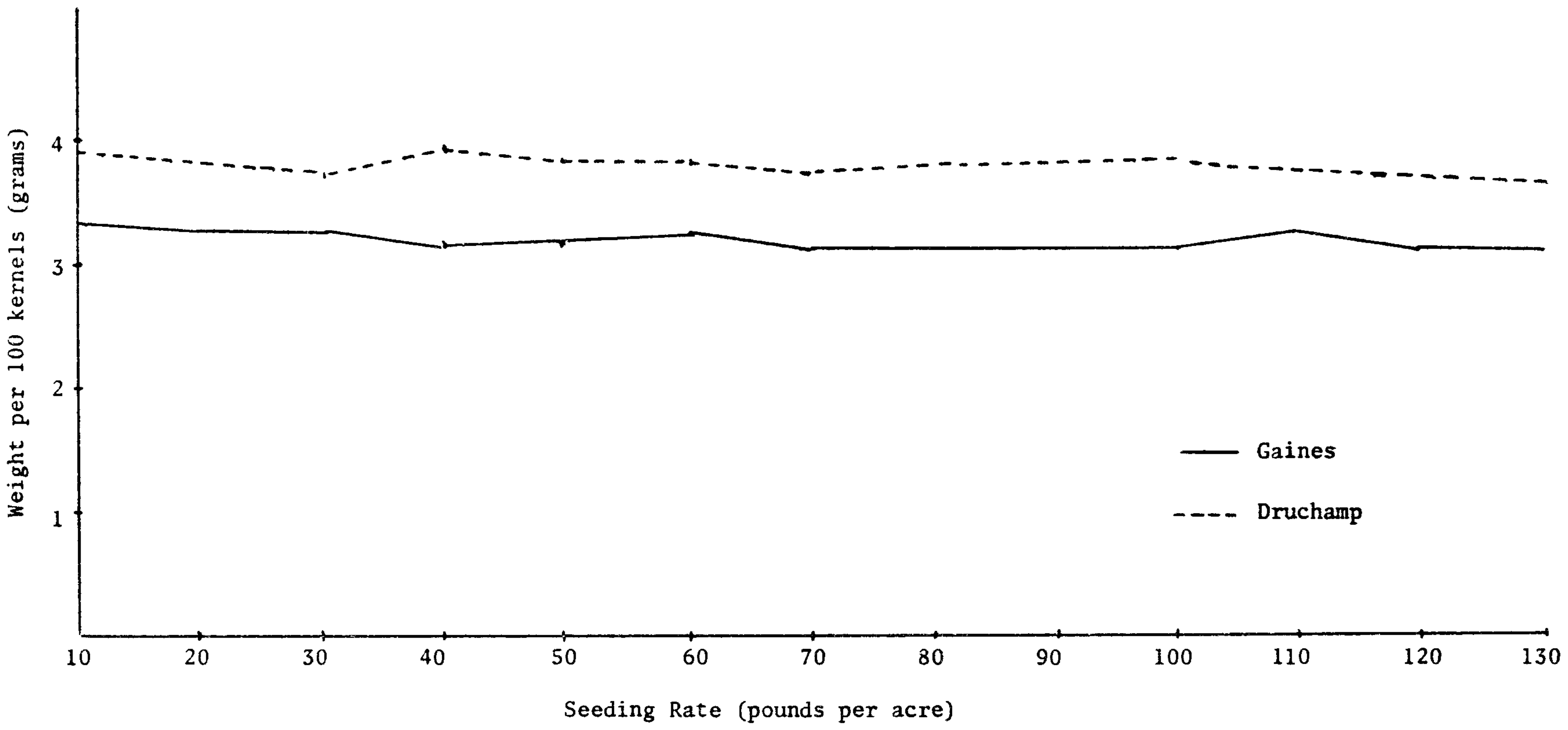


Table VII. Summary of average kernel weights (in grams) for Gaines and Druchamp winter wheats at various seeding rates of pounds per acre for three years

Seeding rate	Gaines 1964	1965	1966	Av.	Druchamp 1964	1965	1966	Av.
10	3.89	2.03	4.14	3.35	5.02	2.08	4.65	3.92
20	3.91	1.82	4.12	3.28	4.74	2.17	4.58	3.83
30	3.68	1.89	4.31	3.29	4.76	2.08	4.41	3.75
40	3.74	1.66	4.19	3.20	4.71	2.34	4.87	3.97
50	3.82	1.64	4.26	3.26	4.82	2.08	4.71	3.87
60	3.78	1.64	4.40	3.27	4.79	2.12	4.67	3.86
70	3.67	1.60	4.13	3.13	4.73	1.94	4.65	3.77
80	3.69	1.66	3.99	3.11	4.90	2.06	4.06	3.85
90	3.67	1.66	4.03	3.12	4.66	2.13	4.76	3.85
100	3.74	1.61	4.08	3.14	4.93	2.00	4.73	3.87
110	3.72	1.70	4.52	3.31	4.74	2.21	4.56	3.84
120	3.71	1.66	4.09	3.15	4.58	1.96	4.70	3.75
130	3.57	1.57	4.26	3.13	4.59	2.10	4.31	3.67
LSD(5%)	NS	0.71	0.02		0.26	1.12	NS	

Figure 4. Average kernel weights for the two winter wheat varieties at various seeding rates



three different years and the averages are given in Table VIII. The three-year averages are graphically shown in Figure 5. Druchamp consistently outyielded Gaines at the different seeding rates. The yield of both varieties increased with a corresponding increase in seeding rates. According to the three-year averages, Druchamp gave the highest yield at 100 pounds per acre (91.20 bushels per acre), followed by 120 pounds per acre rate with 89.9 bushels per acre and 110 pounds per acre rate of seeding with 87.4 bushels per acre. Gaines gave the highest yield of 73.6 bushels per acre at the 110 pound per acre rate of seeding, followed very closely by 130 pounds per acre and 60 pounds per acre rates of seeding with their corresponding yields of 72.9 and 72.8 bushels per acre, respectively.

The yield for all seeding rates was highest in the 1966 season for Gaines, followed by 1964 and 1965. In the case of Druchamp, the 1964 season gave the highest yield followed by 1965 and 1966 seasons.

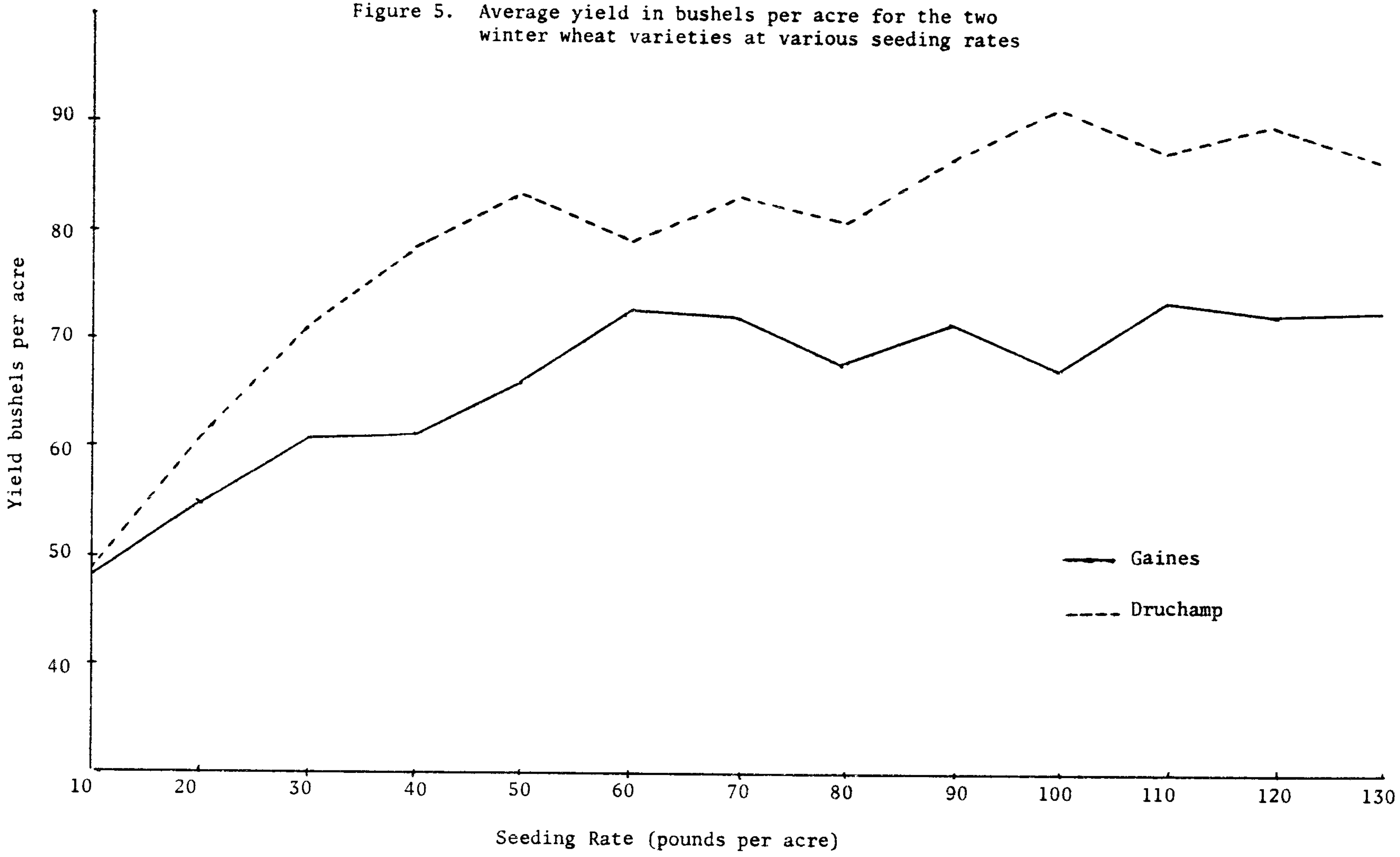
In general, both varieties in the individual years showed a constant increase in yield with a corresponding increase in seeding rate. The increase in yield for both varieties was sharp with the lower rates of seeding and then a gradual increase in the higher rates.

In 1964 and 1966, the lower seeding rates of Gaines, i.e. 60 pounds per acre, produced the highest yield. In 1965, the higher seeding rate of Gaines (110 pounds per acre) produced the maximum yield. In all seasons under study, the higher seeding rates, i.e.

Table VIII. Summary of average yields in bushels per acre for Gaines and Druchamp winter wheats at various seeding rates of pounds per acre for three years

Seeding	Gaines				Druchamp			
rate	1964	1965	1966	Av.	1964	1965	1966	Av.
10	37.4	41.4	65.7	48.2	63.2	38.5	44.4	48.7
20	48.4	43.4	72.6	54.8	79.0	68.2	51.2	66.2
30	48.6	55.5	77.7	60.6	86.1	82.6	45.5	71.4
40	46.2	60.8	75.9	61.0	95.0	84.5	55.9	78.5
50	57.1	63.1	78.5	66.2	107.3	88.5	54.4	83.4
60	64.0	65.9	88.6	72.8	101.9	83.1	53.0	79.3
70	57.3	76.0	83.7	72.3	103.1	99.6	46.9	83.2
80	54.5	69.4	79.0	67.6	105.6	94.4	43.3	81.1
90	52.4	76.7	84.7	71.3	109.7	93.1	56.9	86.6
100	52.2	69.2	80.0	67.1	111.0	108.0	54.6	91.2
110	62.7	77.9	80.1	73.6	111.6	99.4	51.2	87.4
120	61.8	73.9	80.8	72.2	108.7	111.6	49.5	89.9
130	53.8	80.1	84.8	72.9	97.7	110.7	50.8	86.4
LSD(5%)	8.0	13.7	NS		9.3	19.2	5.1	

Figure 5. Average yield in bushels per acre for the two winter wheat varieties at various seeding rates



90 to 120 pounds per acre of Druchamp, outyielded lower seeding rates.

In Table IX, the yield and yield components are expressed as a percentage of the mean of each component (from the three-year averages given in Tables IV, V, VI, VII, and VIII) for both varieties and are graphically shown in Figures 6 and 7. A scrutiny of both Figures 6 and 7 reveals that the yield and yield components of both varieties responded similarly to the different seeding rates. The effect of different rates of seeding on the yield and number of spikes per unit area of both varieties was similar. The number of spikelets per spike, number of kernels per spike, and the weight of one hundred kernels of both varieties were slightly effected by the different rates of seeding.

Table IX. Yield and components of yield expressed in percentage of their respective means (3-year average) for two winter wheat varieties

Gaines

Seeding rate lbs/A	Yield	No. spikes/ 2-ft row	No. spike-lets/spike	No. ker-nels/spike	Wt/100 kernels
10	72.8	56.9	104.1	110.9	104.4
20	82.8	77.4	104.1	108.6	102.2
30	91.5	79.6	104.1	104.3	102.5
40	92.1	91.0	104.1	102.2	99.6
50	100.0	97.8	104.1	104.3	101.6
60	110.0	101.2	98.3	100.0	101.9
70	109.2	109.2	98.3	97.8	97.5
80	102.1	106.9	98.3	97.8	96.8
90	107.7	110.4	98.3	97.8	97.2
100	101.4	117.2	98.3	97.8	97.8
110	111.2	116.0	98.3	95.7	103.1
120	109.1	116.0	98.3	95.7	98.1
130	110.1	120.6	92.5	86.9	97.5

Druchamp

Seeding rate lbs/A	Yield	No. spikes/ 2-ft row	No. spike-lets/spike	No. ker-nels/spike	Wt/100 kernels
10	61.3	50.8	105.0	114.2	102.3
20	83.3	74.1	105.0	109.1	100.0
30	89.8	79.4	105.0	109.1	97.9
40	98.7	94.2	105.0	104.1	103.7
50	104.9	89.9	99.4	101.5	101.0
60	99.7	92.1	99.4	101.5	100.8
70	104.7	101.6	93.9	91.4	98.4
80	102.1	111.1	93.9	93.9	100.5
90	108.9	111.1	99.4	91.4	100.5
100	114.7	119.6	99.4	93.9	101.0
110	109.9	120.6	99.4	101.5	100.3
120	113.1	129.1	99.4	91.4	97.9
130	108.7	127.8	93.9	96.4	95.8

Figure 6. Effect of seeding rate on yield and yield component of Gaines

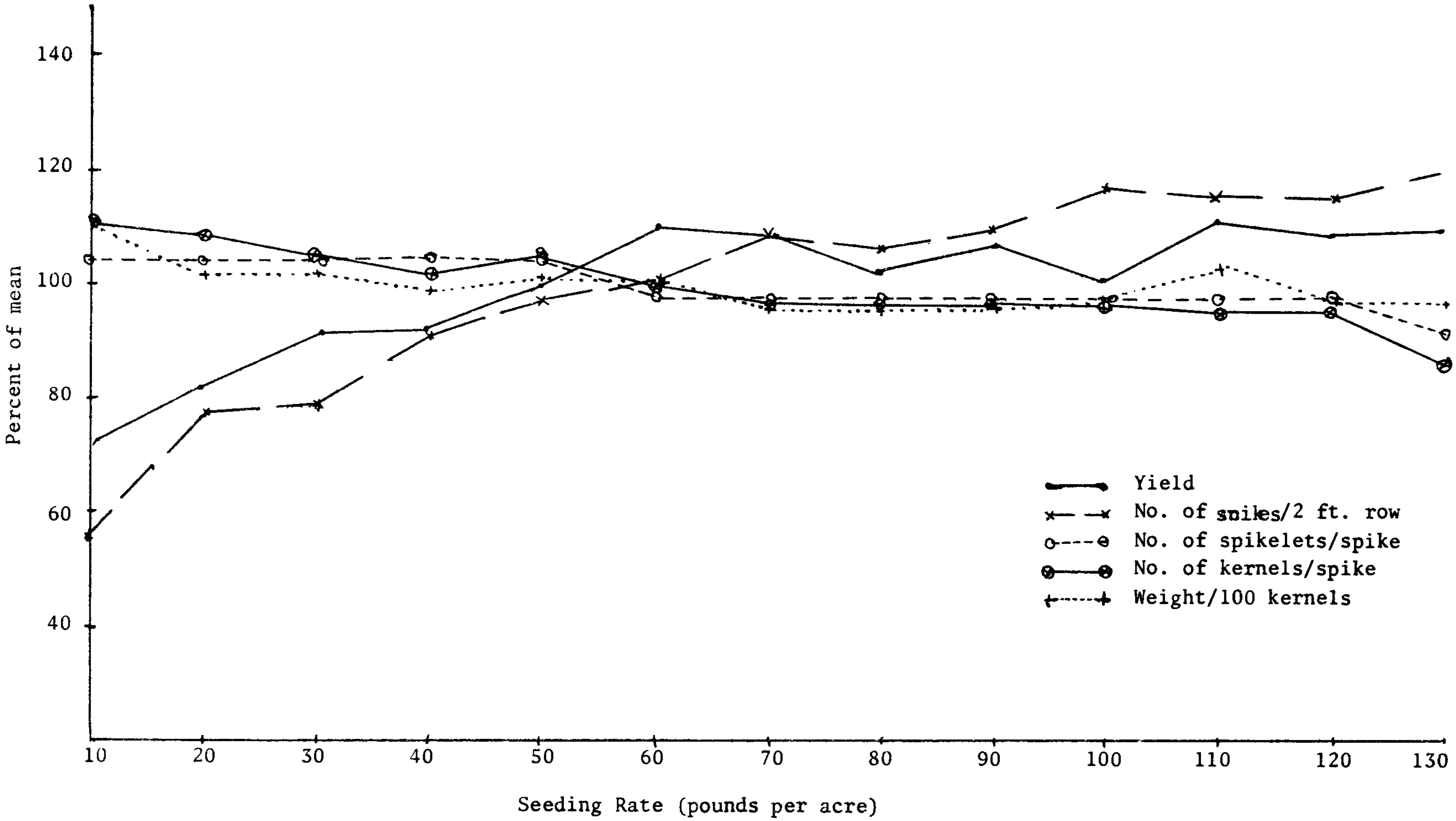
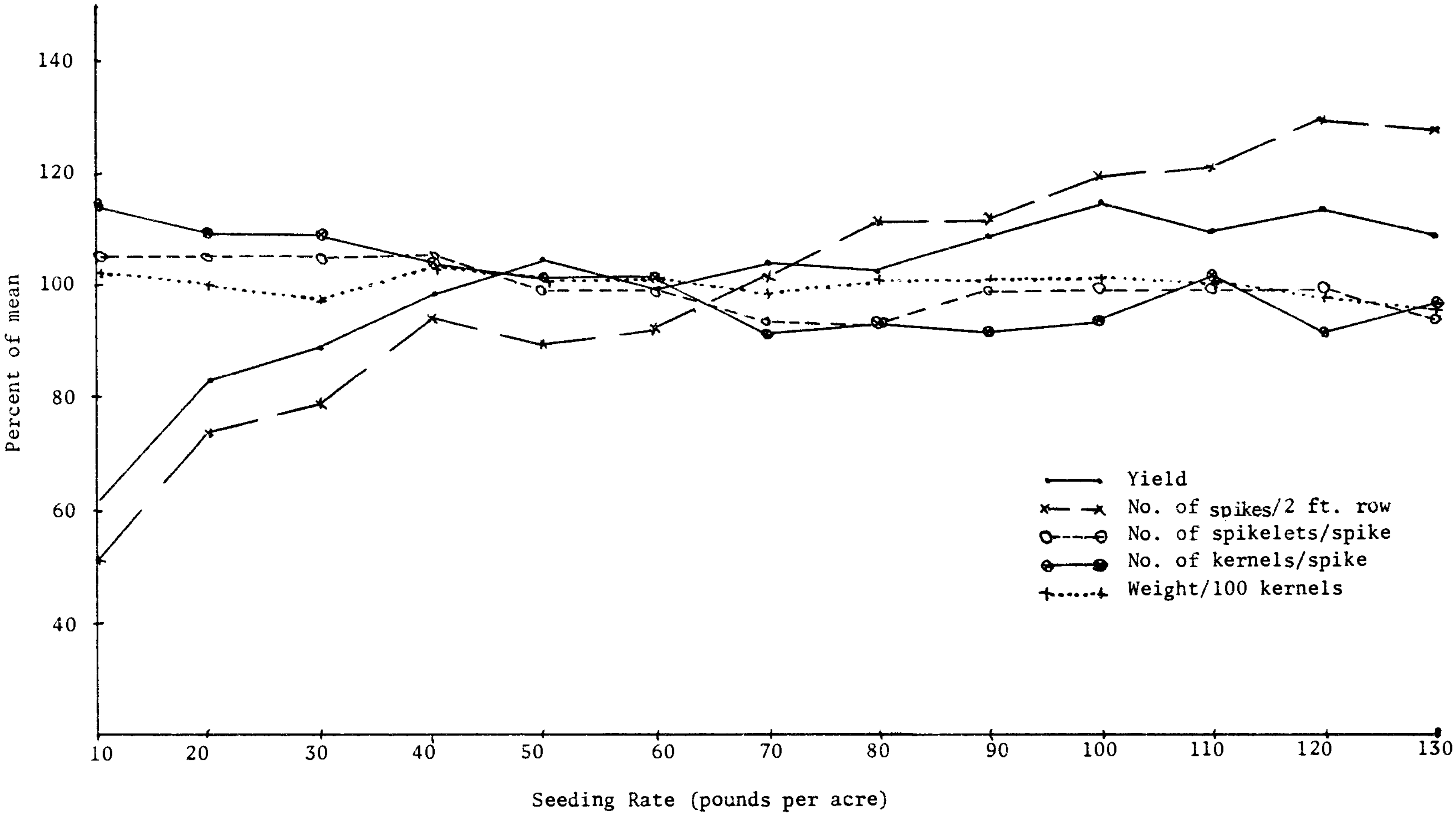


Figure 7. Effect of seeding rate on yield and yield component of Druchamp



DISCUSSION

The purpose of this study was to determine the effect of seeding rate on yield and the yield components of two winter wheat varieties. The other objective was to find the optimum seeding rate for both varieties for the Willamette Valley of Oregon. A further objective was to see how the yields of lower seeding rates compared with the yields of higher seeding rates for both varieties.

From the results as given in Table IX and Figures 6 and 7, it was quite clear that the higher seeding rates of both varieties produced higher yields. It must be mentioned here that although these differences were statistically significant, it is open to question whether to recommend the higher rates of seeding from the economic viewpoint. From Table VIII, it can be observed that the yields obtained from the lower seeding rates of both varieties can be compared favorably with yields obtained from higher rates of seeding. This shows that when the supply of seed is limited, low rates of seeding could be used without any appreciable reduction in yield.

Although Martin (1926) reported that the optimum rate of seeding for wheat was practically independent of soil type, moisture, locality, date of seeding, cultural treatment and variety, the results of this experiment in respect to varieties were not in agreement with his results.

The results of this experiment were similar to those of Guitard, Newman and Hoyt (1961) and other authors in respect that yield was increased with increases in seeding rates and that the highest yields were obtained from higher rates of seeding. However, it was in sharp contrast with results of the experiments of Fikry (1937) and others.

Seeding rates directly influenced number of spikes per unit area which in turn had the maximum effect on yield of both varieties. Similar results were reported by Curtis and Haus (1967), Grafius (1956b) and other investigators.

Guitard, Newman and Hoyt (1961) and other authors, reported similar results on the effect of seeding rates on the number of spikelets per spike, number of kernels per spike and weight per 100 kernels and their lack of effect on yield.

Although Arny and Garber (1918) had reported that the yield of wheat was closely related with increase in number of kernels in the environmental conditions of their experiment, such relationship was not present in these experiments. Bonnett and Woodworth (1931) found that yield was in some measure affected by the weight of the grain produced, whereas in these experiments, it was quite evident that different rates of seeding had little or no effect on the weight of grain. Unlike the results of the experiment conducted by Grantham and Groff (1916), in which the seeding rates effected the number of spikelets per spike, these trials did not show this effect. Johnson, et al. (1966) reported that in shorter varieties, the yield of kernel was increased by more spikelets per spike and more kernels per spikelet. Gaines, the shorter of the two varieties in these experiments, failed to have more spikelets per spike but it did, however, have a higher number of kernels per spike than Druchamp.

Comparing the components of yield and yielding capacities of the two winter wheat varieties, it can be seen from Figures 1 to 5 that Druchamp yielded more because it tillered more profusely than Gaines, producing more spikes per unit area and had heavier kernels than Gaines, whereas the high yield of Gaines was due to more kernels per spike.

According to Grafius (1956a), the yield of cereal crops could be likened to a box. To represent the three dimensions of the box, he had used (a) number of spikes per unit area, (b) number of grains per spike, and (c) average weight per grain. The volume of the box was said to represent yield which was determined by the product of the three. An increase in any one of the three components would result in an increase in the total yield, provided there was no corresponding decrease in the other two components. In this experiment, there were four components, three of which remained more or less constant with all the different seeding rates, and only one component, i.e. number of spikes per unit area, increased with yield, thus illustrating this statement of Grafius (1956a) very well.

These experiments have clearly demonstrated the effect of seeding rate on yield and yield components of two winter wheats, Gaines and Druchamp. The number of spikes per unit area was most effected by seeding rates, which in turn had the greatest effect on yield. Seeding rates did not influence number of spikelets per spike, number of kernels per spike, and weight of one hundred kernels in a manner by which they effected yield. The optimum seeding rates varied with seasons in spite of the fact that higher seeding rates did yield higher in both varieties. From these experimental results, seeding rates ranging from 60 to 100 pounds per acre for Gaines and Druchamp could be safely recommended for the Willamette Valley of Oregon, below which lesser but satisfactory yields could be obtained.

SUMMARY AND CONCLUSIONS

These studies were made to determine the effect of various seeding rates on the yield and yield components of two high yielding winter wheat varieties grown in the Willamette Valley. Observation of the effect of seeding rates on the yield and yield components were made to determine which of the components of yield contributes most to the grain yield of a winter wheat variety. Also, information was obtained to aid in developing optimum seeding rate recommendations. Two winter wheat varieties were seeded with various rates of seeding during 1963, 1964, and 1965. The results of these experiments were as follows:

1. On the basis of three-year averages:
   (a) Druchamp consistently outyielded Gaines at all seeding rates.
   (b) Higher seeding rates of both varieties gave higher yields.
2. The yield for all seeding rates was highest in the 1966 and 1964 seasons for Gaines and Druchamp, respectively.
3. The yield and yield components of both varieties responded similarly to the different rates of seeding.
4. The yield component number of spikes per unit area was most effected by various rates of seeding which in turn influenced the yield of both varieties. Seeding rates had no effect on the other components, i.e. number of spikelets per spike, number of kernels per spike, and weight of 100 kernels for both varieties.

5. The high yield of Druchamp was attributed to the production of more spikes per unit area and heavy kernels, while that of Gaines was due to the production of more kernels per spike.

BIBLIOGRAPHY

Arny, A. C. and R. J. Garber. 1918. Variation and correlation in wheat. Journal of Agricultural Research 14:359-392.

Atkinson, Alfred. 1917. Date and rate of seeding tests with spring grains under irrigation. Montana, Agricultural Experiment Station, Bulletin 120:107-117.

Bergh, Otto I. 1919. General report of the North Central Experiment Station, Grand Rapids, 1915-1919. St. Paul, the University of Minnesota, Agricultural Experiment Station. 79 numb. leaves.

Bolley, H. L. 1901. Work with wheat in 1900. Fargo. 117 numb. leaves. (North Dakota. Agricultural Experiment Station. Eleventh annual report)

Bonnett, O. T. and C. M. Woodworth. 1931. A yield analysis of three varieties of barley. Journal of the American Society of Agronomy 23:311-327.

Bracken, A. F. and George Stewart. 1930. A quarter century of dry farm experiments at Nephi, Utah. Logan. 46 p. (Utah. Agricultural Experiment Station. Bulletin 222)

Brown, H. M. and E. E. Down. 1937. Winter wheat culture in Michigan. East Lansing. 16 p. (Michigan. State College. Extension bulletin 187)

Buffam, B. C. 1898. The stooling of grain. Wyoming, Agricultural Experiment Station, Bulletin 37:207-241.

Burnett, L. C. 1928. Iogold oats. Iowa, Agricultural Experiment Station, Bulletin 247:185-198.

Clark, J. Allen and John R. Hooker. 1926. Segregation and correlated inheritance in Marquis and Hard Federation crosses, with factor for yield and quality for spring wheat in Montana. Washington, D. C. 70 p. (U. S. Department of Agriculture. Bulletin 1403)

Cobb, N. A. 1903. Seed wheat. The Agricultural Gazette of New South Wales 14:145-169.

Coffman, Franklin A. 1925. Experiments with cereals at the Akron (Colorado) Field Station in the 15 year period, 1908 to 1922 inclusive. Washington, D. C. 62 p. (U. S. Department of Agriculture. Department bulletin 1287)

Curtis, B. C. and T. E. Haus. 1967. High wheat yields produced by low seeding rates and wide rows. Crops and Soils 19:25.

Doughty, L. R. and F. L. Engledow. 1928. Investigation on the yield in the cereals. Journal of Agricultural Science 18:317-345.

Dowling, R. N. 1908. Experiments on tillering and thick versus thin sowing of Red Fife wheat. The Journal of the South Eastern Agricultural College, Wye, Kent 17:49-56.

Downing, R. C. 1911. Thick and thin seeding trials with wheat at Bathurst Experiment Farm 1910. The Agricultural Gazette of New South Wales 22:609.

Engledow, R. C. and K. Ramiah. 1930. Investigation on yield in cereals. VII. A study of development and yield of wheat based upon varietal comparison. Journal of Agricultural Science 20:265-345.

Fikry, M. A. 1936. Influence of size and weight of seed upon the course of subsequent growth and upon yield of wheat. Cairo. 52 p. (Royal Agricultural Society of Egypt. Bulletin 23) (Abstracted in Biological Abstracts 11: no. 16824. 1937)

Forster, H. C. and A. J. Varsey. 1930. Some census studies on the wheat crop in Victoria. The Journal of the Department of Agriculture of Victoria 28:449-458.

Frey, K. J. 1959. Yield components in oats. I. Effect of seeding date. Agronomy Journal 51:382.

Georgeson, C. C. 1896. Experiment with wheat. Kansas, Agricultural Experiment Station, Bulletin 59:89-105.

Georgeson, C. C., F. C. Burtis and W. M. Shelton. 1892. Experiments with wheat. Manhattan. 50 p. (Kansas. Agricultural Experiment Station. Bulletin no. 33)

Godel, Geo. L. 1935. Relation between rate of seeding and yield of cereal crops in competition with weeds. Scientific Agriculture 16:165.

Grafius, J. E. 1956a. Components of yield in oats. A geometrical interpretation. Agronomy Journal 48:425.

____________________. 1956b. The relationship of stand to panicles per unit area in oats. Agronomy Journal 48:462.

Grantham, A. E. 1914. The effect of rate of seeding on competition in wheat varieties. Journal of the American Society of Agronomy 6:127.

_________________. 1917. The tillering of winter wheat. Newark. 119 p. (Delaware. Agricultural Experiment Station. Bulletin 117)

Grantham, A. E. and Frazer Groff. 1916. Occurrence of sterile spikelets in wheat. Journal of Agricultural Research 6:235-250.

Grenfell, C. N. 1901. Some experiments with wheat made at Mount Templeton, South Australia. The Agricultural Gazette of New South Wales 12:1053-1062.

Guitard, A. A., J. A. Newman and P. B. Hoyt. 1961. The influence of seeding rate on the yield and the yield components of wheat, oats and barley. Canadian Journal of Plant Science 41:751-758.

Harlan, H. V. 1925. Barley: culture uses and varieties. Washington, D. C. 29 p. (U. S. Department of Agriculture. Farmers' Bulletin 1464)

Hayes, W. M. 1893. Grain and forage crops. Fargo. 72 p. (North Dakota. Agricultural Experiment Station. Bulletin 10)

Hays, H. K., O. S. Aamodt and F. J. Stevenson. 1927. Correlation between yielding ability, reaction to certain diseases and other characters of spring and winter wheats in rod row trials. Journal of the American Society of Agronomy 19:896-910.

Hickman, J. Fremont. 1897. Field experiments with wheat. Ohio, Agricultural Experiment Station, Bulletin 82:214-235.

_________________. 1901. Field experiments with wheat. Wooster. 27 p. (Ohio. Agricultural Experiment Station. Bulletin 129)

Hudson, A. W. and W. C. Stafford. 1934. The rate of seeding wheat in relation to varietal trials. Empire Journal of Experimental Agriculture 2(2):29-39.

Hudson, H. G. 1941. Population studies with wheat. Seed rates in nursery trials and field plots. Journal of Agricultural Science 31:142.

Hutchison, Roy E. 1936. Rates of seeding wheat and other cereals with irrigation. Journal of the American Society of Agronomy 28:699-703.

Jain, D. L. et al. 1963. Investigation on period of sowing, seed rate and fertilization of wheat in Gang Canal tract of Rajasthan. Indian Journal of Agronomy 7(3):197-205.

Jardine, W. M. 1916. Effect of rate and date of sowing on yield of winter wheat. Journal of the American Society of Agronomy 8:163-166.

Johnson, V. A. et al. 1966. Comparison of yield components and agronomic characteristics of four winter wheat varieties differing in plant height. Agronomy Journal 58:438-441.

Kaukis, K. and L. P. Reitz. 1955. Tillering and yield of oat plants grown at different spacings. Agronomy Journal 47:147.

Kiesselbach, T. A. 1918. Studies concerning the elimination of experimental error in comparative crop tests. Lincoln. 95 p. (Nebraska. Agricultural Experiment Station. Research bulletin 13)

Kiesselbach, T. A. 1924. Relation of seed size to yield of small grain crops. Journal of the American Society of Agronomy 16:670-682.

______________________. 1926. The relation of seeding practice to crop quality. Journal of the American Society of Agronomy 18:661-684.

Kiesselbach, T. A. and C. A. Helm. 1917. Relation of size of seed and sprout value to the yield of small grain crops. Lincoln. 73 p. (Nebraska. Agricultural Experiment Station. Research bulletin 11)

Kiesselbach, T. A., Arthur Anderson and W. E. Lyness. 1934. Cultural practice in winter wheat production. Lincoln. 28 p. (Nebraska. Agricultural Experiment Station. Bulletin 286)

Kirna, K. L. et al. 1963. Effect of seeding rate, row spacing and rate of placement of fertilizer on winter wheat performance in Michigan. Agronomy Journal 55:27.

Kronstad, W. E. and W. H. Foote. 1964. General and specific combining ability estimates in winter wheat. Crop Science 4(6): 616-619.

Leighty, Clyde E. 1910. Correlation of character in oats with special reference to breeding., 1st January 1910 to 31st December 1910. Washington, D. C. p. 50-61. (American Breeders' Association. Annual report Vol. 7)

Leighty, Clyde E. and J. W. Taylor. 1927. Rate and date of seeding, seedbed preparation for winter wheat at Arlington Experiment Farm. Washington, D. C. 19 p. (U. S. Department of Agriculture. Technical bulletin 38)

Love, H. H. 1910. A study of large and small grain question. 1st January 1910 to 31st December 1910. Washington, D. C. p. 109-118. (American Breeders' Association. Annual report vol. 7)

Love. H. H. and C. E. Leighty. 1914. Variation and correlation of oats (Avena sativa). Part 1. Studies showing the effect of seasonal changes on biometrical constants. Ithaca. 70 p. (Cornell. Agricultural Experiment Station. Memoir 3)

Martin, John H. 1926. Factors influencing results from rate and date of seeding experiments with wheat in the United States. Journal of the American Society of Agronomy 18:193-225.

Martin, John H. and Warren H. Leonard. 1962. Principles of field crop production. 12th ed. New York, The Macmillan Company. 489 p.

McClelland, C. K. 1931. Quality determinations of seed for rod rows of spring oats. Journal of the American Society of Agronomy 23:708.

McNeal, F. H. 1960. Yield components in a Lemhi and Thatcher wheat cross. Agronomy Journal 52:349.

Montgomery, E. G. 1910. Competition in cereals. 1st January 1910 to 31st December 1910. Washington, D. C. p. 118-127. (American Breeders' Association. Annual report vol. 7)

Myers, Clyde H. 1910. Effect of fertility upon variation and correlation in wheat. 1st January 1910 to 31st December 1910. Washington, D. C. p. 61-74. (American Breeders' Association. Annual report vol. 7)

Nelson, Martin and L. W. Osborn. 1915. Report of cultural and varietal tests with wheat. Fayetteville. 31 p. (Arkansas. Agricultural Experiment Station. Bulletin 121)

Nelson, Martin and C. V. Ruzek. 1914. Oats. Arkansas, Agricultural Experiment Station, Bulletin 118:620-637.

Olsen, P. J. et al. 1942. Cultural studies with barley differential response to fertilizer treatment and rate of seeding with respect to yield. Scientific Agriculture 22:659-673.

Papadakis, J. S. 1940. Relation of the number of tillers per unit area to the yield of wheat and its bearing on fertilizing and breeding, this plant - the space factor. Soil Science 50:369-389.

Parker, W. H. 1914. A case of correlation in wheat. Journal of Agricultural Science 6:179.

Pendleton, J. W. and G. H. Dungan. 1960. The effect of seeding rate and rate of nitrogen application on winter wheat varieties with different characteristics. Agronomy Journal 52:310-312.

Pitt, J. M. 1916. Rate of seeding and fertilizing trials with wheat, Yanco experiment. The Agricultural Gazette of the New South Wales 27:232.

Poehlman, John Milton. 1959. Breeding field crops. New York, Henry Holt and Company, Inc. 110 p.

Quisenberry, Karl S. 1928. Some plant characters determining yields in fields of winter and spring wheat in 1926. Journal of the American Society of Agronomy 20:492-499.

Roberts, H. F. 1910. Variation and correlation in wheat. 1st January 1910 to 31st December 1910. Washington, D. C. p. 80-109. (American Breeders' Association. Annual report vol. 7)

Robertson, D. W. et al. 1936. Barley production in Colorado 1928-1935. Fort Collins. 28 p. (Colorado. Agricultural Experiment Station. Bulletin 431)

Salmon, S. C. and J. W. Taylor. 1939. Growing wheat in the Eastern United States. Washington, D. C. 58 p. (U. S. Department of Agriculture. Farmers' bulletin 1817)

Smith, H. F. 1937. The variability of plant density in fields of wheat and its effect on yield. 28 p. (Commonwealth of Australia Council for Scientific and Industrial Research. Bulletin 109)

Smith, Ralph W. 1925. The tillering of grain as related to yield and rainfall. Journal of the American Society of Agronomy 17:723.

Sprague, H. B. 1926. Correlation and yield in bread wheats. Journal of the American Society of Agronomy 18:971-996.

Sprague, H. B. and N. F. Farris. 1931. The effect of uniformity of spacing seed on the development and yield of barley. Journal of the American Society of Agronomy 23:531.

Stephen, David E., H. M. Wanser and Aaron F. Bracken. 1932. Experiments in wheat production on the dry lands Oregon, Washington and Utah. Washington, D. C. 68 p. (U. S. Department of Agriculture. Technical bulletin 329)

Stevens, J. G. J. 1965. Wheat seeding rates. Queensland Agricultural Journal 91(1):40-42.

Ten Eyck, A. M. and V. M. Shoesmith. 1907. Small grain crops. Kansas, Agricultural Experiment Station, bulletin 144:141-224.

Thatcher, L. E. 1922. Wheat cultural notes. Ohio, Agricultural Experiment Station, Monthly Bulletin 7:130-143.

Thayer, J. W., Jr. 1938. Rate of seeding barley. Michigan, Agricultural Experiment Station, Quarterly Bulletin 20(3):167-163.

Thayer, J. W., Jr. and H. C. Rather. 1937. The influence of rate of seeding upon certain plant characters in barley. Journal of the American Society of Agronomy 29:760.

Thompson, J. L. 1899. The tillering or stooling proclivities of wheat. The Agriculture Gazette of New South Wales 10:1248.

Voelker, J. Augustus. 1901. Head versus tail corn for seed wheat. Journal of the Royal Agriculture Society of England 63:356.

____________________. 1904. Thick versus thin sowing of wheat. Journal of the Royal Agriculture Society of England 63:323.

Waldron, L. R. 1929. A partial analysis of yield of certain common and durum wheats. Journal of the American Society of Agronomy 21:295-309.

____________________. 1941. Analysis of yield of Hard Red spring wheat grown from seed of different weights and origin. Journal of Agricultural Research 62:445-460.

____________________. 1942. The effect of light and heavy weight seed wheat upon the yield of the resulting crop. North Dakota, Agricultural Experiment Station, Bimonthly Bulletin 4(3):15-21.

Wiggans, S. C. and K. J. Frey. 1957. Your oats seeding. How early? What rate? Iowa Farm Science 11:470.

Williams, C. G. 1920. Wheat: variety and cultural work. Ohio, Agricultural Experiment Station, Monthly Bulletin 5(7):195-198.

Woodcock, J. W. 1939. Rate of sowing wheat. Nothing to be gained by reduction of seed below 120 pounds per acre. New Zealand Journal of Agriculture 58:403.

Zavitz, C. A. 1912. Annual report. 1st January 1912 to 31st December 1912. Guelph. 191 numb. leaves. (Ontario. Agricultural College and Experiment Farm. Report 38)

Zavitz, C. A. 1915. Farm Crops. Results of the experiment at Ontario Agriculture College. Toronto. 80 p. (Ontario. Department of Agriculture. Bulletin 228)

Zook, L. L. and W. W. Burr. 1923. Sixteen years grain production at the North Platte Station. Lincoln. 52 p. (Nebraska. Agricultural Experiment Station. Bulletin 193)