POLLEN AMOUNT AND DISTRIBUTION IN RELATION TO SEED SET OF MALE-STERILE *TRITICUM AESTIVUM*

by

ADRIAN L. ARP

B. S., University of Wyoming, 1965

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

Approved by:

Major Professor

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

INTRODUCTION

Cytoplasmic male-sterility and fertility restoring factors in wheat have stimulated great interest about the practibility of hybrid wheat. This thesis is a study on the pollen availability upon seed set.

The first objective was to determine the amount of pollen available for pollination at various distances from the pollen source, and its relation to seed set. This objective was dependent on techniques for measuring pollen amount and its transfer in the field.

The second objective was to determine the effect of time stigmas were exposed to natural pollination on percent seed set.

The third objective was to relate the amount of seed obtained on A-lines to production practices, and climatic factors of temperature, rain, humidity and wind velocity.

Hybrid wheat production probably will depend on the economic yields of F_1 seed. Knowledge relating to cross-pollination factors is of particular interest.

Phases of this study were conducted at Newton and Manhattan, Kansas. Climatic records were obtained to relate these effects upon flowering, pollen shedding, and seed set.

The need for studies such as this one was exemplified by Heyne (1964) who indicated that many phases of hybrid production must be studied carefully, and by Kihara and Tsunewaki (1966) who mentioned that hybrid wheat production research was lagging behind genetic research. Only through cooperative research will hybrid wheat be available to farmers in a minimal time.

REVIEW OF LITERATURE

Wheat once was thought to be completely self-pollinated, but Pope (1916) reported natural crossing to be about 1%. With the advent of hybrid wheat natural cross-pollination became necessary for successful development. Shebeski (1966) stated that the feasibility of the widespread development of hybrid wheat depended upon obtaining adequate wind-pollination of the seed crop.

Only recently have field crossing blocks of hybrid wheat been grown (Wilson and Ross, 1962; Porter, Lahr, and Atkins, 1965). These studies were the result of the discoveries of cytoplasmic male-sterility and fertility restoring genes in wheat.

Early work by Leighty and Taylor (1927) revealed that natural cross-pollination ranged from 0 to 34% over a ten year period. The range was attributed to varying weather conditions and marked differences in the ability of varieties to provide pollen and to be cross-pollinated. Chan (1925) indicated that varieties produced different quantities of pollen. In the field Kota had 856 pollen grains per anther while Marquis had 1380; in the greenhouse 416 and 1011 pollen grains per anther were obtained, respectively. Fertility could not be correlated with pollen per anther since Kota produced more seed per head than Marquis under field conditions; the reverse was observed in the greenhouse.

Recent studies by Olsen (1966) indicated that the type of head was important in the ability to release pollen. By comparing ten pairs of club and lax headed lines from Suwon 921/Omar BC4, he found that head compaction reduced the amount of pollen shed by almost one half. Lax strains averaged 562.7 and club strains 315.8 pollen grains during the flowering period. Taller varieties having lax, awnless spikes released more pollen than bearded and club types. Olsen also rated 62 varieties for their ability to shed pollen. Pollen counts for the entire flowering period ranged from 65 to 1714 pollen grains/17.28 mm^2. He collected pollen on slides in an indoor pollen trap from five heads which were excised daily in the field. The heads were agitated periodically throughout the collection period. Heads were selected which were just starting to bloom. He concluded that varieties exhibit different inherent abilities to produce pollen. A regression heritability estimate of parent to offspring pollen shedding ability was found to be 75%.

Cook (1913) suggested that varieties were different in their ability to exert their anthers, thus releasing more pollen to the atmosphere. Lucken[1] noted that definite

[1]Personal Communication. 1966. Dr. K. Lucken. North Dakota State University. Fargo, North Dakota.

differences occurred between varieties in their ability to cross-pollinate. This was speculated to be due to differences in anther extrusion. Takegami (1958) placed wheat varieties into four categories based on their mode of anther extrusion. His classes were: (1) varieties with short filaments in which the anthers failed to emerge past the glume tip; (2) anthers trapped by the palea; (3) long filaments which allowed anther extrusion beyond glumes; and (4) varieties in which retained and extruded anthers occurred in various numbers. Olsen (1966) found that extrusion of anthers and shattering were associated with high pollen counts. Lucken[2] suggested that varieties which are susceptible to shattering seem to cross-pollinate better. At Kansas State University, greenhouse crossing using the approach method has indicated that shatter susceptible varieties, such as Wichita, averaged more cross-pollinated seeds than resistant types.

Rajki (1962) presented data which indicated the degree of flower opening and anther extrusion varied within variety from year to year, but hard wheats tended to have a high degree of open florets. Spirova (1965) reported that of 13 wheat varieties studied all 4 of the hard wheats and 3 soft wheats could be classified as chasmogamous. Six soft wheats could not be consistently classed as either cleistogamous or

---

[2] Ibid.

chasmogamous because of differences from one season to another.

The size of lodicules may be important in determining anther extrusion. Pedersen and Jørgensen (1966) noted that closed flowering in barley was associated with small lodicules. They found that medium sized anthers were dominant over large and small ones, but there was some evidence that lodicule size and the tendency to open flowers may involve extranuclear factors.

Leighty and Sando (1924) investigated the nature of wheat flowering. They discovered that the time required for anther extrusion was highly variable, but the average time was 3 minutes 36 seconds. Anthers remained extended for an average of 26.5 minutes. Blooming progressed from the lower one half of the upper one third of the head. They reported 86.2% of the flowers bloomed in the day and 6.9% for both night and twilight blooming. The range for opening and closing of glumes was from 11 to 66 minutes. Blooming was reported to occur in temperatures of 56 to 78° F., but pollen was released in temperatures as low as 52°. Anther extrusion was retarded at temperatures below 55° F.

Jones and Newell (1946) studied pollination cycles and pollen dispersal in several grasses. Although they did not experiment with wheat, their findings could be applied to any genus of Gramineae. They found that grasses have a daily pollination cycle. This is the daily regularity of blooming and pollen shedding. Also they reported a "seasonal pollination cycle" which consisted of a succession of blooming of florets within a spiklet and the blooming of florets in different spiklets of a head. From their studies they indicated that temperature had the greatest effect on pollen shedding and flowering.

Pollen grain size is important in the physical ability of pollen to be transported by wind. Wodehouse (1935) found that wheat pollen was 48-57 μ in diameter; rye was 40-62 μ; and corn was 90-100 μ. Cet'l (1961) found that measurements of pollen grains from diploid, tetraploid, and hexaploid species of wheat showed pollen grain size to increase with the number of genomes present. By using the diploid genome A as 100%, the influence of genome B was 62% and genome D was 29%; therefore, hexaploid pollen is 191% larger than diploid pollen.

Pedersen et al. (1961) determined pollen shedding and its relation to seed set of diploid and tetraploid rye. Although tetraploid pollen grains were almost twice the volume of the diploid, there was no difference in the distribution pattern which could be attributed to differences in size of pollen grains.

The genetic characteristics of the pollen supplied for cross-pollination is an important factor when considering wheat hybrids. Oganesyan (1964) showed differences in seed set of four varieties of wheat by pollinating with different pollen sources. He obtained 50.0 to 64.7% seed set when a source of a single closely-related variety of wheat pollen was used; 43.7 to 47.5% with a mixture of closely related pollen; 20.4 to 26.7% with a mixture of distantly related pollen; and 8.6 to 11.0% for a single distantly related pollen.

With the addition of rye pollen to wheat in intervarietal crosses Bardier (1963) discovered that seed set was altered. If the stigmas were pollinated with a wheat and rye pollen mixture, seed set was reduced, but if rye pollen was supplied prior to wheat pollen or a few hours afterwards a marked increase in seed set occurred. Kruzkova (1964) and Puskarev and Kvitko (1964) reported increases in seed set by supplemental rye pollination. Yields were improved and seed set was increased in 4 varieties from 4.1 to 18.5%, according to the variety.

One of the basic problems encountered in producing cross pollinated seed is the synchronization of flowering of male and female parents. Not only do varieties differ in their flowering date, but the introduction of male sterile cytoplasm has created additional problems. Fukasawa (1959) noted that Aegilops cytoplasmic factors delayed flowering, thus preventing proper synchronization of male-sterile (A lines) and pollinator (B lines). Using Ae. caudata and Ae. ovata cytoplasm Porter et al. (1965) found seed sets ranging from 1.8 to 20.5%. The low seed set was due to the fact that the male-sterile flowered approximately ten days later than the pollinator. Seed set with Ae. caudata cytoplasm was greater because its flowering period coincided more closely with that of the pollinator. Patterson and Bitzer (1966) presented data on seed set obtained from hand emasculated seed parents. The range of 9 to 91% seed set was attributed to whether or not the male sterile's receptivity coincided with the pollination cycle of the pollinator (B line).

Wilson and Ross (1962) reported highest seed sets in various ratios of male-sterile and pollinator lines where flowering began simultaneously.

Laptev (1963) reported protogyny as responsible for the low percentage of fertilization of emasculated plants. By applying nitrogen fertilizer the flowering period of the female parent was somewhat extended. He increased the seed set in two varieties 10.6% and 21.9%, respectively. Smith[3] found that T. timopheevi cytoplasm coincided more closely with the pollen parents than did Ae. ovata. The average per cent seed set for all strains containing Ae. ovata cytoplasm was 6.6% as compared with 22.6% for T. timopheevi cytoplasm. Glenn[4] reported that T. timopheevi strains were properly synchronized with pollinators because both reached 50% bloom on the same day.

---

[3]Personal Communication. 1966. Dr. E. L. Smith. Oklahoma State University. Stillwater, Oklahoma.

[4]Personal Communication. 1966. Dr. D. E. Glenn. Dekalb Agricultural Association, Inc. Dekalb, Illinois.

Faegri and van der Pijl (1966) reviewed factors affecting pollination. They mentioned that the feather like stigmas of Gramineae were more able to collect drifting particles than that of a leaf of the same gross area. Several studies have reported the effect of stigma age upon cross pollination. Kovacik (1962) indicated that stigmas aged two to four days were best suited for pollination, but under optimum conditions they would remain receptive up to ten to twelve days. Similar results were obtained by Bardier (1962) and Rajki (1962) who emasculated spikes at heading time and found that seed set increased with length of interval between heading and pollination. The maximum seed set was reached on the third or fourth day. Vozda (1962) observed that pollen selection by the stigma occurred at a definite stage in floral development. Young flowers have little or no pollen selection capabilities, but fertilization of older flowers gave less vigorous offspring. The best stigma age appears to be an intermediate one which may be the stage of full maturity.

Rajki (1962) studied the effect of developmental stage of anthers upon fertilization. Seed set increased with increasing stages of anther maturity. Seed set was highest when fresh pollen from yellow anthers which were just dehiscing was used. Balint, Kovacs, and Schneider (1959), Rajki (1962), and Sorokina and Laptev (1958) have observed the number of pollen grains reaching the stigma and resulting seed set. Balint and co-workers obtained seed sets of 69.9%, 92.6% and 100% on emasculated heads when one, two, and three anthers per floret were used for pollination, respectively. Yield was decreased 9% when only one anther was used. Rajki (1962) utilizing a similar technique reported more pollen grains per stigma with more anthers used. Higher seed set and kernel weight resulted from using more anthers. Sorokina and Laptev (1958) obtained pollen counts per stigma and per cent seed set in relation to length of exposure when emasculated heads were exposed for varying lengths of time. In 1954 the average pollen grains per stigma was 2.4 after 24 hours exposure. In 1955 heads exposed for 2, 25, and 108 hours revealed 2.0, 2.9 and 4.4 pollen grains per stigma. This resulted in 29.0, 42.0 and 51.8% seed set, respectively. Seed set with unbagged heads was 87.8%. In 1956 no pollen counts were made, but the seed set and length of exposure were as follows: 31.6%, 2-4 hr.; 52.8%, 8 hr.; 29.0%, 16-28 hr.; 44.4%, 48-100 hr.; 78.5%, unbagged.

In a three year study where many thousands of florets were emasculated and exposed for 1 to 15 days, Rajki (1962) obtained seed sets as high as 97% and as high as 85% when the female was exposed only 24 hours at the time of maximum pollen shedding. General increases in seed set were obtained with increasing days of exposure during the pollen shedding cycle. Ukolov, Puhalsky, and Maksimov (1963), working with cross-pollination of hybrid winter wheats in Russia, reported maximum seed set to occur when heads were exposed during the hours of maximum pollen counts. These results suggest that seed set is dependent on the amount of pollen available when stigmas are receptive.

By artifically culturing pollen of one variety, pollen mixtures of several varieties, and a mixture of wheat and rye pollen, Lui (1960) found that pollen grains excreted a liquid substance when in the presence of other pollen grains. This unnamed substance promoted pollen tube growth which may be the reason why several pollen grains per stigma resulted in a higher seed set.

The quantity of pollen reaching the female stigma through an air medium may not be as important as the quality of pollen received. Kovacik and Holienka (1963a) found wheat pollen under natural conditions to lose its germination capacity rapidly. The ability of pollen to fertilize decreased to 5% within one hour from the time of pollen shedding, and it took three hours for fertilization to take place. From their studies they deducted that the most suitable times for artificial crossing were 8 to 10 a.m. and 5 to 8 p.m.

Climatic factors have caused much of the variation which has been reported in hybrid wheat studies. Spirova (1962) revealed that the period of maximum flowering in wheat was correlated with changes in temperature and relative humidity of the air. Kovacik and Holienka (1963b) found that temperatures of 20-25^{o} C. (68-77^{o} F.) and a relative humidity of 60-70% were optimum for wheat pollination. Decreases in relative humidity below 50% and temperature increases above 25° C. decreased pollination. Salmon (1914) reported 19% sterility in Durum wheat under conditions of high temperatures and low relative humidity. Thirty-six per cent sterility was observed when relative humidity was lowered further by artificial means. Kovacik (1964) found temperatures below 20° C. (68° F.) with high humidity to be unfavorable for pollination.

Environmental effects on pollination have been studied in other cereal crops. Coffman (1937) reported that low seed set in oat crossings at high temperatures may be due to rapid desiccation of pollen and stigma by the drying effects of heat. He noted that low humidity and high evaporation are partly a result of high temperature. At low temperatures, anthers were spongy and did not open readily. Coffman and Stevens (1951) showed that high temperatures retarded normal flowering periods of oats. Flowering would not occur until later in the day when temperatures were favorable. Seed set on emasculated heads increased from 5.4 to 24.8% by pollination in the evening rather than during the normal flower shedding period of 2 to 5 p.m. Brown and Shands (1957) confirmed previous studies of temperature effects on seed set in oats. Depending on the temperature, stigma receptivity was found to be best at 1 to 3 days following emasculation. Harlan, Martin, and Stevens (1943) disclosed information on the effect of temperature in barley crosses. They remarked that the interval between emasculation and pollination was a function of temperature: As the temperature became higher, the interval became shorter, and vice versa.

Temperature and drought effects on male-sterile seed set have been observed by several recent studies. Lucken[5] mentioned that hot weather during flowering at Fargo, N. D., caused sterility in restorer (R-lines) and regular wheat varieties (B-lines) besides causing poor seed set in A-lines. Ausemus[6] noted similar low fertilization due to high temperatures at flowering time.

Livers (1964) reported that male-steriles gave lowest seed set in the locations which had the most drought. It was concluded that there was poor anther exsertion of the B-lines which decreased the amount of available pollen. Seed set ranged from 9 to 63% at 9 sites on 5 Kansas stations. The highest seed set was reported at Manhattan with ms^t x Ottawa, and the lowest was reported at Hays with ms^t x Bison. The average seed set was 35%. Corresponding yields ranged from 7 to 54% of the check but Manhattan data were not included.

In 1965 the average yield of five male-steriles grown at Garden City on fallow was 14.9 bushels per acre or 44.3% of the pollinators. Under irrigation ms^t x Bison yielded 60.1 bushels per acre or 95.7% of the average of six varieties.

---

[5]Personal Communication. 1966. Dr. K. Lucken. North Dakota State University. Fargo, North Dakota.

[6]Personal Communication. 1966. Dr. E. R. Ausemus. Northrup King. Minneapolis, Minnesota.

In fact, the sample of male-sterile Bison out-yielded its own pollen parent (Livers[7]). In 1966 it was found that seed set was very good on male-sterile Scout grown with irrigation in western Kansas. The yield was 61.4% of the pollinator. At Hays, Kansas in 1965 the extended pollination period had moderate temperatures and above average humidity and followed a rainy period. The average yield of three male-steriles was 57% of their pollinators. In 1966 at Hays extremely low seed sets were reported. In some instances less seed was harvested than was planted. The yield of the pollinators also was low due to spring freezes and a hail. The poor seed set was attributed to a short, dry pollination period during which flowers did not open and allow anthers to become extruded, or else flowers opened, but the filaments failed to elongate and force the anthers into the open where they could shed pollen into the atmosphere. Very few anthers could be found on the ground after blooming, and examination of developing fertile florets revealed that most anthers remained inside the glumes. Livers reported that this occurrence was noted at three dryland locations in western Kansas in different years. He thought slow growth and development due to drought before and during blooming caused failure of anther exsertion. Glenn[8] and Smith[9] stated that late freezes

[7]Personal Communication. 1966. Dr. R. W. Livers. Hays Experiment Station. Hays, Kansas.

[8]Personal Communication. 1966. Dr. D. E. Glenn. Dekalb Agricultural Association, Inc. Dekalb, Illinois.

[9]Personal Communication. 1966. Dr. E. L. Smith. Oklahoma State University. Stillwater, Oklahoma.

in western Kansas and Oklahoma have lessened the amount of viable pollen. Smith also reported that extreme variability in weather conditions and drought stress at heading time may have caused more cleistogamy than is normal. Porter[10] reported seed sets in Texas of only 15% on crossing blocks where extremely low rainfall had occurred. Even under irrigated conditions low seed set was found where the soil moisture level was not high enough at flowering time to promote good anther exsertion. Under conditions of sufficient soil moisture, seed set was examined to be 55 to 60% in a crossing block of male sterile Bison pollinated by a composite of the World Wheat Collection. Temperatures during the flowering period were below normal. The period of pollen shedding was somewhat extended by the different flowering habits of strains included in the collection.

Hoshikawa (1961) studied cytologically the effects of wheat fertilization at three temperatures--10, 20, and 30° C.--and three levels of nitrogen. He found the times required for fertilization at 10, 20, 30° C. were 11, 8 to 9, and 6 to 7 hours, respectively. At each temperature fertilization took place most rapidly under the medium level of nitrogen. The level of soil moisture was not mentioned, but it was assumed to have been adequate. Turov (1963) applied various fertilizers and micronutrients to the soil of pollen parents. He found improved pollen viability, better grain quality, and

---

[10] Personal Communication. 1966. Dr. K. Porter. Texas Agricultural Experiment Station. Bushland, Texas.

increased percentage of successful crosses between *T. durum* x *T. dicoccum* or *T. polonicum* when certain fertilizers were used. No specific nutrients and application rates were mentioned in the abstract. Both boron and manganese showed tendencies to cause patrocliny. Sekun (1964) stated that the type of flowering was affected by levels of fertility and soil moisture. When sufficient moisture was available before and during flowering, fertilizers increased chasmogamic flowering. Under droughty conditions fertilizers increased cleistogamic flowering. As reported before Laptev (1963) delayed flowering by applying nitrogenous fertilizers; thus, greater cross pollination was obtained between parents which did not have synchronized flowering periods.

As pollen must be liberated, transported and deposited by the wind, studies of the effects of wind on pollination are important. After pollen is released by the anther, its final destination is wholly dependent on the wind and air currents for transportation to a stigma. Gregory (1961) reviewed the movement of pollen from a source point. He stated that diffusion or growth of a pollen cloud was in all directions, but the main direction was down-wind and had the shape of a cone. The growth of the pollen cloud was measured by increases in the standard deviation after the center of the cloud had traveled three positions down-wind. Of course, the speed of the wind and the size of pollen grains would greatly influence the dispersal pattern from any one point. Faegri and van der Pijl (1966) indicated that the bouyancy of pollen was most important and that pollen weight was too dependent on relative humidity to be used in measuring dispersal. They also indicated that small populations, such as crossing blocks, are at a disadvantage for pollination because adequate pollen massivity is not obtained.

Saito (1964) reported on the wind profile within a wheat field. He stated that normal wind profiles have different shapes due to the strength of wind velocity at the crop surface. The increasing drag coefficient as wind passed over a field seemed to cause these different shapes. He also indicated that turbulence which is common in the temperate regions in the spring is affected by the wind profile.

Faegri and van der Pijl (1966) presented an equation which could be used to determine various factors of wind pollination. The following equation-- $\frac{n}{N} = \frac{a}{A}$ where n equaled the number of pollen grains carrying out pollination, N equaled the total output of pollen produced, a equaled the areas of stigmatic surfaces, and A equaled the total area of the surroundings--could be utilized to find one missing component if three components were known. This equation, however, does not consider down-wind and turbulence effects.

Jones and Newell (1946), utilizing glass slides covered with petroleum jelly, collected pollen at various distances from 1/10-1/4 acre fields of different grass species. These included corn and rye. Slides were exposed at 2.5, 5.0, and

10.0 foot levels at eight directions from the field. Slides were changed every 30 minutes at distances of 5, 15, 25, 40 and 60 rods. They found that it was necessary to collect only in a down-wind direction from the pollen source. The results of this study revealed that many factors are involved in pollen dispersal. They found that wind was important in anther exertion and pollen dispersion into the air. The pollen load decreased rapidly with distance for most grasses. Heavy pollen shedding occurred with more wind and more pollen was collected. The exact time of flowering appeared to be a function of temperature. Using the center of a rye field as 100% the percentages of pollen collected at 5, 15, 25, 40, and 60 rods from the field were 38.1, 7.2, 2.1, 0, and 0%, respectively in 1944. At the same distances in 1945 the percentages collected were 41.8, 21.4, 11.4, 4.8, and 1.0%, respectively. The difference in amounts of pollen collected in 1944 and 1945 was attributed to the speed of wind. The wind speed in 1944 was low compared to 1945. Similar results were obtained with corn pollen. Using the same distances as for rye, the percentages of pollen collected in 1944 were 10.7, 1.6, 1.1, .5, and .5%, respectively, and 17.2, 4.4, 3.0, 1.0, and .5%, respectively, in 1945. The stronger winds of 1945 were believed to cause the increase in pollen. Gregory (1961) indicated that wheat produced only a small amount of pollen compared to rye.

Ogden, Raynor, and Hays (1965) discussed the dispersion of corn pollen in relation to the speed of wind. It was found that 90% of the pollen fell within 25 feet of the source with a 1.8 to 2.5 m.p.h. wind. Bateman (1947) reported that only 1% of the corn pollen could be found at 50 and 60 feet respectively in two sampling years. Wind speed was not indicated.

Jones and Sieglinger (1951) used a defective endosperm in sorghum to determine the effect of wind direction on natural crossing. Highest crossing occurred in the block opposite the predominately south wind. The effect of wind speed was clearly demonstrated when light south winds in 1947 resulted in only 1.8% crossing as compared with 21.5% in 1946 when strong winds were recorded.

Smith[11], in Oklahoma, found seed set on male-sterile wheat to be the highest in crossing blocks opposite the predominant south winds which occurred during pollen shedding. Goertzen[12] indicated that prevailing south winds at Scott City, Kansas, had an effect upon seed set within crossing blocks. Smith[13] reported that the number of rows of pollinator south of the A-line rows determined the seed set and yield. With 4, 12, and 20 pollinator rows south of the male-sterile rows, seed set and yield were as follows: 18.35, 26.35,

---

[11]Personal Communication. 1966. Dr. E. L. Smith. Oklahoma State University. Stillwater, Oklahoma.

[12]Personal Communication. 1966. Mr. B. L. Goertzen. Frontier Hybrids. Scott City, Kansas.

[13]Personal Communication. 1966. Dr. E. L. Smith. Oklahoma State University. Stillwater, Oklahoma.

41.05%; 13.6, 22.0, and 29.3 bushels per acre, respectively.

Livers (1964) found that seed set in a range of distances up to 22 feet from the pollinator had little if any effect upon cross-pollination of male-sterile heads. The average seed set was 29%. Smith[14] measured the amount of seed set in *Ae. ovata* and Nebr.^{A} x Kaw male-sterile rows located 30, 90, and 130 feet to the north of the pollen source. A male-sterile check surrounded by pollinators had an average seed set of 34.9% and a yield of 11.7 bushels per acre. The remaining plots did not show a significant difference. The average seed set was 20.9% with a yield of 6.7 bushels per acre. It was concluded that distance from pollen source did not affect seed set within ranges of 30 to 130 feet. Wind was variable and pollen from a large wheat field approximately 350 feet away may have caused distortions in the seed set percentages. At Cherokee, Oklahoma, six rows of restorer were planted to the south of six Nebr.^{A} x Kaw male-sterile rows. The average seed set was 26.7%; however, the expected decrease in percent seed set with increasing distance from pollen was not recorded. With increasing distance seed sets of 16.2, 39.0, 33.4, 28.9, 23.9, and 18.8% were obtained in the six rows which were planted one foot apart.

Glenn (1965) studied cross-pollination in Hard Red Spring wheat. A ratio of two *T. timopheevi* male-sterile 8-foot drill

---

[14] *Ibid.*

strips to one pollinator drill strip was utilized to obtain seed set at various distances from the pollen source. Both seed set and seed weight were recorded. Seed weight generally ranged from 3 to 5% higher than seed set and is probably more indicative of actual yield. At 2, 4, 6, 8, 12, and 16 feet from the pollen source seed sets of 62, 56, 65, 59, 57, and 30% were recorded, respectively. Glenn[15] reported cross-pollination results of Hard Red Winter wheat using the same _T. timopheevi_ cytoplasm and pollen source at two locations. In Shawnee County, Kansas, drill strips of pollinator 10 feet wide were alternated with drill strips of male-sterile 7 feet 8 inches wide. Samples taken 2 feet 4 inches north of the pollen source, 2 feet 4 inches south of pollen, and 4 feet 8 inches from both north and south of pollen had average percentage seed weights compared to the pollinator of 32.5, 31.9, 39.2%, respectively. A yield of 18 bushels or 36% of the pollinator was measured for the entire five acre field. At Moore County, Texas, pollinator and male-sterile lines were alternated in 13 feet 4 inches drill strips. This study and the previous one were planted in an east west direction to take advantage of prevailing south winds. Samples taken 3 feet 4 inches north of the pollinator, 3 feet 4 inches south of pollen, and 9 feet 2 inches from both north and south of pollen had average percentage seed weights compared to the

[15]Personal Communication. 1966. Dr. D. E. Glenn. Dekalb Agricultural Association, Inc. Dekalb, Illinois.

pollinator of 44.6, 50.5, and 43.3%, respectively. A yield of 23 bushels or 48.5% of the pollinator was measured for the entire 15 acre field.

Porter[16] reported that male-sterile wheat with a pollinator set only slightly more seed than male-sterile rows planted 1 to 4 feet adjacent to the pollinator. Patterson and Bitzer (1966) found that a 3:1 ratio of B- to A-lines produced 70% seed set, whereas a 2:1 ratio produced about 80% seed set.

Wilson and Ross (1962) reported only small differences in seed set--69.8 to 72.6%--from 3:1 and 1:1 ratios of B- to A-line, respectively. This was obtained under simulated field conditions where several potted plants of Ae. ovata male-sterile lines were exposed to pollen at distances of 2.5, 5.0, and 7.5 feet. Seed set was calculated using two seeds per spiklet as normal. In this study Parker (CI 13285) was used as the pollen parent.

Lucken and Maan (1965) presented seed set data which were obtained in crossing blocks grown at three locations in North Dakota. Crossing blocks consisted of 1 or 2 rows of T. timopheevi male-sterile and 6 to 10 rows of pollinator on either side. Seed sets were not only variable between varieties at a location, but also with varieties between locations. Seed set was calculated as in the previous study. The range

[16]Personal Communication. 1966. Dr. K. Porter. Texas Agricultural Experiment Station. Bushland, Texas.

at Fargo was from 14.5 to 59.4%, at Casselton 41.1 to 56.5%, and at Langdon 26.0 to 70.5%. Male-sterile Chris seed set ranged from 18.6% at Fargo to 67.8% at Langdon. Male-sterile Justin seed set ranged from 16.6% at Fargo to 26.2% at Casselton.

Lucken[17] used a one to one ratio of male to female by planting alternate 10 foot drill strips of male-sterile and normal Chris. A three foot space was provided between drill strips for purity. Samples were taken 3 feet west of the pollinator, 3 feet east, and 8 feet from both east and west. Seed sets were 53.3, 57.2, and 41.5%, respectively. Heads selected at random throughout the strip had 51.9% seed set. The yield of the male-sterile was 44.3% of the pollinator.

At Pullman, Washington, Olsen (1966) reported the results of crossing blocks. These contained at least six rows of Gaines pollinator to each row of male-sterile. In 1964, 35.5% seed set was obtained, in 1965, 15.8% (early fall planting) and 64.0% (late fall planting). In 1965 at Lind and Walla Walla, Washington, seed sets of 18.0 and 69.0% were obtained, respectively. He concluded that a combination of climatic and ecological factors caused the wide seed set variation. By using various ratios of A- to B-lines at the same location, Olsen tried to establish a relationship between airborne pollen and seed set. In a Gaines crossing block,

---

[17] Personal Communication. 1966. Dr. K. Lucken. North Dakota State University. Fargo, North Dakota.

he obtained 58.2, 41.6, and 64.0% seed set for 1:2, 1:4, and 1:8 ratios of A- to B-lines, respectively. Since variation within blocks was high and no definite pattern between blocks could be established, no relationship between seed set and the amount of pollinator plants could be made. He found that crossing blocks with 1:1 ratios had lower seed sets than higher B:A-line ratios, but on a per unit area basis the smaller ratios produced more yield. Olsen concluded that the percent seed set appeared to depend on the ratio of A- to B-lines or the variety used as the B-line. Relative rankings of pollen shedding ability seemed to agree with the effectiveness of the pollinator line.

Watkins and Curtis[18] studied the influence of distance on the seed set of male-sterile rows. From the center of a 115 x 115 foot pollinator field, eight male-sterile rows extended 80 feet from the corners and 60 feet from the sides. He found seed sets to decrease with distance from the field, but the amount of seed set varied considerably with direction. The rows extending in the north and west directions showed the largest seed set. The southwest row had the lowest seed set. It was noted that there was only a 20% synchronization of flowering which greatly lowered the seed set.

[18] Personal Communication. 1966. R. E. Watkins and Dr. B. C. Curtis. Colorado State University. Fort Collins, Colorado.

METHODS AND MATERIALS

Field Plot - Newton, Kansas

A one-acre field of Ottawa Selection (KS 60770) isolated in a field of winter barley was the source of pollen. Four 200-foot rows of male-sterile wheat were planted outward from each corner of the field (Fig. 1). The genotype of the west, east, and south rows was male-sterile *T. timopheevi* x Bison4 2x open pollinated with hard wheats 3x Bison. Two rows planted east to west through the center of the pollinator were *T. timopheevi* x Bison4 2x Ottawa4 3x Ottawa Selection3. The north row and a row planted along the north side of the pollinator field was a mixture of the two pedigrees.

The project was planted 6 October, 1965 and harvested 25 June, 1966.

Pollen Collection

The 200-foot rows were subdivided into ten 20-foot segments. In the center of each segment a 2 x 2 inch stake was driven to head height which served as a collection station. Collection stations were also placed in each corner and the center of the pollinator field as well as 100 feet in each direction from the middle of the sides of the pollinator field (Fig. 1). The resulting collection distances in the four rows were 10, 30, 50, 70, 90, 110, 130, 150, 170, and 190 feet from the pollen parent. The center collection served as a check. A 3/4 inch band of clear tape on glass

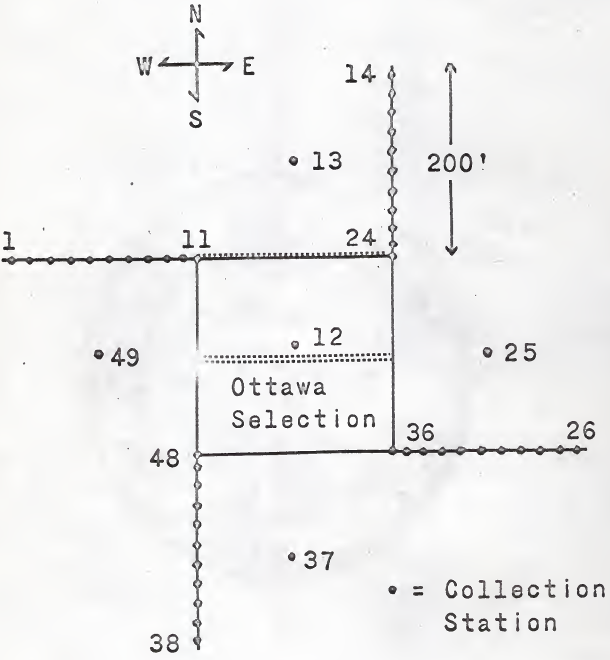

Fig. 1. Newton field plot to determine pollen amount and distribution as it influences seed set of A-line rows in various directions and distances from the source of pollen. Dotted lines were A-line rows adjacent and within the Ottawa Selection field.

rods 5 x 150 mm was the collecting device. Silica gel applied to the tape trapped air-borne pollen. Rods were placed in the pollen collection stations in a systematic procedure. Each station was numbered from 1 to 49 (Fig. 1) and rods were exchanged in the same order each changing time. Rods were exposed for one hour periods and then collected and replaced by a fresh uncontaminated rod. A sealed box was utilized during collections to prevent contamination. This was necessary since collections were made near the center of the pollinator field. As the rods were stationary the tape was marked with pencil and the marked surface was placed into the wind. The mark served as a reference point for counting pollen under a microscope. If drastic wind changes would have occurred during a collection period the pollen counting location on the tape would have been altered. After the rods were collected the tapes were removed and placed on glass slides which were marked by collection time and station. The slides were sealed in slide boxes until microscope examination.

Collections on rods were made each day from 7 a.m. to 5 p.m. on May 17, 18, and 19, 1966. As Jones and Newell (1946) reported only small amounts of grass pollen were trapped in directions against the wind, collections were made only in the locations down-wind from the pollen source. A few collections were made up-wind to test for contamination of foreign pollen.

Two Kramer-Collins spore traps (Kramer and Pady, 1966) were placed 5 and 40 feet, respectively, down-wind from the pollen source. The collection opening was about 18 inches above the ground. These traps deposited pollen grains in a band on 25 x 75 mm slides. A clock motor advanced the slide and activated a microswitch which turned on a battery powered vacuum pump. A band was collected every 30 minutes with two sampling periods of 3 minutes 8 seconds each. Since the flow meter was adjusted to 0.8 cubic foot per minute, a total of 5 cubic feet of air was sampled for each band. Slides were changed at 6 a.m. and 6 p.m. each day, and pollen counts were made the same day as collected.

Pollen counts were made on a microscope with a 10 power objective and a 10 power eyepiece. The diameter of the field was approximately 1.38 mm. Rod tapes were read starting at the marked point and across the entire 3/4 inch tape; therefore, 22.6 mm^2 were observed. Each band on the sampler slide contained material from 5 cubic feet of air. The pollen on the entire band was counted equal to an area of 34.5 square mm. Approximately 95% of the pollen grains could be counted in the 1.38 mm. diameter field. Lower magnification to include all pollen would have made counting very difficult.

Meteorlogical Observations

At both Newton and Manhattan an official weather shed was used to house minimum and maximum thermometers and a hydrothermograph which recorded temperature and humidity on a continuous daily chart. Wind speed and direction was observed by using a hand anemometer. Wind observations were taken periodically and when a change was noted. Rainfall was taken from airport data at Newton and from agronomy farm records at Manhattan.

Yield and Seed Set

A 9.6 foot section was harvested for yield from each 20-foot segment of the A-line row. Four samples were cut from the male-sterile rows in the center of the field, the row along the north side, and the pollinator field. The grain obtained was weighed in grams and multiplied by 5 to give pounds per acre.

To determine seed set ten heads were selected at random from each sampling area. Forty additional heads were taken at random from the bundles before threshing to provide a larger sample; therefore, a total of 50 heads were counted. Two florets per spikelet were used as normal. Seed set percent equaled: $\frac{\text{total seeds/head} \times 100}{2 \times \text{spikelets/head}}$. This method was used at both Newton and Manhattan.

Field Plot - Manhattan, Kansas

The effect of male-sterile exposure was studied by using male-sterile *T. timopheevi* x Bison4 2x Ottawa4 3x Ottawa Selection3 as the female and Ottawa Selection as the pollinator. A drill strip of male-sterile was planted in the pollinator field with a 9-hole, 8-inch drill (Fig. 2). Ottawa

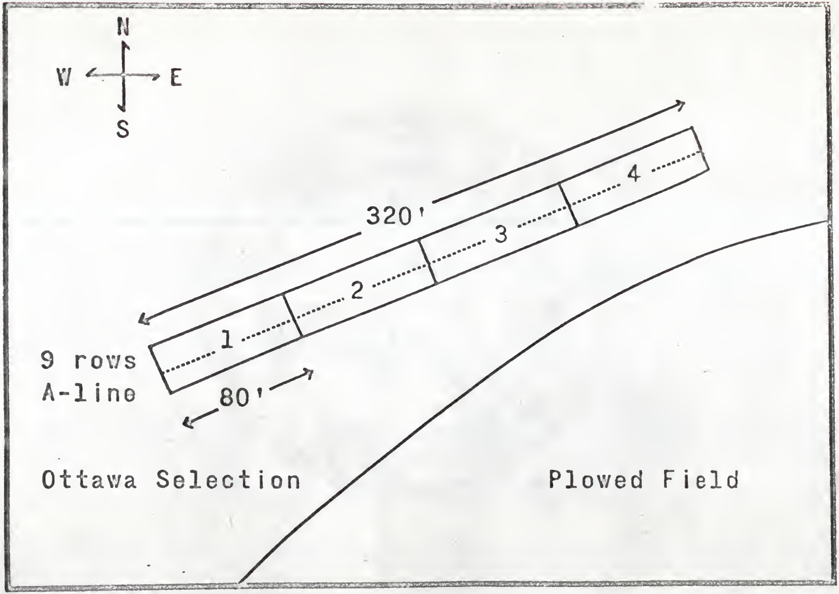

Fig. 2. Field plot of the male-sterile exposure study at Manhattan. The dotted row was utilized for bagging and exposing A-line heads.

Selection was planted to the west, south, and east of the male-sterile block. The study was planted 7 October, 1965 and harvested 26 June, 1966.

Starting at the west edge of the male-sterile rows, four 80-foot linear replications were marked. All heads that were utilized were present in the fourth row from the south side.

In a field of Parker on the agronomy farm, two rows of male-sterile T. timopheevi x Bison5 2x Parker5 were planted. Seed set of male-sterile Parker and the effect of isolation bags upon pollinator seed set were determined. Sixty male-sterile heads were randomly tagged before flowering and 60 were tagged and covered with glycine bags to prevent pollination. Similarly 60 pollinators were tagged and 60 were tagged and bagged before flowering.

Pollen Collection

The Kramer-Collins spore trap was used to determine the amount of pollen in the air. The trap was placed approximately 10 feet south of the male-sterile rows and 80 feet from the west end of the A-line rows. No rods were used in the Manhattan study. The same technique used at Newton was utilized for counting pollen.

Exposure Procedure

As the length of the wheat flowering period varies with weather conditions, this study was designed for a seven day pollination period. A male-sterile exposure schedule was developed to expose heads on different days during pollen shedding for different days of duration (Table 1). The start of the exposures was on the first pollen shedding day.

Table 1. Exposure schedule per replication of male-sterile heads exposed on various days of May for various days of duration during pollen shedding.

Duration of Exposures[a]	No. of Heads[b]	Days of May 21	22	23	24	25	26	27	Total Heads per Rep.
1	5	X[e]	X	X	X	X	X	X	35
2	5	X	X	X	X	X	X		30
3	5	X	X	X	X	X			25
4	5	X	X	X	X				20
5	10	X	X	X					30
6	10	X	X						20
7	15	X							15
Check[c]	15	X							15
Check[d]	15								15

[a]Duration of male-sterile exposure in days

[b]The number of heads exposed per X per day

[c]Male-sterile heads exposed the entire pollen shedding period

[d]Male-sterile heads bagged the entire pollen shedding period

[e]This figure indicates that exposures were made on that day

A rebagging schedule was devised to replace glycine bags on designated heads after the proper duration of exposure to pollen (Table 2). A system of colored tags, which were randomly placed on male-sterile heads that were estimated to be in the same developmental stage, was utilized in the exposure and rebagging schedules. All tags were oil treated to prevent insect damage and fading and were placed below the flag leaf to reduce loss by wind.

Table 2. Rebagging schedule per replication of male-sterile heads exposed on various days of May for various days of duration during pollen shedding.

Days of May							
21	22	23	24	25	26	27	28
Exposure only	21[a]-1[b]	22-1	23-1	24-1	25-1	26-1	27-1
		21-2	22-2	23-2	24-2	25-2	26-2
			21-3	22-3	23-3	24-3	25-3
				21-4	22-4	23-4	24-4
	[c]				21-5	22-5	23-5
						21-6	22-6
							21-7

[a]The date of exposure in May

[b]The duration of exposure in days

[c]All groups included under a particular day were rebagged that day.

Seed set of the Ottawa Selection was determined by bagging 60 heads and tagging 60 heads. This determined the effect of glycine bags upon pollinator seed set. The two groups of 60 heads each were equally divided into four replications.

Statistical Analysis

At Newton, correlation coefficients were determined between paired observations at the distances of 10, 30, 50, 70, 90, 110, 130, 150, 170, and 190 feet from the pollinator for yield and seed set, yield and pollen count, and seed set and pollen counts within male-sterile rows. Pollen counts, yield, and seed set were correlated between rows. A correlation coefficient was determined for the two methods of pollen sampling at the distances of 5 and 40 feet.

At Manhattan, an analysis of variance was conducted to investigate possible significance of day and date effects. Since the number of heads harvested and counted varied from group to group, the mean was used for analysis. As the data were recorded in percentages an arcsin transformation was performed before analysis conducted. All data are reported in the arcsin value since it has a normal distribution. The Least Significant Difference (LSD) was calculated for those sources of variation which showed significance in the analysis of variance (Snedecor, 1956).

Correlation coefficients were determined between the pollen counts per date and the seed set of the one-day male-sterile exposure and between pollen counts per date and the average seed set of that date.

Analysis of variance was conducted to determine if isolation bags had any effect on the seed set of the pollinators, Parker and Ottawa Selection.

RESULTS

Newton - Precision of Technique

Only one row of male-sterile wheat was present in each direction from the pollen source as only correlations and general observations could be made because there was no replication.

The Kramer-Collins spore trap works at an efficiency of 100% in 2 m.p.h. winds, but this efficiency decreases rapidly with increasing wind speed. As samples were taken in a wide range of wind speeds the amounts of pollen collected probably varied somewhat because of the changing efficiency of the traps. The effect of wind speed was probably reduced because the openings of the collectors were only 18 inches from the ground where the wind speeds were greatly modified by the wheat. Only one tape for each sampling sample distance was used.

Glass rods with tape containing silica gel exposed the surface perpendicular to the ground. Pollen which fell downward due to gravity may not have been collected with much efficiency. However, the round rods have the advantage over other methods like slides in that the curved surface forms a raised area where pollen collection efficiency is great. Although the potential quantities of pollen being collected are reduced, the efficiency remains high.

The male-sterile rows varied in stand because of poor fall emergence. This made sampling for yield difficult. A few fertile plants occurred in the male-sterile rows which may have influenced seed set.

Pollen Collection

Pollen collections made by the Kramer-Collins spore traps at the distances of 5 and 40 feet from the Ottawa Selection pollinator field revealed the effect of distance on the quantity of pollen collected and the diurnal pollen shedding pattern of wheat (Fig. 3). The length of the pollen shedding period was six days although little pollen was collected on 14, 15, and 19 May. The greatest amount of pollen was collected on 17 May. On this day over one-half of the pollen shed throughout the flowering period was collected. The amount of pollen collected at the 40 foot distance was about 30% of the amount collected at the 5 foot distance. The relative amounts are shown in Fig. 3.

A comparison of the diurnal pollen shedding patterns exposed the two daily pollen shedding periods of wheat. One occurred in the morning from 6 to 8 a.m. and the second occurred in the afternoon from 4 to 6 p.m. The time at which the pollen began to shed seemed to be a function of temperature. Morning flowering occurred after a warming trend, but if the night temperature was high flowering started at 4 or 5 a.m. (Fig. 4). This occurred on the night of 16 May which resulted in tremendous flowering and pollen shedding before 6 a.m. on 17 May. The afternoon flowering period was at the high temperature on cool days, but was delayed until late afternoon on warmer days.

The amounts of pollen collected on an hourly basis throughout each of the pollen shedding days are shown in Figs. 4 and 5. Two pollen shedding periods are evident. One occurred in the early morning and another occurred in the late afternoon.

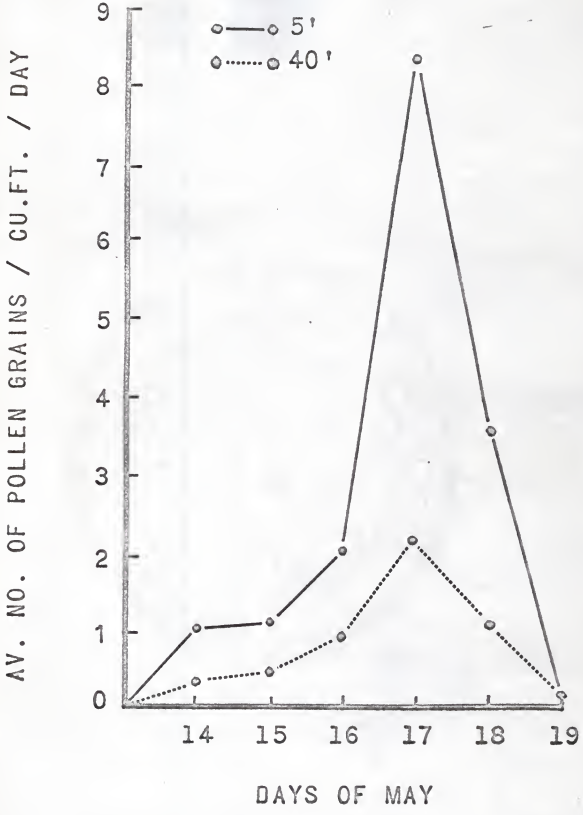

Fig. 3. The average number of pollen grains collected per cubic foot per day of pollen shedding at Newton with the Kramer-Collins spore traps, located 5 and 40 feet from the source of pollen.

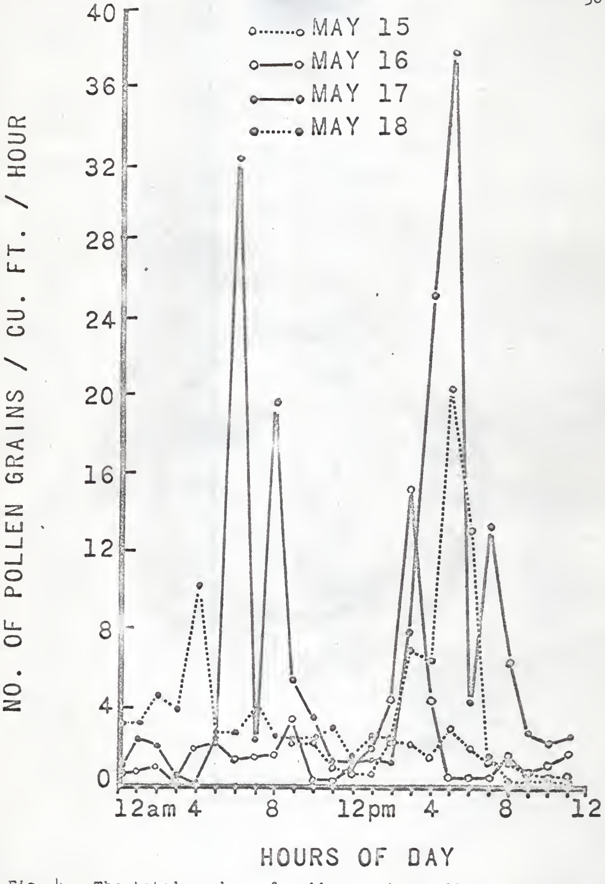

Fig. 4. The total number of pollen grains collected per cubic foot per hour during the days of pollen shedding at Newton with a Kramer-Collins spore trap which was located 5 feet from the source of pollen.

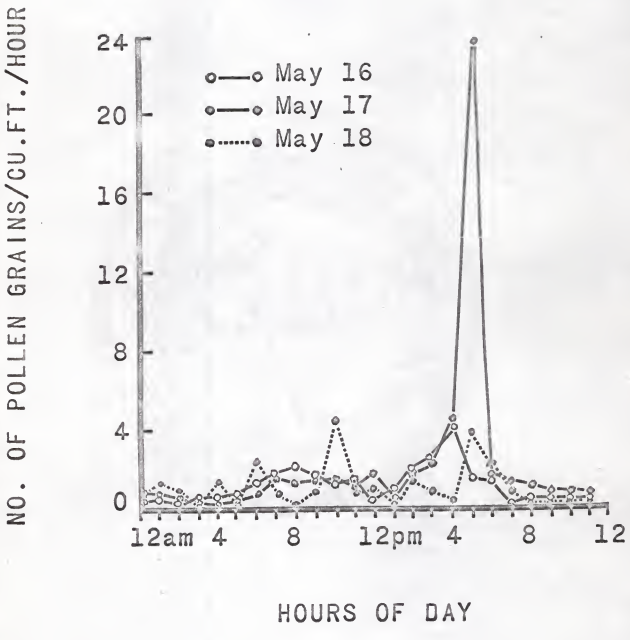

Fig. 5. The total number of pollen grains collected per cubic foot per hour during the days of pollen shedding at Newton with a Kramer-Collins spore trap which was located 40 feet from the source of pollen.

Table 3. The pollen counts, seed set, and yield recorded for male-sterile wheat at various sampling distances from the source of pollen at Newton.

Distance from Pollen	West			North			East			South					
	Pollen[a]	Yield[b]	Seed Set[c]	Pollen[d]	Yield	Seed Set	Pollen	Yield	Seed Set	Pollen	Yield	Seed Set	Av. Pollen	Av. Yield	Av. Seed Set
0	147	----	----	----	----	----	66	----	----	246	----	----	153.0	----	----
10	122	1.75	13.26	----	2.88	13.40	31	.92	5.21	132	2.50	8.50	95.0	2.01	10.09
30	132	1.85	11.82	----	2.77	10.64	10	1.23	3.82	106	2.65	7.23	82.7	2.13	8.38
50	116	1.30	6.28	----	1.08	6.70	10	1.38	1.82	64	2.93	8.85	63.3	1.67	5.91
70	109	1.23	5.57	----	2.63	8.00	7	1.50	1.92	58	1.85	5.59	58.0	1.80	5.26
90	89	1.08	6.95	----	2.65	6.63	4	.62	1.55	42	1.02	3.52	45.0	1.34	4.66
110	78	.65	4.80	----	1.58	6.09	3	.97	2.37	32	1.40	2.73	37.7	1.15	4.00
130	47	.80	1.90	----	1.83	4.08	1	.80	2.12	20	1.62	3.10	22.7	1.26	2.80
150	40	.63	1.14	----	1.23	5.20	1	1.22	3.06	23	1.52	3.98	21.3	1.15	3.35
170	38	.85	2.01	----	1.62	6.70	1	.33	.66	28	1.23	3.76	22.3	1.01	3.28
190	28	.15	.55	----	.78	4.09	2	.45	2.44	8	1.25	3.09	12.7	.66	2.54
Check				----									485	8.45	42.31

[a]Total pollen counts from glass rods for all hours of collecting in that direction

[b]Yield recorded in bushels per acre

[c]Seed set recorded in percent

[d]No collections made for north row

Pollen Counts, Seed Set, and Yield

The pollen counts, yield, and seed set of the male-sterile segments in the 200-foot rows and within the pollinator field are recorded in Table 3. As no pollen was collected in the north row only seed set and yield data were available.

A comparison of the seed set obtained at various distances from the pollinator, the check grown within the B-line field, and the pollinator are given in Table 4.

Table 4. Percent seed set of the male-sterile at various distances from the pollination compared with the check and pollinator at Newton.

Distance from Pollen in feet	Seed Set av. percentage[a]	Percent of Check	Percent of Pollen
10	10.09	23.9	11.0
30	8.38	19.8	9.1
50	5.91	14.0	6.4
70	5.26	12.4	5.7
90	4.66	11.0	5.1
110	4.00	9.5	4.3
130	2.80	6.6	3.0
150	3.35	7.9	3.6
170	3.28	7.9	3.6
190	2.54	6.0	2.8
ms North row	31.42[b]	74.3	34.1
Check[c]	42.31[b]		46.0
Pollinator	92.06[b]		

[a]Seed set percentage is an average of four rows

[b]Seed set percentage is an average of four samples

[c]Male-sterile grown in the pollinator field

Average seed set decreased with distance from the source of pollen. The range of percentages as compared to the check was 6.0% at 190 feet to 23.9% at 10 feet. The north row male-sterile showed 74.3% of the check and 34.1% of the pollinator. The check was 46.0% of pollinator and the range of percentages in the male-sterile rows as compared to the pollinators was 2.8% at 190 feet to 11.0% at 10 feet.

The yield of the male-sterile at various distances as compared with the check and the pollinator are given in Table 5.

Table 5. Yield of male-sterile at various distances from the pollinator as compared to the yield of the check and pollinator at Newton.

Distance from Pollen	Av. Yield[a] in Bu./A.	Percent of Check	Percent of Pollinator
10 ft.	2.01	23.8	7.6
30	2.13	25.2	8.0
50	1.67	19.8	6.3
70	1.80	21.3	6.8
90	1.34	15.9	5.0
110	1.15	13.6	4.3
130	1.26	14.9	4.7
150	1.15	13.6	4.3
170	1.01	12.0	3.8
190	0.66	7.8	2.5
ms North row	6.38[b]	75.5	24.0
Check	8.45[b]		31.8
Pollinator	26.55[c]		

[a]Average yield of the four rows

[b]Check and North row yields are averages of four samples

[c]Yield adjusted to compensate for row spacing

Yield of male-sterile segments also generally decreased with distance from the pollen source. The percentages of the check ranged from 7.8% at 190 feet to 25.2% at 30 feet. The north row male-sterile showed 75.5% of the check. The check had

24.0% seed set of pollinator. The range in the male-sterile rows was from 2.5% at 190 feet to 8.0% at 30 feet.

Correlations

The two methods of collecting pollen were correlated at the distances of 5 and 40 feet from the pollinator (Table 6).

Table 6. Correlation of pollen collected at Newton on glass rods and the Kramer-Collins spore traps at the distances of 5 and 40 feet from the pollinator.

Distance from Source of Pollen	Day of May	Total Pollen Collected[a] Pollen Trap	Rods[b]
5 feet	16	306	131
	17	438	198
	18	283	54
40 feet	16	124	118
	17	121	96
	18	107	10
r = +0.92**			

[a]Total pollen collected during the hours when rod collections were being made

[b]Counts are averages between glass rod pollen counts obtained at 0 and 10 feet and 30 and 50 feet

**Significant at the .01 level

The correlation coefficient, +.92, was highly significant which indicated that the two methods were similar in amount of pollen collected.

The correlation of pollen counts and seed set of male-sterile rows at various distances from the pollinator are presented in Table 7.

Table 7. Correlation of pollen counts and seed set percentages of male-sterile rows at various distances from the pollinator at Newton.

Seed Set Row	Pollen Row	r
West	West	+0.95**
East	East	+0.83**
South	South	+0.94**
Total	Total	+0.995**

**Significant at the .01 level

Correlations of total yield and pollen collected at various distances from the pollinator are presented in Table 8.

Correlations of the seed set percentages and yields of the male-sterile at various distances from the pollinator are evident in Table 9. All correlations were highly significant.

Correlations for pollen counts, seed set, and yield also were determined between male-sterile rows. The correlation of row yields is presented in Table 10, seed set in Table 11, and pollen counts in Table 12.

Environmental Data

Wind Velocity

The velocities of wind recorded during the pollen shedding period at Newton, Kansas are presented in Table 13. A variation of wind directions helped to supply pollen to all male-sterile rows, but no south wind was present during day time pollen collections by glass rods; therefore, no pollen

Table 8. Correlations of yield of the male-sterile and pollen counts at various distances from the pollinator at Newton.

Distance from Pollen in feet	Total Yield[a] in bushels	Total Number of Pollen Counts[b]
10	5.17	285
30	5.73	248
50	5.61	190
70	4.58	174
90	2.72	135
110	3.02	113
130	3.22	68
150	3.37	64
170	2.41	67
190	1.85	38
Check	8.45[c]	459

Yield row - Pollen row

1. Total yield-Total pollen r = +.96**
2. West yield -West pollen r = +.98**
3. East yield -East pollen r = +.65*
4. South yield-South pollen r = +.91**

* Significant at the .05 level

**Significant at the .01 level

[a]Total yield of the west, south, and east rows

[b]Total pollen counts of the west, south, and east rows

[c]Average yield of four samples

Table 9. Correlation of seed set and yield of male-sterile rows at various distances from the pollinator at Newton.

Seed Set Row	Yield Row	r
West	West	+0.96**
North	North	+0.97**
East	East	+0.89**
South	South	+0.99**
Total	Total	+0.98**

**Significant at the .01 level

Table 10. Correlation of yields between rows at various distances from the pollinator at Newton.

Row Directions	r
West-North	+0.96**
West-East	+0.91**
West-South	+0.96**
North-East	+0.90**
North-South	+0.91**
East-South	+0.96**

**Significant at the .01 level

Table 11. Correlation of seed set percentages between rows at various distances from the pollinator at Newton.

Row Directions	r
West-North	.94**
West-East	.89**
West-South	.92**
North-East	.95**
North-South	.98**
East-South	.91**

**Significant at the .01 level

Table 12. Correlation of pollen counts between rows at various distances from the pollinator at Newton.

Row Directions	r
West-East	.79**
West-South	.92**
East-South	.95**

**Significant at the .01 level

Table 13. Wind velocities recorded during pollen shedding of Ottawa Selection at Newton, Kansas.

Date in May	Time	Speed[c]	Direction
15	6 a.m.[a]	23	SSW
	1 p.m.	12	NW
	2 p.m.	8	NW
	6 p.m.[b]	8	N
16	6 a.m.[a]	10	ESE
	1 p.m.	20	SE
	4 p.m.	15	SSE
	6 p.m.[b]	5	SSE
17	6 a.m.[a]	Calm	Slight S
	7 a.m.	5	NE
	9 a.m.	4	ESE
	11 a.m.	6	NE
	4 p.m.	15	N
	6 p.m.[b]	17	N
18	6 a.m.	1	N
	8 a.m.[a]	8	NNW
	12 Noon	15	NNW
	5 p.m.[b]	20	NW

[a]Wind velocity during the morning period of pollen shedding

[b]Wind velocity during the afternoon period of pollen shedding

[c]Wind speed in miles per hour

counts were available for the north row. Low wind speeds were noted during two morning pollen shedding periods. One was 17 May, the peak pollen shedding day.

Temperature

The recorded temperatures for maximum, minimum, morning, and afternoon flowering periods of Ottawa Selection are presented in Figure 6. Above average temperatures were recorded on two days. A hydrothermalgraph recorded observations on a continuous daily chart. The precision of the instrument was checked daily by maximum and minimum thermometers and a sling psychrometer.

The morning flowering occurred after a warming trend on two days while the afternoon flowering occurred after the high temperature for the day had been recorded. Higher afternoon temperatures resulted in delayed flowering periods.

A frost occurred on 13 May or just 2 days before the start of pollen shedding. Very eradic temperature variations and late spring frosts occurred during the juvenile and reproductive growth stages of the wheat.

Relative Humidity

The recorded relative humidity for maximum, minimum, morning, and afternoon flowering periods of Ottawa Selection are presented in Figure 7. All observations were recorded on a continuous hydrothermalgraph chart.

The humidity during the early morning was high each day,

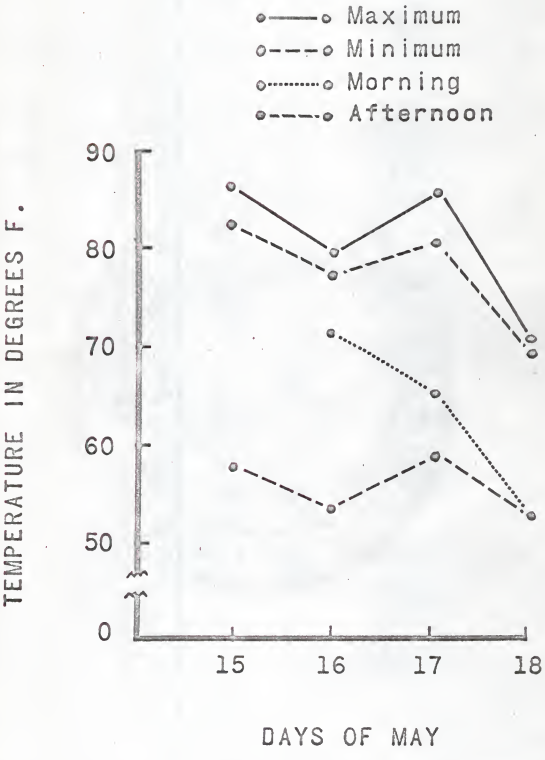

Fig. 6. The recorded temperatures for maximum, minimum, morning and afternoon flowering periods of Ottawa Selection grown at Newton.

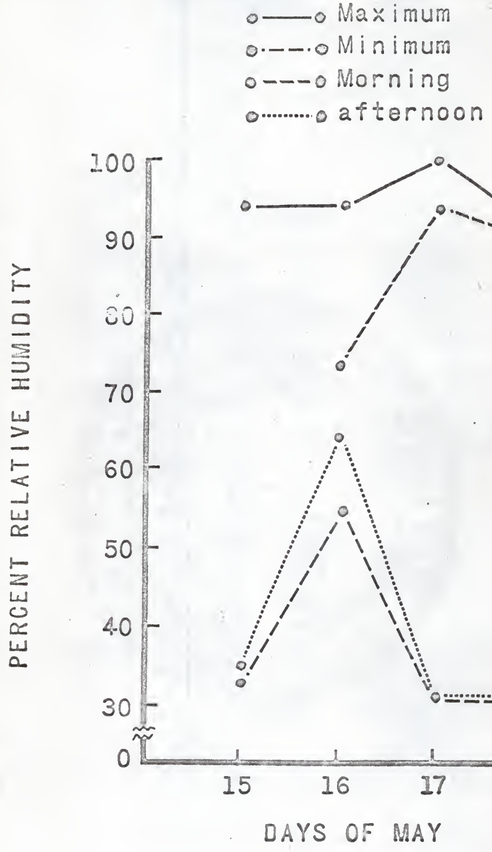

Fig. 7. The recorded relative humidity for maximum, minimum, morning and afternoon flowering periods of Ottawa Selection grown at Newton.

but the afternoon humidity on three days was relatively low (below 35%). The morning flowering period occurred when the humidity was above 90% on two days. The afternoon flowering period occurred on three days when the humidity was low.

Precipitation

Only 0.1 inch of rain fell during the pollination period on 18 May, the last pollen shedding day. The time of the rainfall was from 7 to 8 a.m.

Although soil moisture readings were not taken it was concluded that adequate soil moisture was not available during flowering. Large cracks were evident in the soil surface and moist soil was not found at the 4 inch depth. Total precipitation from 1 January through maturity was only about one-half of normal. The amount received was 7.23 inches or 8.00 inches below normal. The precipitation for May was .58 inch, or 3.83 inches below normal (Kansas Climatological Data, 1966).

Competition

The row spacing for the Ottawa Selection field was 8 inches, but the male-sterile rows had a 16-inch space on each side before the first strip of Will barley was planted. As the male-sterile rows had less competition for moisture than the male-sterile and pollinator plants in the one-acre field, the maturity of the male-sterile rows was delayed. The low seed sets at close distances to the pollinator as compared to the check within the pollen source revealed this effect. It was estimated that about 20% of the male-sterile flowers were in bloom during the 6-day period of observations.

Manhattan - Precision of Technique

This study involved bagging heads to control pollination. Heads for bagging were selected at the same stage of development. Culm breakage was noted on bagged heads. The percentage of heads used for the analysis was 81.5%. Approximately 19% of the bagged heads were lost due to wind damage of culms and loss of tags.

Only one trap was used for pollen collection. Variation in sampling technique could not be measured.

Pollen Collections

Pollen collections made by the Kramer-Collins spore trap in the Ottawa Selection pollinator field showed the quantity of pollen collected each day during the pollination period (Figure 8). The pollen shedding period was 7 days; however, only small amounts of pollen were collected from the 23rd through the 26th of May. The peak pollen shedding days were 21 and 22 May.

Morning and afternoon pollen distribution was similar to that observed at Newton (Figure 9). The amounts of pollen collected on an hourly basis throughout the pollen shedding days are presented in Figure 9. Not only can the two daily

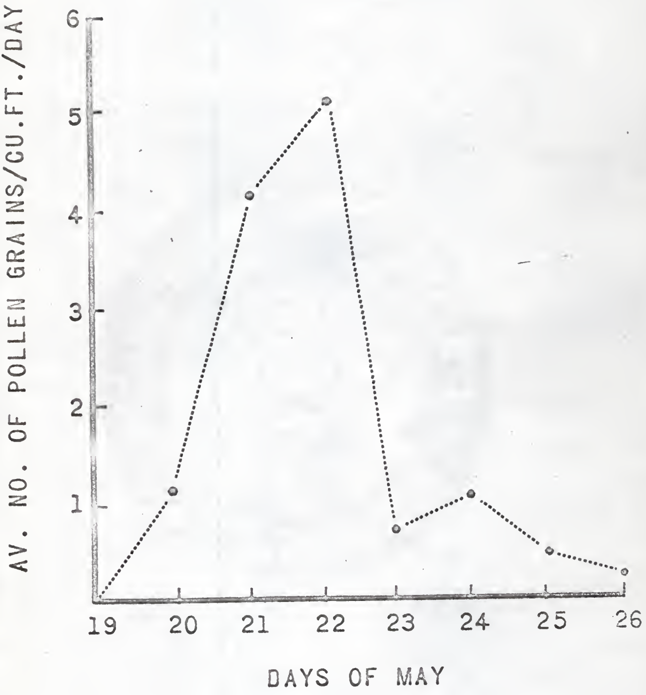

Fig. 8. The average number of pollen grains collected per cubic foot per day of pollen shedding with the Kramer-Collins spore trap at Manhattan.

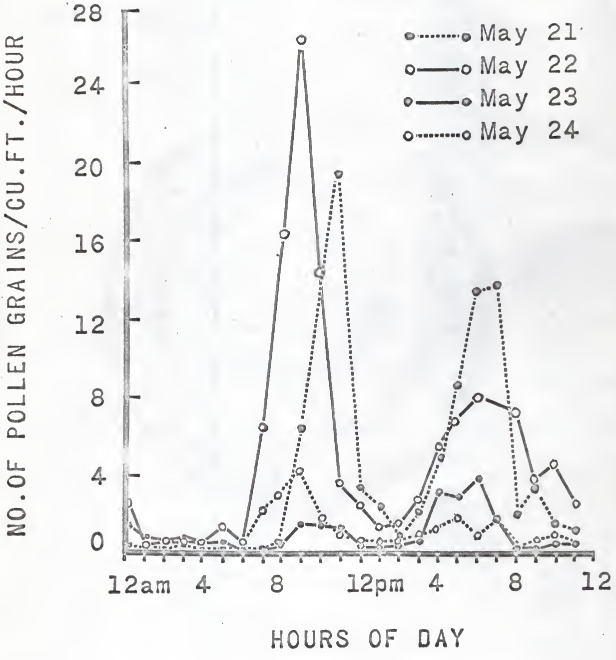

Fig. 9. The number of pollen grains collected per cubic foot per hour throughout the pollen shedding days at Manhattan from a Kramer-Collins spore trap which was located in an Ottawa Selection wheat field.

peaks of pollen shedding be noted but also the differences in the amount of pollen collected and the hours of maximum collection.

The time of the day during which most pollen was shed appeared to be dependent on temperature.

Seed Set

The experiment was designed for a seven day pollination cycle. The exposure and rebagging schedules were terminated on the fourth day as little pollen was collected. The average percentage seed set and arcsin transformation values of the four replications and four days are recorded in Table 14.

The seed set of Parker A- and B-lines are presented in Table 15. The seed set of both Ottawa Selection and Parker A-line was similar although the two plots were grown at different locations on the agronomy farm. Some seed set occurred on heads tagged the entire pollinating cycle for both varieties (Tables 14 and 15). This indicated that pollen was being shed before heads were bagged and/or the bags did not exclude all pollen from receptive stigmas during the pollination period.

The analysis of variance of the Ottawa Selection male-sterile length of exposure study is recorded in Table 16. Replications and durations were significant while treatments, check versus all others, and dates were highly significant. Date by duration interaction was not significant.

Table 14. The mean seed set percentages and arcsin values of Ottawa Selection obtained from four replications during four days of exposure and four durations.

Exposure Days of May	Duration in Days									
	1		2		3		4		Check	
	% Seed Set	Arcsin	% Seed Set	Arcsin	% Seed Set	Arcsin	% Seed Set	Arcsin	% Seed Set	Arcsin
21	7.06	15.41	31.09	33.88	42.70	40.80	29.27	32.81	40.97	39.80[a]
22	41.25	39.90	35.20	36.39	33.75	35.52	39.28	38.81	.56	4.29[b]
23	13.72	21.74	5.97	14.14	9.59	18.04	17.29	24.57	88.06	69.78[c]
24	2.02	8.16	3.63	10.98	2.94	9.88	3.71	11.11	84.37	66.72[d]

[a]Male-sterile heads exposed the entire pollination period

[b]Male-sterile heads bagged the entire pollination period

[c]Average values from unbagged heads of Ottawa Selection

[d]Average values from bagged head of Ottawa Selection

Table 15. The mean seed set percentages and arcsin values obtained from four replications of Parker.

Group	% Seed Set	Arcsin
A-line bagged	0.14	2.14
A-line exposed	43.37	41.18
B-line bagged	80.56	63.84
B-line exposed	93.76	75.53

Table 16. Analysis of variance of the Ottawa Selection male-sterile exposure study conducted at Manhattan, Kansas.

Source	DF	SS	MS	F
Replications	3	343.43	114.48	3.99*
Treatments	16	10,613.88	663.37	23.12**
Check[a] vs. All Others	(1)	1,883.18	1,883.18	65.64**
Dates	(3)	8,096.30	2,698.77	94.07**
Durations	(3)	284.93	94.98	3.31*
D x D	(9)	349.47	38.83	1.35 NS
Error	48	1,377.06	28.69	

*Significant at the .05 level

**Significant at the .01 level

[a]Male-sterile heads exposed the entire pollen shedding period

The LSD of durations, dates, and replications at the .05 level of significance are given in Table 17.

Table 17. The Least Significant Difference at the .05 level of durations, dates, and replications for the Ottawa Selection male-sterile exposure study.

DURATIONS

LSD* .05 = 3.80

Length	4 Day	3 Day	2 Day	1 Day
Mean	26.79	26.06	23.63	21.43

DATES

LSD* .05 = 3.80

Dates	2nd	1st	3rd	4th
Mean	37.66	30.61	19.62	10.43

REPLICATIONS

LSD* .05 = 3.69

Rep.	1	11	111	1V
Mean	29.19	24.67	24.27	23.38

*Note: Means not connected by the same line are significantly different at the .05 level.

To determine the influence of pollen shedding per cubic foot per day upon seed set of the same day, a correlation coefficient was calculated (Table 18). The correlation coefficient, +0.96, was highly significant.

Table 18. Correlation of pollen counts per cubic foot per day and the average seed set per date of exposure.

Exposure Date	Total % Seed Set	Pollen Grains per Cu. Ft.
May 21	30.61	4.10
22	37.66	5.10
23	19.62	0.70
24	10.43	1.01

r = +0.96**

**Significant at the .01 level

A correlation coefficient also was calculated on the relationship of pollen counts per cubic foot per day and the seed set of one-day exposures made on the same day (Table 19). The coefficient, 0.90, was significant at the .05 level.

Table 19. Correlation of pollen counts per cubic foot per day and the seed set of one day male-sterile exposure made the same day.

Exposure Date	Seed Set %	Pollen Grains per Cu. Ft.
May 21	15.95	4.10
22	39.90	5.10
23	21.74	0.70
24	8.16	1.01

r = +0.90*

*Significant at the .05 level

An analysis of variance concerned with the effect of bagging on seed set in the B-lines of Ottawa Selection and Parker are given in Table 20.

Table 20. Analysis of variance for seed set obtained from bagged and unbagged spikes of Ottawa Selection and Parker B-lines at Manhattan.

Source	DF	SS	MS	F
Ottawa Selection, KS 60770				
Treatments	1	15.93	15.93	6.45 NS
Within Trt.	6	23.27	3.88	
Replications	3	15.67	5.22	
Ex. Error	3	7.40	2.47	
Parker, CI 13285				
Treatments	1	298.31	298.31	34.64**
Within Trt.	6	76.65	12.78	
Replications	3	40.83	13.61	
Ex. Error	3	25.82	8.61	

**Significant at the .01 level

No differences were detected in Ottawa Selection, but highly significant differences were found in Parker. No reasons could be determined why the difference between varieties was found.

Environmental Factors

Wind Velocity

The velocities of wind that occurred at Manhattan during the pollen shedding period are recorded in Table 21. Wind direction varied from day to day as it did at Newton. Moderate wind speeds were noted for most pollen shedding days. Strong, gusty winds were present the afternoon of 22 May, one of the peak pollen shedding periods.

Table 21. Wind velocities recorded during pollen shedding of Ottawa Selection at Manhattan, Kansas.

Date in May	Time	Speed[c]	Direction	Av. Speed[c]
20	7 a.m.[a]	17	SW	4.7
	9 a.m.	10	NW	
	3 p.m.	15	E	
	7 p.m.[b]	20	NW	
21	7 a.m.[a]	15	SE	6.2
	12 Noon	10	N	
	3 p.m.[b]	12	E	
22	7 a.m.[a]	20	S	14.4
	3 p.m.[b]	30	S	
23	7 a.m.[a]	20	NW	5.8
	2 p.m.[b]	25	NW	
24	7 a.m.[a]	4	NE	2.4
	3 p.m.[b]	6	NE	
25	7 a.m.[a]	8	SW	3.3
	3 p.m.[b]	10	SW	
26	7 a.m.[a]	5	SW	4.3
	4 p.m.[b]	4	SW	

[a]Wind velocity during the morning period of pollen shedding

[b]Wind velocity during the afternoon period of pollen shedding

[c]Wind speed in miles per hour

Temperature

The recorded temperatures for maximum, minimum, morning and afternoon flowering periods of Ottawa Selection are presented in Fig. 10. Above average maximum temperatures occurred on three flowering days. On 24 May a minimum temperature of 39^{o} F. was recorded.

Wheat grown at Manhattan was subjected to a variation of above average warm periods and below average cold weather. Two late frosts occurred after the head primordia had been formed.

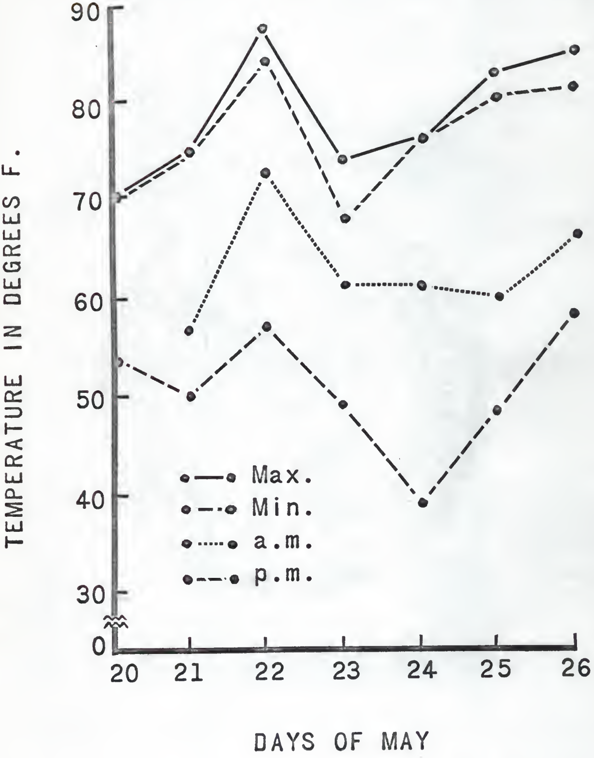

Fig. 10. The recorded temperatures for maximum, minimum, morning and afternoon flowering periods of Ottawa Selection grown at Manhattan.

Relative Humidity

The recorded relative humidity for maximum, minimum, morning and afternoon flowering periods of Ottawa Selection are presented in Figure 11.

A 92% humidity was recorded during the morning flowering period on 21 May. Humidities below 30% were present during four afternoon flowering periods.

Precipitation

On 20 May, 0.83 inches of rain fell at the agronomy farm. This was the day before the first male-sterile heads were exposed. Even though rain occurred on 20 May, adequate soil moisture was not available during flowering.

Total precipitation from 1 January through maturity of the wheat was less than one-half of normal. The amount received was 6.21 inches or 8.60 inches below normal. The precipitation for May including the 0.83 inches was 1.65, or 2.50 inches below normal (Kansas Climatological Data, 1966).

Competition

No definite planting rate was available because the drill was not operating properly. The first replication was planted at a higher rate than the other three replications. The B-line also was planted at a higher rate than usual but similar to replication one.

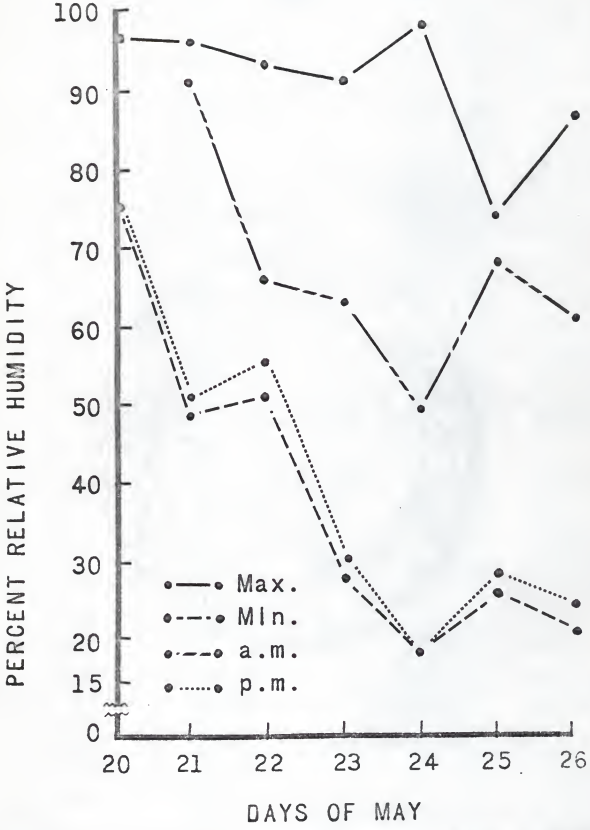

Fig. 11. The recorded relative humidity for maximum, minimum, morning and afternoon flowering periods of Ottawa Selection grown at Manhattan.

Mechanism of Exposure

During both phases of this study the action of the male-sterile in exposing the stigma was observed. In both the A-line and the B-line the first separation of the lemma and palea occurred due to the enlargement of the lodicules. After the unfertilized A-line flower closed it did not re-open again until the ovule flattened which pushed the glumes apart for the second time. The time between the first and second opening seemed to depend on the environmental conditions. During hot days male-sterile flowers were observed to open early in the morning, closed by mid-morning, and re-opened by late afternoon. On cool days the development took longer.

Male-sterile flowers remained open with a wide separation of lemma and palea until pistillate organs were pollinated or dehydrated. If fertilization occurred the ovary soon reduced in horizontal width and partial closing resulted.

The lodicules appeared not to function during the second opening of A-line sterile flowers. B-line lodicules functioned in subsequent openings. Also the pollinator ovule enlarged vertically between the lemma and palea, but no opening was observed.

DISCUSSION

The efficiency at which B-line pollen causes seed set in A-line florets may largely govern hybrid seed costs. The mechanisms of cytoplasmic male-sterility and fertility restoring seem dependable; therefore, the practibility of hybrid wheat production may depend on the economics of cost of seed as related to increased hybrid wheat yields.

In Manitoba Shebeski (1965) estimated that it would take 53,000 acres of A-line parent to plant every million acres of wheat if seed set were 50%. He further assumed that with a 20% increase in yield and a seed price of three times normal, it would be economical to grower and producer.

It would take approximately 350,000 acres of A-line parents for planting the Kansas acreage annually if 50% seed set was obtained.

The results of this study indicated many factors were involved in determining seed set of A-lines. Distance from pollen source was an important factor. At Newton average percent seed set ranged from 10.1% at ten feet to 2.5% at 190 feet. Direction from the pollinator was involved. Seed set at 10 feet in the north row was 13.4% as compared to only 5.2% at the same distance in the east row. Synchronization of flowering of A- and B-lines was the most important factor influencing seed set percentages of A-lines. Approximately 20% of the A-lines flowered while pollen was being shed. Three factors may have delayed flowering of the A-lines which resulted in the poor synchronization of parents. These were inherent flowering date, rate of planting, and row spacing.

The north row at Newton had the highest total yield although it had less exposure to pollen than other rows. Its lack of exposure to pollen may have been compensated because over one-half of the plants were Ottawa A-line, whereas the other three rows were Bison A-line. Bison normally flowers later than Ottawa; therefore, the lack of synchronization was partly due to different inherent flowering dates. Similar seed set in the north row resulted because of better simultaneous flowering of the two parents although less pollen may have been available.

Some differences may have existed in planting rates at both locations. At Newton the stand in the A-line rows was not uniform due to poor fall emergence. At Manhattan, replication one was believed to possess significantly more seed set because either its flowering date synchronized more closely with the pollinator due to equal planting rates or more pollen was available due to the location in the B-line field (Fig. 2).

Planting rates influenced the date of flowering. Thin rates delayed flowering while heavy rates hastened flowering. Many hybrids may need to be planted at unequal rates so flowering of the two parents will be synchronized.

Row spacing also affected flowering date. At Newton approximately a 16-inch space existed between the A-line rows and the Will barley. Flowering of the A-line rows was delayed because of less competition for water and nutrients. The A-line rows within the pollinator flowered simultaneously because their row spacing was synonomous with the B-line. Forty-six percent seed set was obtained in the B-line field but only 10% was found in A-line rows near the pollinator. Lack of synchronized flowering due to unequal competition greatly reduced the seed set percentages in A-line rows. Patterson and Bitzer (1966) reported from 9 to 91% seed set depending on the line and coincidence of stigma receptivity and pollen dispersal.

At Newton, correlations of pollen counts, seed set percentages, and yields within and between A-line rows at various distances from the pollinator were highly significant except one. This revealed that pollen quantity, seed set and yield showed similar trends with distance from the source of pollen. All three measurements decreased with distance although some variations in yield were noted. Yield variations could be due to uneven stands of the A-line.

Sufficient isolation to maintain seed purity may be a problem because seed set percentages of over 2% were found at the 190 foot distance. This figure may have been larger if proper synchronization of flowering would have occurred. Isolation distances between varieties of several hundred feet may be required to maintain purity of A-lines and hybrids.

Length of A-line Exposure

Results from the study at Manhattan showed that significantly more seed set occurred on the peak pollen shedding days; therefore, it is imperative that A-line flowers simultaneously with the pollinator lines to give the best seed set. Rajki(1962) reported 85% seed set with one day exposures made on the peak pollen shedding day. Rajki also showed that percent seed set depended on the amount of pollen reaching the stigma. Sorokina and Laptev (1958) found the amount of pollen reaching the stigma was dependent on the amount of pollen in the atmosphere. They reported more pollen on stigmas of emasculated heads with longer durations of exposure to pollen. The amount of pollen in the atmosphere can be controlled by varying the ratio of male:female or by the variety of the pollinator as varieties were found to have different pollen shedding capabilities (Olsen, 1966).

Longer durations of A-line exposure resulted in higher seed set percentages although no significant differences were found between four, three, and two day exposures. One day exposures were significantly different from three and four day durations.

The number of pollen shedding days at both locations was shorter than normal. Livers (1964) has found larger seed set percentages with longer pollen shedding periods. The fewer days of pollen shedding probably was the result of drought and high temperatures. The length of flowering period is not a direct influence on seed set, but is the result of weather conditions which do influence seed set.

High correlations of pollen counts and seed set percentages revealed the close relationship between quantity of pollen shed and the seed set on a particular day. High seed set was obtained with large pollen shedding and low seed set was obtained on days of small pollen shedding.

The artificial microclimate created by glycine bags reduced seed set in B-line heads. A significant difference in seed set between bagged and unbagged Parker B-line heads was found. No significance was found in Ottawa Selection B-line heads. The bags may have resulted in higher temperatures and humidities which affected germination of the pollen. Some bags caused culm breakage, but these heads were not included in the analysis. Bags on A-line spikes may have resulted in excessive drying of stigma surfaces or other physiological changes which decreased the chance for fertilization.

Wells (1962) found no significant differences in seed set in wheat and barley by using three different pollinator bags, but the seed weight under Kraft corn tassel pollinator bags was 23.8% larger in barley and 84.4% larger in wheat than glassine paper and sorma paper bags.

Environmental Effects on Seed Set and Pollen Distribution

Cross-pollination in wheat is dependent on wind for movement of pollen from the pollinator to A-line stigmas. Not only the wind speed but also wind direction altered pollen distribution and concommitant seed set in A-line rows. At Newton on the morning of 17 May slight wind resulted in small amounts of pollen being distributed to the pollen trap at 40 feet, but a large amount of pollen was collected at the 5 foot distance. Wind speed may be a limiting factor for proper pollen dispersion as nearly calm winds are prevalent during the early morning hours in Temperate regions.

High wind speeds may cause too much pollen dispersal at Manhattan. With a given quantity of pollen high wind speeds dispersed the pollen over a much greater area; therefore, the pollen mass was reduced. On the other hand, winds may be advantageous because they cause more agitation of the anthers with the consequent release of more pollen.

At Newton, north and south A-line rows yielded nearly twice as much as the east and west rows. Slight southerly and northeast winds were recorded on the peak pollen shedding day. As most pollen was shed during one day the two wind directions dictated the two rows which received the most exposure to pollen. The greater quantities of pollen present resulted in higher seed set percentages in the two rows.

The exact influence of temperature on pollen distribution and seed set is not known. Kovacik (1964) reported maximum seed set in temperatures of 68 to 77° F. Temperature seemed to determine the times of flowering for both diurnal periods. When the night temperatures stayed above 60° F. flowering started before 6 a.m. When the minimum night temperature was 39° F., as it was at Manhattan, flowering was delayed until 10 a.m. or until temperatures in the high fifty degree range were reached. Afternoon flowering occurred at the maximum temperature on cool days, but was delayed until late afternoon on hot days. Early morning and late afternoon flowering prevailed at both locations as temperatures were above average on several days during pollen shedding.

High temperatures may have caused a reduction in stigma receptivity and reduced the viability of pollen grains. Plant hormones operative in promoting pollen germination and pollen tube growth may not be functional at high or low temperatures. Seed set was reduced because most pollen was shed during high temperature conditions.

The exact pollen and plant response to humidity also is not known, but seed set was lowered at both high and low humidities. Kovacik (1964) found seed set to be highest in a range of 60 to 70% relative humidity. Humidity probably was a limiting factor to seed set in this study as most pollen shedding occurred beyond this range.

High relative humidity or free water on the stigma surface could have caused rupture of the pollen grains. Loo and

Hwang (1944) reported that pollen germination depended on a balance of the osmotic and turgor pressures. Various ions on the stigma surface as well as water could have caused pollen grain rupture or failure of the pollen to germinate. Low relative humidity may have had a desiccating effect of both the pollen and stigma surface.

Probably the same relationship exists in wheat as was found in corn pollination studies. Working on factors affecting seed set in corn, Tatum and Kehr (1951) suggested that temperatures and relative humidity influence pollination indirectly through their effects on evaporation and transpiration. These affect the internal water supply or turgidity of the plant. Lack of moisture in silks to germinate pollen was believed to be more important in causing poor seed set than lack of viable pollen.

Soil moisture was deficient as precipitation was less than one-half of normal from 1 January through maturity. Inadequate soil moisture has been reported to cause short pollination cycles and cleistogamous flowering (Livers, 1964). Pollen shedding at Newton was primarily during four days. At Manhattan an 0.83 inch rain received just before flowering resulted in pollen shedding for six days. Cleistogamous flowering was apparent because anthers that were not extruded were found in the florets.

The moisture deficiency seemed to result in less anther extrusion. Less anther exposure to wind due to drought probably lowered seed set values. The ultimate yield was definitely limited by an inadequate moisture supply.

Irrigation increased seed set, as reported by Livers (1964) to be nearly 100% during wet years and 60% during dry unfavorable years. If this is so seed production probably will be under irrigation in Kansas.

SUMMARY

Pollen dispersion was measured by Kramer-Collins spore traps and glass rods at Newton and Manhattan, Kansas. At Newton the amount and distribution of pollen at various distances from the pollinator were measured. Spore traps were located at 5 and 40 feet downwind from the one acre Ottawa Selection pollinator field. Glass rods were located at 10 feet and then at 20-foot intervals out to 190 feet from the pollinator. Correlation between pollen counts, seed set, and yield within and between four A-line rows, which extended 200 feet in different directions from the pollinator, were positive and significant. Also correlation between pollen collection methods was positive and significant (+.92). Highest seed set occurred in male-sterile spikes located downwind from the pollen source on the day of maximum pollen shedding. Seed set at 10 feet in the north row was 13.4% but only 5.2% at the same distance in the east row. Seed set and pollen counts decreased with increasing distance from the pollen source. Average seed set ranged from 10.1% at 10 feet to

2.5% at 190 feet from the pollinator. Average pollen counts decreased from 95 at 10 feet to 13 at 190 feet. A-line rows in the pollinator field averaged 42.3% seed set. The pollen count was 485. A male-sterile row which only had exposure to south pollen possessed 31.4% seed set.

A-line spikes were exposed on different days for different durations during the pollen shedding period at Manhattan. A highly significant correlation value of +.96 was obtained between pollen counts per cubic foot per day and the average seed set per date of exposure. A significant correlation value of +.90 was obtained between pollen counts per cubic foot per day and seed set of one day A-line exposures made the same day. A significantly larger seed set was obtained on the day of maximum pollen shedding. Seed set was 37.66% on the peak pollen shedding day and was only 10.43% on a low pollen shedding day. Longer exposures to pollen resulted in higher seed set percentages. Four day exposures averaged 26.8% while one day exposures averaged 21.4% seed set. Replication one was found to have a significantly higher seed set than the other three replications.

In 1966 factors that limited seed set on male-sterile lines in Kansas were as follows: high and low relative humidities, high temperatures, high and low wind speeds, inadequate soil moisture, only 20% synchronized flowering of A- and B-lines, different row spacings, and different planting rates of parents.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. E. G. Heyne, Professor of Plant Breeding, the major professor, for his advice and assistance in conducting the study and preparing the manuscript.

Thanks are due to Dr. C. L. Kramer and Dr. J. A. Goss for their assistance and helpful suggestions.

The author is grateful to his wife, Donna, who assisted in typing and collection of data. Her encouragement and understanding throughout the study were inspirational to the author.

LITERATURE CITED

Balint, A., G. Kovacs, and M. Schnieder. 1959. Effect of self pollination on the vitality of plants and its evolutionary significance. (Abst.) Plant Br. Abst. 29:712.

Bardier, N. G. 1962. The effect of the age of flower on the process of pollination and fertilization of winter wheat in intervarietal crossing. (Abst.) Plant Br. Abst. 32: 822.

__________. 1963. The mentor effect of winter rye pollen on fertilization and form development of winter wheats in intervarietal hybridization. (Abst.) Plant Br. Abst. 33:30.

Bateman, A. J. 1947. Contamination of seed crops. II. Wind pollinated crops. Heredity 1:235-246.

Brown, C. M., and H. L. Shands. 1956. Factors influencing seed set in oat crosses. Agron. J. 48:173-177.

Cet'l, I. 1961. The size of pollen grain of the genus Triticum L. (Abst.) Plant Br. Abst. 31:600-601.

Chan, E. 1925. A study of fertility in certain varieties of common wheat with respect to anther length and amount of pollen in parents and offspring. J. Am. Soc. Agron. 17: 591-595.

Coffman, F. A. 1937. Factors influencing seed set in oat crossing. J. Hered. 28:296-303.

__________, and H. Stevens. 1951. Relations of temperature and time of day of pollination to seed set in oat crossing. Agron. J. 43:498-499.

Cook, O. F. 1913. Wild wheat in Palestine. U. S. Dept. Agr. Bur. of Plant Industry Bulk. 274, 71 pp.

Faegri, K., and L. van der Pyl. 1966. The Principles of Pollination Ecology. New York. 248 pp.

Fukasawa, H. 1959. Nucleus substitution and restoration by means of successive backcrosses in wheat and its related genus Aegilops. Jap. J. Botany 17:55-91.

Glenn, D. E. 1965. Wheat Newsletter 12:65.

Gregory, P. H. 1961. The Microbiology of the Atmosphere. Interscience Publishers, Inc. New York. 251 pp.

Harlan, H. V., M. L. Martin, and H. Stevens. 1943. The effect of temperature on seed set in barley crosses. J. Am. Soc. Agron. 35:316-320.

Heyne, E. G. 1964. Problems which must be solved if hybrid wheat is to succeed. Grain Age 5(7):3, 16.

Hoshikawa, K. 1961. Influence of temperature upon the fertilization of wheat, grown in various levels of nitrogen. (Abst.) Field Crop Abst. 14:15.

Jones, M. D., and L. C. Newell. 1946. Pollination cycles and pollen dispersal in relation to grass improvement. Nebraska Agr. Exp. Sta. Bul. 148.

__________, and J. B. Sieglinger. 1951. Effect of wind direction on natural crossing in sorghum. Agron. J. 43: 571-572.

Kansas Climatological Data. 1966. U. S. Department of Commerce. 80:1-6.

Kihara, H., and K. Tsunewaki. 1966. Some fundamental problems underlying the program for hybrid wheat breeding. (Abst.) Plant Br. Abst. 31:36.

Kovacik, A. 1964. The influence of climatic conditions and mechanical interference with the wheat flower upon the results of fertilization. (Abst.) Plant Br. Abst. 34: 472.

__________, and J. Holienka. 1963a. Influence of age difference in pollen on wheat fertilization. (Abst.) Wheat Abst. 1:293.

__________, and J. Holienka. 1963b. Effect of age of stigma on artificial pollination of wheat. (Abst.) Wheat Abst. 1:749.

Kramer, C. L., and S. M. Pady. 1966. A new 24-hour spore sampler. Phytopath. 56:517-520.

Kruzkova, I. V. 1964. Supplementary pollination of winter wheat with pollen of winter rye. (Abst.) Plant Br. Abst. 34:472.

Laptev, Ju. P. 1963. (Improving the pollination of emasculated wheat flowers in open crossing.) Agrobiology, 777 p., (In Russian, English translation).

Leighty, C. E., and W. J. Sando. 1924. The blooming of wheat flowers. Jour. Agr. Res. 27:231-244.

Leighty, C. E., and J. W. Taylor. 1927. Studies in natural hybridization of wheat. J. Agr. Res. 35:865-887.

Liu, T.-T. 1960. Microscopical observations on mutual interaction between pollen grains. (Abst.) Plant Br. Abst. 30:502.

Livers, R. W. 1964. Seed yields of field-grown male-sterile wheats subjected to wind-borne pollen. (Abst.) Agron. Abst. 1964. Annual Meetings American Soc. of Agron., 72 p.

Loo, T.-L., and T.-C. Hwang. 1944. Growth by manganese sulfate, indole-3-acetic acid and colchicine in pollen germination and pollen tube growth. Amer. J. Bot. 31:376.

Lucken, K., and S. S. Mann. 1965. Wheat Newsletter 12:94-95.

Oganesyan, S. 1964. Seed set in wheat during pollination with pollen from closely and distantly related parental forms. Biological Abst. 45:8366.

Ogden, E. C., G. S. Raynor, and J. V. Hayes. 1965. Travels of Airborne Pollen. New York State Museum and Science Service Progress Report No. 6.

Olson, R. J. 1966. The influence of genotype and plant morphology on pollen shedding ability of _Triticum aestivum_ L. M. S. Thesis. Washington State University.

Patterson, F. L., and M. J. Bitzer. 1966. Hybrid wheat research at Purdue University. Agr. Exp. Sta., Purdue Univ., Research Progress Report 222.

Pedersen, P. N., H. B. Johansen, and J. Jørgensen. 1961. Pollen spreading in diploid and tetraploid rye. II. Distance of pollen spreading and risk of intercrossing. Kgl. Vet. - og. Landlohøjsk. Arsskr. 68-86 p.

__________, and J. Jørgensen. 1966. Inheritance of size of lodiculae and closed flowering in barley. (Abst.) Plant Br. Abst. 36:550.

Pope, M. N. 1916. The mode of pollinatin in some farm crops. J. Am. Soc. Agr. 8:209-227.

Porter, K. B., K. A. Lahr, and I. M. Atkins. 1965. Cross-pollination of male-sterile winter wheat (_Triticum aestivum_ L.) having _Aegilops caudata_ L. and _Aegilops ovata_ L. cytoplasm. Crop Sci. 5:161-163.

Pusharev, I. I., and G. P. Kvitko. 1964. Unutilized reserve of increased yield in wheat. (Abst.) Plant Br. Abst. 34:244.

Rajki, E. 1962. Some problems of the biology of flowering in wheat. Symposium on genetics and breeding wheat. Agr. Res. Ins., Hungarian Acad. Sci., Martonvasar, Hungary. 41-62 pp.

Saito, T. 1964. On the wind profile within plant communities. Bull. Nat. Inst. Agr. Sci. Nishigahara, Ser. A. Phys. Statist. 11:67-73.

Salmon, G. 1914. Sterile florets in wheat and other cereals. J. Am. Soc. Agr. 6:24-30.

Sekun, P. F. 1964. The effect of different types and rates of fertilizer on flowering of winter wheat. (Abst.) Plant Br. Abst. 17:97.

Shebeski, L. H. 1966. Hybrid Wheat. (Abst.) Field Crop Abst. 19:18.

Snedecor, G. W. 1956. Statistical Methods. Iowa State University Press. Ames. 534 pp.

Sorokina, O. N., and Ju. P. Laptev. 1958. The amount of pollen in wheat flowers from wind pollination. (Abst.) Plant Br. Abst. 28:266.

Spirova, M. 1962. On the flowering and pollination of wheat. (Abst.) Field Crop Abst. 15:186.

__________. 1965. Studies on flowering and pollination of wheat. (Abst.) Plant Br. Abst. 35:706.

Takegami, S. 1958. The significance of the connection between the mode of anther extrusion in wheat and infection by <u>Gibberella zeae</u>. (Abst.) Plant Br. Abst. 28:491.

Tatum, L. A., and W. R. Kehr. 1951. Observations on factors affecting seed-set with inbred strains of dent corn. Agron. J. 43:270-275.

Turov, G. S. 1963. Efficacy of hybridization and the transmission to the progeny of the parental character of initial forms treated in different environments. (Abst.) Plant Br. Abst. 33:554.

Ukolov, A. A., V. A. Puhalsky, and I. L. Maksimov. 1966. Grain set in hard winter wheat on pollination by different methods. (Abst.) Plant Br. Abst. 36:463.

Vozda, J. 1962. Some problems of the pollination and fertilization processes in distant hybridization in the Gramineae family. (Abst.) Plant Br. Abst. 32:316.

Wells, D. G. 1962. Notes on the hybridization of wheat and barley. Crop Sci. 2:177.

Wilson, J. A., and W. M. Ross. 1962. Cross breeding in wheat, _Triticum aestivum_ L. II. Hybrid seed set on a _cytoplasmic male-sterile_ wheat composite subjected to cross-pollination. Crop Sci. 2:415-417.

Wodehouse, R. P. 1935. Pollen grains. McGraw-Hill Book Company. London. 574 pp.

POLLEN AMOUNT AND DISTRIBUTION IN RELATION TO SEED SET OF MALE-STERILE TRITICUM AESTIVUM

by

ADRIAN L. ARP

B. S., University of Wyoming, 1965

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

Ottawa Selection pollen dispersion was measured by Kramer-Collins spore traps and glass rods at Newton and Manhattan, Kansas. At Newton, the amount and distribution of pollen at various distances from the pollinator were measured. Correlations between pollen counts, seed set, and yield within and between four A-line rows, which extended 200 feet in different directions from the pollinator, were positive and significant. Also correlation between pollen collection methods was positive and significant. Highest seed set occurred in male-sterile spikes downwind from the pollen source on the day of maximum pollen shedding. Seed set and pollen counts decreased with increasing distances from the pollen source. Average seed set ranged from 10.1% at 10 feet to 2.5% at 190 feet from the pollinator.

A-line spikes were exposed on different days for different durations during the pollen shedding period at Manhattan. Significant and positive correlations occurred between pollen counts per day and seed set per date of exposure and the duration of exposure. A significantly larger seed set was obtained on the day of maximum pollen shedding while longer exposures to pollen resulted in higher seed set percentages.

Unfavorable relative humidities, temperatures, and wind speeds; inadequate soil moisture; lack of simultaneous flowering of A and B-lines; and different planting rates and row spacings were factors that limited seed set on male-sterile lines in Kansas in 1966.