THE INFLUENCE OF A COMMERCIAL FERTILIZER TREATMENT ON WEED COMPETITION IN SPRING SOWN WHEAT

by

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ABSTRACT

Controlled densities of wild mustard in wheat were studied to determine if the application of a commercial fertilizer would affect the number of wild mustard plants that could be tolerated before yields of wheat were reduced significantly. In another controlled experiment, an attempt was made to determine when, in the growth of wheat, competition from wild mustard became apparent under different levels of soil fertility. The influence of a commercial fertilizer on weed competition under actual farm field conditions was also studied.

Yields of wheat grown on summerfallow were reduced significantly by competition from 50 to 75 wild mustard plants per square yard. When ammonium phosphate (11-48-0) fertilizer was applied at the rate of 40 pounds per acre, the yield of wheat was not reduced significantly unless 75 to 100 wild mustard plants per square yard were present.

On farm fields the application of ammonium phosphate (11-48-0) fertilizer was effective in reducing losses caused by weed competition. However, increases in yield as a result of fertilizer treatment were often accompanied by decreases in protein content. Removal of weeds by hand gave significant increases in both yield and protein content of wheat. The combined effects of fertilizer treatment and of weed removal by hand produced the largest increases in yield of grain and maintained protein content at a comparatively high level.

Bushel weight of wheat was not influenced by weed competition under varying levels of soil fertility or weed densities.

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INTRODUCTION

The existence of a number of plant species in an association is commonly characterized by a condition detrimental to the welfare of one, several, or perhaps all species concerned. This adverse condition prevails whenever these species must compete for the common requirements of growth and reproduction. Often in nature, or through the practices of man, the supply of required growth essentials is severely limited so that competition for these essentials is inevitable. This competitive phenomenon need not be restricted to individuals of different species alone (interspecific competition). It is known to occur also, and perhaps to an equal extent, between members of the same species (intraspecific competition). However, from an agricultural standpoint, interspecific competition is of far greater significance since it denotes a rivalry which is almost invariably operative when crop plants and weeds inhabit a common growing area. Such competition between crops and weeds is specifically known as "weed competition".

Moisture, mineral nutrients and light are universally recognized as the three basic requirements of plant growth. However, as already implied, seldom are these requirements available in proportions adequate for maximum crop production. In many agricultural areas of the world, plant growers must rely exclusively on seasonal precipitation as a source of soil moisture for plant growth. In the more arid regions very strict moisture conservation measures must be practiced to maintain soil moisture at levels satisfactory for crop production. A full compliment of the essential minerals (in forms available to plants and in amounts required for repeated cropping) normally cannot be incorporated in any soil unless definite, and often very costly measures are taken to maintain a favorable mineral balance in the soil. Light may become growth-limiting when crop plants become thoroughly shaded in the presence of large numbers of broad-leafed weeds.

One of the principal objectives of every plant grower is to ensure maximum utilization of the limited growth essentials by his crop plants. Since weeds demand the same growth essentials as crops, weeds naturally tend to reduce the availability of these essentials. Whatever may be the fraction of available growth essentials utilized by weeds in fulfillment of their own functions, it is the same fraction thereof which is lost entirely to crop production. Obviously, reduction or elimination of weed competition is a logical approach towards a maximization of returns from the restricted supply of growth elements.

Although the phenomenon of weed competition probably dates back to the birth of agriculture itself, only in recent years has considerable basic research been devoted to a better understanding of that phenomenon. Controlled competition studies initiated at the University of Manitoba in 1952 were designed (1) to determine the lowest density of wild mustard that cause significant reductions in yield of wheat and flax, (2) to determine when, in the growth of wheat, competition from wild mustard becomes apparent, (3) to demonstrate that removal of weed competition by spraying with selective herbicides prevents losses in yield of wheat, and, (4) to assess the actual losses that might be attributed to weed competition under farm field conditions. These studies demonstrated that as few as ten wild mustard plants per square yard in flax, or fifty wild mustard plants per square yard in wheat, caused significant reductions in yield. Weed competition was found to commence early in the growing season and, therefore, the need for weed removal at an early stage of crop growth was strongly emphasized. Experiments on Manitoba farm fields revealed that all crops studied (wheat, barley, oats and flax) suffered substantial losses in yield from weed competition, and losses in protein content of wheat and barley were also noted.

However, the above-mentioned series of weed competition studies carried out by the University of Manitoba were not conducted under conditions of varying soil fertility. Results of controlled experiments reported by other investigators demonstrated that application of mineral fertilizers with grain very effectively reduced losses from weed competition.

The effects of fertilizer treatment were commonly manifested by reduced weed seed populations in the soil, more rapid growth of crop seedlings, earlier crop maturity, increased tillering in cereals, increased yields and improved quality of grain. Nevertheless, little is yet known of the true importance of commercial fertilizer in weed competition under actual field conditions with natural infestations of weeds. Therefore, to evaluate the significance of commercial fertilizer as a means of combatting weed competition, the project described in this thesis was undertaken in the spring of 1958 and special emphasis was devoted to a study of the influence of commercial fertilizer on weed competition under farm field conditions.

REVIEW OF LITERATURE

Because of the variations in growth habit, morphology and other inherent qualities, species of plants vary in their relative ability to compete for the essentials of growth and development (7, 8, 9, 16, 36, 38, 39, 40). Pavlychenko (38) stated that grain crops developed more rapidly in the first few weeks of growth and generally possessed a stronger cuticle and more fibrous tissue than did most of the common weeds. He also noted that most of the important grain crops produced larger seeds which could germinate from greater soil depths in a shorter time, in higher percentages and at lower temperatures than could most weed seeds.

In a five-year study Pavlychenko and Harrington (40) measured the relative competitive efficiencies of a number of annual weeds and cereal crops on the basis of characteristics such as total assimilating leaf surface, height, diameter and linear length of root system, and dry weight of top growth. Rapid germination and ability to develop a large photosynthetic leaf surface and an extensive root network early in the seedling stage were concluded to be significant factors which enabled a plant to compete efficiently. From this investigation, the crops studied were arranged in order of decreasing competitive efficiency as follows: barley, wheat, oats and flax. Hannchen barley competed much more successfully with wild oats and wild mustard than did Marquis wheat, principally because of the more rapid root development of barley as compared to wheat. For a similar reason Marquis wheat competed effectively with wild mustard but was seriously depressed by wild oats which had a total root length four times that of wheat.

In another experiment Pavlychenko and Harrington (39) observed the respective rates of root development in the seedling stages of four cereals (barley, rye, wheat and oats) and a number of annual weeds. Data recorded at 5 and 21 days after emergence disclosed the following salient points:

1. Root development of weeds and crops differed in growth habit, extent and distribution within the soil.
2. At 5 days after emergence the root systems of all 4 cereals exceeded in length those of the weeds studied.
3. At 21 days after emergence wild mustard had the largest root system of all plants examined.
4. Barley had the highest number of primary roots per plant.
5. The primary and secondary roots of rye and barley were found to be comparatively closer to the soil surface than were those of wheat, oats and wild oats.
6. Root development in wild oats was found to be slow in the early seedling stage but progressed very rapidly as the wild oats became older. Wild oats also produced more root material than any of the cereals and its roots penetrated the soil to comparatively great depths.

From this study Pavlychenko and Harrington concluded that rate and habit of root growth in crops and weeds were factors of considerable importance in weed competition. Ability to produce primary roots in large numbers and the rapid, spreading habit of root growth enabled cereals such as rye and barley to compete effectively. Production of abundant root tissue and the deep penetration of its roots accounted for the severity of wild oats as a weed.

From a two-year study conducted with wheat, barley, oats and flax, Friesen (18) obtained results that agreed closely with those of Pavlychenko and Harrington (40), whereby he stated that barley was undoubtedly the most efficient competitor of the crops studied, followed by wheat, oats and flax in order of declining competitive efficiency.

Nelson and Nylund (36) showed that white mustard competed much more severely with field peas than did foxtail-millet. The aggressiveness of white mustard as compared to foxtail-millet was attributed mainly to the ability of the former to emerge more rapidly and to its greater tolerance of low temperatures at germination time.

Robinson and Dunham (43) demonstrated that winter wheat or winter rye, when grown as companion crops, were very effective in reducing weed competition in soybean stands. Under weedy conditions, soybeans drilled with either of these cereals in non-cultivated rows 6 inches apart yielded as much, or more, than soybeans without companion crops, whether in non-cultivated 6-inch drill rows or in cultivated rows 40 inches apart.

Arny *et al.* (4) demonstrated that wheat may be grown advantageously as a companion crop with flax on weedy land. Since flax is a weak competitor, growing of flax in mixed cultures with a more competitive crop such as wheat suppressed annual weed growth markedly. These researchers indicated, however, that wheat was ineffective as a competitive crop where perennial weeds were present in large numbers.

Blackman and Templeman (7) found that the intensity of weed competition varied with the species of weeds present. Wild mustard, in competition with barley, reduced the number of tillers and fertile shoots in barley, whereas wild radish, in competition with the same crop, reduced not only the extent of tillering and fertile shoot growth, but also the size of spike.

Aside from the various vegetative attributes which enable weeds to compete effectively, the prolific nature of many species of weeds is one other feature which favors their ability to compete with crops. According to Stone (48), an average plant of wild oats may bear 250 seeds and a large, vigorous plant of tumbling mustard is estimated to produce 11 million seeds. Stevens (47) studied the seed-producing capacity of a large number of weed species and reported that the average number of seeds produced by 61 non-creeping perennial species was 16,629; by 19 biennial species, 26,000; and by 101 annual species, 20,832 seeds were produced.

Other features, such as the dormant behaviour of weed seeds and longevity of weed seeds under conditions unfavorable to germination and growth, render summerfallowing, as a means to eliminate weed competition in subsequent crops, largely ineffective or even totally inadequate (10, 38). Because of their dormant behaviour, weed seeds produced by a plant in any given year continue to germinate over a period of succeeding years. Chepil (10) studied dormancy of 58 species of weeds in cultivated soil and demonstrated that maximum duration of dormancy for 40 of these species exceeded 3 years. Longevity studies reported by Darlington (15) indicated that seeds of several common weed species remained viable after having been buried in soil to a depth of 18 inches for 40 years. Seeds of a few of the species studied were viable even after 70 years of burial.

Perennial weeds are generally recognized as more serious competitors than are most annual weed species (3, 12, 13, 41, 42). The persistence of perennial weeds, even when the most effective control measures were practiced, has been attributed primarily to their extensive, specialized root systems (rootstocks) or, in many instances, to an underground stem network (rhizomes). Like annuals, perennials can reproduce from seed, but in addition the rootstocks and rhizomes enable them to propagate vegetatively. Furthermore, these rootstocks and rhizomes function as organs for the storage of large food reserves which are vitally important to plant survival under adverse growing conditions. Since the rootstocks and rhizomes penetrate the soil for relatively long distances both laterally and vertically, perennials are comparatively immune to eradication by the same chemical and cultural methods recommended for the destruction of many annual weeds.

It is commonly realized that the extent of damage caused by weed competition is dependent not only upon the species of weeds present and the type of crop grown, but also upon the density of these weeds and the length of time that competition is permitted (3, 8, 9, 35, 44, 45). Burrows and Olson (8, 9) reported that competition from 50 plants of wild mustard per square yard until the 5-leaf stage of wheat, or 10 plants of wild mustard per square yard until flax was 3 inches tall, resulted in permanent injury to these crops. Suppression of tillering in wheat, and of the basal branching in flax, by the mustard plants led to significant losses in yield. Yields tended to decrease as the density of wild mustard increased. Although bushel weight and commercial grade of wheat were not affected by the degree of weediness, protein content was significantly lowered in plots where wild mustard was present.

In a weed competition study conducted on 21 farm fields in Manitoba, Friesen (18) measured the effect of weed removal by hand on the yield and protein content of wheat. In fields with moderate or heavy weed infestations, yield of wheat from weed-free plots was invariably higher than yield from weedy plots. Increases in protein content from weed-free plots were obtained in 17 wheat fields, and in 8 of these fields the increases in protein content were significant at the 5% level. Wheat grown on summerfallow land was generally higher in protein content than wheat grown on stubble land.

As reported by Anderson (3), weed workers at Regina observed that, on the basis of a nine-year average, yields of wheat were reduced 15 per cent when wild mustard comprised 20 per cent of the stand. When wild mustard constituted 40 per cent of the vegetation, reductions in yield were 35 per cent and increased to 53 per cent when mustard density constituted 60 per cent of the vegetation.

McRostie and Tildesley (35) found that Reward wheat grown in association with seven sow-thistle plants per every two square feet of area suffered yield reductions of 71 per cent. Reduction in culm number, as a result of weed competition, was principally responsible for the losses in yield of wheat. In addition, fewer spikelets per head and a decrease in the average number of seeds per spikelet were other manifestations of sow-thistle competition which contributed to yield reduction. These researchers also demonstrated that competition from a thick stand of sweet clover in the year prior to fallow reduced the total amount of roots produced by sow-thistle in the fall of that year and delayed the growth of new roots in the following year.

Shadbolt and Holm (44) made quantitative studies on red beets, carrots and onions to determine the degree and permanency of injury resulting from several levels of natural weed infestations where red-root pigweed, water hemp and lady's thumb comprised the predominant weed species. The desired weed densities were obtained by careful thinning of weed stands early in the growing season. Quantitative growth data gathered 4, 5 and 6 weeks after emergence, at which time weed competition was also removed, indicated that all three crops had been affected considerably by weed competition. In some instances, weed stands which were thinned to 15 per cent of the normal weed infestation were as injurious to the crop at this early stage as weed stands which had not been thinned at all. Similar measurements repeated at maturity illustrated that the injurious effects of weed competition earlier in the season did not necessarily persist until maturity in all cases. Mature red beets generally showed no reductions in yield or total plant weight when weed competition was removed 4 weeks after emergence. Considerable yield reductions occurred, however, when a 50 per cent weed stand competed with the crop during the first 6 weeks of growth. With carrots, reductions in yield varied from 30 to 60 per cent, depending on the severity of weed competition. At the time of weed removal, substantial losses in total plant weight, and decreases in diameter of roots and leaf area were noted. Since these reductions were generally of a much higher order at the time of weed removal than at maturity, it appeared that carrots had made substantial recovery after weed competition was eliminated. Of the three crops, onions were most seriously injured by weed competition and yield losses of 90 per cent, or more, were common under higher levels of weed infestation. As compared with red beets and carrots, onions exhibited an inferior recuperative capacity to injury resulting from weed competition early in the season.

Under the relatively dry climate of the Canadian prairies, weed competition is often intensified by low soil moisture levels (5, 38, 40, 42, 46). Pavlychenko and Harrington (40), and Barnes and Hopkins (5) shared the opinion that moisture is nearly always quite limiting to crop growth under prairie conditions and that the full capacity of plants to utilize soil moisture is rarely satisfied. Burrows and Olson (8, 9) suggested that the reductions of tillering in wheat and of basal branching in flax in competition with wild mustard could, in some measure, be attributed to competition between these crops and the mustard for the limited soil moisture.

Some very interesting observations compiled at the University of Manitoba over a four-year period strongly indicate a close inverse relationship between per cent reduction in yield of wheat from mustard competition and the amount of precipitation during the growing season (April-August)*.

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* Unpublished data.

Table 1. The effect of mustard competition on the yield of wheat under various levels of "growing-season" precipitation.

Year	Growing season precipitation	% reduction in yield of wheat as a result of competition with 100 mustard plants per sq.yd.	Reference
1952	10.4	20	(8)
1953	15.6	32	(8)
1954	19.6	56	*
1955	10.0	32	*

The recorded data are presented in Table 1. Since the average precipitation for the growing season in the Winnipeg area is 9.4 inches (14), it may be noted that in 1952 and 1955 growing season precipitation closely approximated this average, whereas the growing seasons of 1953 and 1954 were, perhaps, two of the wettest on record. Accordingly, the per cent reductions in yield of wheat as a result of competition with 100 mustard plants per square yard in 1952 was 20 per cent and in the wet years of 1953 and 1954 reductions in yield climbed to 32 and 56 per cent, respectively. Although growing season precipitation returned to about average in 1955, per cent reductions in yield from mustard competition remained relatively high as compared to 1952, probably because of a substantial carry-over of soil moisture from the wet year of 1954.

As stated by several investigators, most weeds appear to suffer more seriously from soil moisture deficits, particularly in the early spring, than do most of our common

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* Unpublished data.

grain crops. Staniforth (46) observed the effects of various levels of foxtail infestations on the yield of soybeans under four patterns of controlled seasonal precipitation. Reductions in yield of soybeans were greatest when soil moisture was adequate from the time of planting until the end of July but limiting to crop growth thereafter until soybean maturity, and least when soil moisture was growth-limiting from the time of planting to the end of July but adequate from then to maturity.

Pavlychenko and Harrington (40) investigated the competitive efficiencies of a number of cereals and species of weeds under conditions of limited soil moisture. The study was based on the examination of characteristics such as height, total assimilating leaf surface and extent of root development. All measurements were taken early in the growth of plants so that competition for light was not an influencing factor. Results indicated that competition commenced under the soil surface when the root systems of neighboring plants overlapped in their quest for moisture and mineral nutrients. Grasses, in general, did not appear to be as adversely affected by crowding as were the broad-leafed weeds. When grasses such as wheat, barley and wild oats were grown singly in a 10 square foot area under a specified soil moisture level they attained a total growth ten times that when grown in rows spaced 6 inches apart. Similar studies with weeds such as hare's ear mustard, wild mustard and

Russian thistle showed that when plants of these weed species were grown singly they attained a total growth ranging from 100 to 1000 times that of plants grown in cultivated 6-inch drill rows.

Several experimenters have demonstrated the value of commercial fertilizer as an effective means of increasing the advantage of a crop in competition with weeds. It has been reported that application of mineral fertilizers with seed on weedy land improved the quality of grain (7, 26), promoted crop growth early in the spring when the soil was cool and bacteria inactive (22), hastened crop maturity (22), increased yields of grain (23, 26), increased tillering in cereals (34), reduced weed seed populations (22) and checked losses from diseases such as Browning root rot (51).

Blackman and Templeman (7) reported that decreases in the nitrogen and potassium contents of cereals resulting from weed competition could be eliminated by the application of a nitrogenous fertilizer.

Godel (22) showed that drilling of ammonium-phosphate fertilizer with wheat on weedy land generally increased yield, hastened maturity and lowered weed seed populations. However, some aggressive weeds such as wild mustard and wild oats apparently derived material benefit from fertilizer under conditions of late seeding and at low rates. Heavier rates of seeding than normally recommended generally increased the efficiency of fertilizer utilization by the crop. The combined effects of increased rates of seeding and application of fertilizer on weedy land increased yields of wheat from 29.7 to 45.7 bushels per acre, reduced the average days to maturity from 92.8 to 85.7 days, and lowered wild oat seed populations by 92.9 per cent and that of wild mustard by 57.7 per cent.

McNeil and Davis (34) studied the effects of three levels of nitrogen fertility (0, 50 and 100 pounds of nitrogen per acre) on such characteristics as yield, culm number and protein content of nine spring wheat varieties. With all wheat varieties the number of culms increased consistently with increased nitrogen fertility. Ceres wheat showed the slightest increase in culm number with respective increases of 7.5 and 31.8 per cent for the 50- and 100-pounds per acre rates of nitrogen application while Lee wheat responded most favorably to fertility treatment with corresponding increases in culm number of 46.6 and 105.7 per cent for the same respective rates of nitrogen fertilization. Date of heading was advanced by 1 to 4 days with earliest maturity generally attained with the highest level of fertility. Bushel weight was not affected by the additional nitrogen. Although nitrogen fertilization at both the 50- and 100-pounds per acre rates produced substantial increases in yield and culm number of all wheat varieties, neither rate of fertilization was apparently adequate to increase protein content as well. Samples from plots which received nitrogen application at the rate of 50 pounds per acre were consistently lower in protein content than samples from corresponding check plots, while losses in protein content of samples from plots treated with 100 pounds of nitrogen per acre were much less frequent. Further analyses indicated that protein content from kernels arising from lateral florets was higher than protein content from kernels located more centrally on the spikelets. Also, spikelets from an intermediate location on the spike were higher in protein content than were the terminal spikelets. From these observations, McNeil and Davis concluded that, since earlier maturing kernels, nitrogen, even at the 100-pounds per acre rate of application, became deficient in the late growth stages of the crop.

Hunter et al. (26) reported increases in both yield and protein content of several varieties of pastry-type wheats as a result of nitrogen fertilization, but observed that per cent yield increases were usually more significant than were increases in protein content. However, protein content of these wheat varieties was not raised to objectionably high levels until the rate of nitrogen application exceeded that which was required to produce "maximum yields". In general, increases in protein content were only slight, provided that the additional nitrogen increased yields significantly.

Hedlin *et al*. (23) found that application of 16-20-0 ammonium-phosphate fertilizer at a rate that contributed 17 pounds of actual nitrogen per acre increased yield of wheat grown as second crop after fallow or as first crop after breaking sod. Protein content was not increased probably because the added nitrogen was entirely utilized earlier in the season for vegetative growth. However, these researchers demonstrated that crop residues (such as legumes used for green manure) which nitrified rapidly and released large amounts of available nitrogen during the growing season gave increases in both yield and protein content.

From experiments with corn, Gleason and Laird (20) determined that increasing the rates of fertilizer application diminished losses in yield from weed competition. Yield losses associated with 55 pounds of applied nitrogen per acre were 76.5 per cent, whereas by tripling the rate of nitrogen fertilization, losses were reduced to 50 per cent. These researchers stated that, at the lower rate of nitrogen fertilization, additional nitrogen was available only when corn roots comprised a comparatively small proportion of the total absorbing root surfaces under the weedy conditions. However, at the higher level of nitrogen fertility, nitrogen was still plentiful when corn root development surpassed that of weeds and the resulting acquisition of a greater portion of the total nitrogen by the corn was reflected in higher yields.

The importance of light as an essential for plant growth has undoubtedly been realized for many years. The physiological significance of light as an activator of pro-chlorophyll (precursor of chlorophyll), as a vital agent in photosynthesis and as a very probable inactivator of auxin is general knowledge (50). Some plants, such as the cereals and other grasses, thrive under continuous light, while successful growth and reproduction in other species is governed by a definite photoperiod; some are adapted for growth in an environment with reduced light such as that provided by the forest floor while other "sun-loving" plants cannot tolerate prolonged shade. But, despite the importance of light in crop management, scant research has been devoted to the study of light as a factor in weed competition and, accordingly, literature relating to the subject is scarce. Nevertheless, several investigators (21, 37, 38, 42) have hinted that the amount of light received by crops may become growth-limiting, especially in cases where broad-leafed weeds are numerous.

In recent years considerable emphasis has been placed upon evidence that certain species of plants are known to liberate into the soil some unidentified substance, or substances, harmful to subsequent growth of other plant species within the same soil (6, 29, 30, 31, 52). Varma (52) disclosed that these toxic substances were present in higher concentrations in decaying root tissues than in those which were living. Kommedahl *et al*. (29) detected a substance in the rhizomes, leaves and germinating seeds of quackgrass from which tissues the substance was secured as a leachate from soil in which quackgrass was grown and as aqueous extractions of macerated quackgrass tissues. When supplied as a source of moisture to potted alfalfa, wheat, barley, oats and flax, these leachates and aqueous extractions suppressed germination and impeded subsequent crop growth to a marked extent. In field trials, growth of crops was materially depressed in soil from which quackgrass rhizomes had been recently removed.

Le Tourneau and Heggeness (31) tested the effects of aqueous extracts of leafy spurge foliage and of quackgrass rhizomes on germination and growth of wheat and pea seedlings. With very low concentrations of the extracts from either source, root growth of both wheat and pea seedlings was suppressed, while at increased concentrations germination and coleoptile growth of wheat were also adversely affected. These researchers concluded that the degree of growth inhibition was approximately a direct function of concentration of the toxic material.

Without doubt, liberation of such toxic substances by field crops, or by weeds, might logically be expected to materially influence the nature of weed competition, especially if these substances were selective in action.

Studies of Varma (52) indicated that these substances were, indeed, selective. Benedict (6), however, found that dead roots of bromegrass inhibited the growth of bromegrass seedlings. Le Tourneau _et al_. (30) tested the effects of tissue extracts from 23 species of plants (representing a total of 16 families) on germination and growth of Mida wheat and Alaska peas. Extracts of Mida wheat and of Alaska pea plants were included in the trials. All extracts, including those of Mida wheat and of Alaska peas, inhibited germination of both wheat and peas, and also inhibited the growth of wheat seedlings. As a consequence of such conflicting evidence, the true importance of these toxic plant substances as an instrument of weed competition appears to be imperfectly understood.

Numerous host-specific organisms dependent upon higher plants for their survival can be mentioned (37). Some of the more familiar are microorganisms such as the various seed-borne pathogens, fungi such as rust and larger organisms such as the many phytopagous insects. Whenever the selected host is a field crop, the competitive efficiency of the crop might logically be threatened. Reference has already been made to rapid, unimpeded crop development in early growth stages as an important factor in lessening weed competition (40). Thus, parasitic attacks which commonly result in destruction of plant tissues, or in derangement of the photosynthetic or other physiological plant functions, must inevitably restrict a crop plant's capacity to compete.

In 1935, Vanterpool (51) reported that Browning root rot seriously lowered the ability of cereals to compete with weeds, but advocated that application of fertilizer with the seed provided an economical means by which weed competition could be reduced under such conditions. Machacek et al. (32) also stressed the significance of seed-borne pathogens as a decided factor in weed competition and suggested the use of fungicides and increased rates of seeding as two additional methods for combatting competition. Weeds flourished when wheat seed infested with Browning root rot was sown at rates below 1 bushel per acre, but when wheat seed treated with a mercurial fungicide was substituted at the same rates of seeding, yields were increased and weeds were correspondingly fewer.

Although considerable merit has been placed upon increased rates of seeding as aid to crops growing in competition with weeds, researchers are in general agreement that rates of seeding higher than those normally recommended should be avoided under weed-free conditions or under conditions of relatively light weed infestations. As expressed by Oosting (37), "competition occurs between individuals of the same species, as well as between members of different species, because these individuals are alike and their demands for the requirements of growth are identical." Investigators, who studied the nature of intraspecific competition by varying the rate of seeding under weed-free conditions, demonstrated that reductions in yield were common when crop plants were over-crowded (8, 11, 49). Hutchison (27) reported uniformity of crop yield over strikingly wide ranges of rates of seeding with wheat (61 - 129 pounds per acre), barley (58 - 135 pounds per acre) and oats (44 - 116 pounds per acre). Rates of seeding higher than the maximum expressed in each range generally depressed yields.

Burrows and Olson (8) found that, although the average number of wheat culms in weed-free plots sown at 1 bushel per acre was much reduced in comparison to similar weed-free plots sown at rates of 2 and 3 bushels per acre, the development of larger spikes at the lowest rate of seeding appeared to compensate fully for the reduction in culm number. Yields from plots sown at 1 bushel per acre equalled yields from plots sown at 2 bushels per acre, and exceeded the yields from plots seeded at 3 bushels per acre.

Clements et al. (11) sowed Marquis wheat under weed-free conditions at rates of one-half normal, normal, twice normal, four times normal and obtained the respective yields of 19, 21, 23.6 and 21.6 bushels per acre. Observations during the growing season indicated that wheat plants from plots sown at lower rates of seeding were markedly more vigorous in all characteristics observed than were wheat plants from plots sown at higher rates. Progressively intensified competition for the limited essentials of growth was undoubtedly responsible for the reduced vigor in plants and the subsequent diminishing yields at successively higher rates of seeding.

Rates of seeding higher than those normally recommended appear to be quite beneficial where cropping on weedy land is concerned (21, 32, 38). Godel (21) advocated earlier seeding on weedy land to permit the grain to germinate before weed seeds germinate, shallow seeding for more rapid emergence of grain seedlings and application of fertilizer with the seed to promote more rapid crop growth. This investigator added that "heavier than normal" rates of seeding combined with the above-mentioned practices hastened the formation of a dense root mat and provided a denser crop cover which reduced inter-row competition from weeds through a more thorough shading of weed growth. Pavlychenko (38) recognized the benefits of increased rates of seeding on weedy land and proposed cross-seeding as another effective means for more complete shading of weed growth.

By increasing the rate of barley seeding from $1\frac{1}{2}$ to 3 bushels per acre, McCurdy (33) reduced wild oat seed populations in the soil by 46 per cent. By combining fertilizer treatment with higher seeding rates, a 62 per cent reduction in wild oat seed populations was obtained.

Burrows and Olson (8) reported that for wheat sown at the rate of 1 bushel per acre the critical density of wild mustard which reduced yields significantly was 50 plants per square yard, but for the 2 and 3 bushels per acre rates of seeding yields were not reduced significantly until the mustard density reached 200 and 400 plants per square yard, respectively.

Within the past decade, the use of 2,4-D (2,4-dichlorophenoxyacetic acid) formulations to control broad-leafed weeds in cereals has become widespread. Applications of 2,4-D at recommended dosages during early 2,4-D-tolerant stages of growth in cereal crops have often resulted in reduced weed competition and attendant increases in yield of grain (2, 8). Several investigators reported that treatment of wheat with 2,4-D had, either directly or indirectly, also increased the protein content of the wheat (17, 24, 28). Erickson et al. (17) reported that 2,4-D applied at rates sufficient to kill sensitive weeds increased the protein content of wheat. These investigators specified that increases in protein content were not influenced by factors such as variety of wheat, dryland or irrigated conditions or the stage of wheat growth, prior to heading, at which time the herbicide was applied. Helgeson (24) also found increases in protein content of wheat resulting from treatment with 2,4-D, but stated that variations in protein content of wheat varieties differed with the type of 2,4-D derivative employed and the stage of wheat growth at which time chemical treatment was applied.

Friesen (19) demonstrated that the largest increases in protein content of wheat were obtained where 2,4-D caused the severest reductions in yield.

Aitken *et al*. (1) tested the effects of sodium salt, amine and ester formulations of 2,4-D over a two-year period on several varieties of wheat, oats and barley treated with various dosages of the formulations at the blade and heading stages of crop development. Although the protein content of threshed samples was often increased, these increases were generally not significant. Increases in protein content were greatest in wheat and most pronounced when the ester formulation of 2,4-D was applied.

MATERIALS AND METHODS

Three different investigations were undertaken in this study:

(a) To determine the density of wild mustard that can be tolerated before yield and quality of wheat are significantly reduced under varying levels of soil fertility.

(b) To determine when, in the growth of wheat, competition from wild mustard becomes apparent under different levels of soil fertility.

(c) To evaluate the influence of a commercial fertilizer on weed competition under farm field conditions.

(a) To determine the density of wild mustard that can be tolerated before yield and quality of wheat are significantly reduced under varying levels of soil fertility.

Since the objective of this study was to evaluate the competitive effects of carefully controlled densities of wild mustard grown in association with wheat, it was considered preferable to conduct the experiment on land which was relatively weed-free to facilitate establishment of the required mustard densities. Consequently, land at the University of Manitoba which had been fallowed intensively the previous summer was selected for this study. Wheat was chosen as the crop principally because of its economic importance, and wild mustard as the weed because of its prevalence in Western Canada.

The experimental design consisted of 4 replicates each consisting of 9 main plots which were randomized as to 9 different densities (0, 25, 50, 75, 100, 125, 150, 175 and 200 plants per square yard) of wild mustard. Main plots were divided into 2 sub-plots, one of which was treated with 11-48-0 ammonium-phosphate fertilizer applied at a rate of 40 pounds per acre, and the other received no fertilizer treatment. Sub-plots were 18.5 feet long and consisted of 8 rows of wheat spaced 6 inches apart. On May 10, 1958 Selkirk wheat was sown at a rate of 1.5 bushels per acre in all plots by means of a V-belt seeder. Fertilizer was applied directly with the seed. The following day sufficient wild mustard seed to provide the desired mustard densities was broadcast over the plots and raked into the soil by means of a garden rake. It was anticipated that thinning of mustard seedlings by hand would be essential to establish the correct weed densities.

To alleviate the dry soil conditions prevalent in the spring of 1958, approximately an inch of water was applied to the plots by sprinkler irrigation at 3 and 12 days after seeding.

As a result of inadequate soil moisture at the time of seeding and abnormally high winds immediately after seeding, the distribution of wild mustard seedlings within the plots was extremely irregular. Consequently, it was impossible to establish the correct mustard densities of uniform plant distribution by thinning of mustard seedlings as planned originally. As an expedient, sub-plots were divided into sections and, on the basis of these sub-plot divisions, wild mustard densities were simply recorded and thinning of mustard seedlings was avoided. In dividing the sub-plots for the purpose of recording mustard densities, one foot of plot length at each end of the sub-plot was disregarded and the remaining rod-length plot was demarcated transversely into 4 equal parts. Mustard densities were recorded when the wheat was in the 3-leaf stage of growth (8 - 10 inches stretched height) and mustard seedlings were from 2 to 5 inches tall.

When the wheat reached maturity, the sub-plots were again demarcated in the same manner described above for recording of mustard densities. A square yard sample of wheat was harvested from the centre of each of the 4 sub-plot divisions. Plots were harvested on August 16, 1958 and yield and bushel weight of the samples were recorded. Protein content of the grain was determined by the improved Kjeldahl method for nitrate-free samples (25).

(b) <u>To determine when, in the growth of wheat, competition from wild mustard becomes apparent under different levels of soil fertility</u>.

This second experiment, like Experiment (a) of the project, was conducted on a block of fallow land at the University of Manitoba in 1958. Wheat was chosen as the crop in this experiment primarily because of its tolerance, at certain stages of growth, to 2,4-D (2,4-dichlorophenoxy-acetic acid). Wild mustard was selected as the weed mainly because of its marked susceptibility to 2,4-D and because of its prevalence in Western Canada.

The experiment was replicated 5 times. Each replicate consistented of 5 main plots which were randomized according to 4 dates of weed removal by chemical treatment, and an untreated check. Main plots contained 2 randomized sub-plots, one of which was to be infested with wild mustard at a density of 100 plants per square yard, and the other maintained weed-free throughout the growing season. Sub-plots were divided into 2 sub-sub-plots, each 18.5 feet long and consisting of 8 rows of wheat spaced 6 inches apart. Sub-sub-plots were randomized as to fertility treatment (no fertilizer applied versus application of 11-48-0 ammonium-phosphate fertilizer at a rate of 40 pounds per acre).

Plots were sown to Selkirk wheat at a rate of 1.5 bushels per acre by means of a V-belt seeder on May 13, 1958.

On the same day wild mustard seed, sufficient to provide the desired density of 100 mustard plants per square yard, was broadcast over the plots and raked into the soil by means of a garden rake. Water was applied to the plots by sprinkler irrigation at 2 separate dates (2 and 10 days after seeding). With each irrigation approximately 1 inch of water was applied.

Mustard densities were recorded when the wheat was at the 3-leaf stage of growth. Because of drought and soil drifting, seedling survival was extremely poor and, as a result, mustard densities in the weedy plots were invariably below the desired density of 100 plants per square yard. Thinning of mustard stands was not required. Since the distribution of mustard seedlings was quite uniform, mustard densities in this experiment were recorded on a sub-sub-plot basis.

Mustard competition was removed from the wheat at 4 successive stages of growth by spraying with butyl ester of 2,4-D at the rate of 4 ounces acid-equivalent per acre. Spraying commenced at the late 3-leaf stage of wheat (wheat 8 - 10 inches stretched height) and terminated when wheat had reached the 6-leaf stage. Intervals of one week were allowed between successive dates of weed removal. At each of the four dates of weed removal a different main plot in each replicate was treated with 2,4-D.

At harvest time one foot of plot length at each end of the sub-sub-plots and the four outermost rows of each sub-sub-plot were discarded to eliminate "border effect".

Four rod-rows were harvested from each sub-sub-plot. Yield and bushel weight of the samples were recorded. Protein content of the grain was determined by the improved Kjeldahl method for nitrate-free samples (25).

(c) <u>To evaluate the influence of a commercial fertilizer on weed competition under farm field conditions</u>.

This experiment was conducted on fertilizer trial strips laid out on farm fields in Manitoba during the spring of 1958 by the Soils Department, University of Manitoba. Six fields, four in the Roblin area and two in the vicinity of Portage la Prairie, were selected for this experiment. All fields had been fallowed the previous summer and were sown to Selkirk wheat in the spring of 1958.

Fertilized strips and check strips in these fertilizer trials consisted of 12 or 14 six-inch drill rows (one-half width of farmer's drill) and were one-half mile long. A number of fertilizer formulations, which were drilled with the seed at various rates of application, were tested in these trials. However, for the requirements of this experiment, a strip treated with 11-48-0 ammonium-phosphate fertilizer at the rate of 40 pounds per acre and an adjacent check strip were selected in all fields.

Shortly after the wheat emerged and the boundaries of the strips became plainly discernible, a row of ten paired plots were staked in each of the selected strips. Paired plots in either strip were spaced 60 paces apart. One plot of each pair was maintained weed-free by hand "weeding", the other was left in its natural weedy condition for the duration of the growing season. "Weeding" of the plots commenced soon after the weeds emerged (wheat generally 2 - 3 inches tall) and was repeated thereafter at intervals of 10 days, as required. In one of the six fields, the plots were weeded three times. Weed seedlings removed from the plots were placed in polyethylene bags and brought to the laboratory for counting and identification.

Square yard samples were harvested from the center of each plot when the wheat was mature. Yield and bushel weight of the samples were determined. Protein content of the grain was determined by the improved Kjeldahl method for nitrate-free samples (25).

RESULTS AND DISCUSSION

(a) To determine the density of wild mustard that can be tolerated before yield and quality of wheat are significantly reduced under varying levels of soil fertility.

As a result of severe wind and drought conditions at the time of planting and for several days thereafter, germination of mustard seed was delayed and survival and subsequent growth of mustard seedlings were somewhat impeded. At the time when densities of wild mustard were recorded wheat was 8 to 10 inches tall (stretched height) and the mustard plants varied from 2 to 5 inches in height. A rather severe outbreak of flea beetles which attacked the mustard after the first week in July may also have reduced the ability of mustard plants to compete with wheat.

For purposes of statistical analysis the 288 samples (4 from each of the 72 sub-sub-plots) were grouped into 12 categories on the basis of wild mustard density and fertility treatment. The categories were 0, 1-25, 26-50, 51-75, 76-100 and 100+ mustard plants per square yard for samples harvested from both the fertilized and the unfertilized plots. The number of observations in each category and the respective means for yield, protein content and bushel weight are presented in Table 2.

Because of the varying number of observations in the categories listed in Table 2, the unpaired t-test was selected as the statistic suitable for analysis of the data.

Table 2. The effects of varying densities of wild mustard on yield, protein content and bushel weight of wheat grown under two levels of soil fertility.

Wild mustard plant per sq. yd.	Fertilized Plots				Unfertilized Plots			
	Number of observations	Av. yield bu./ac.	Av. protein %	Av. bu. wt. lb./bu.	Number of observations	Av. yield bu./ac.	Av. protein %	Av. bu. wt. lb./bu.
0	47	70.96	15.49	64.63	52	74.71	15.48	64.63
1-25	30	73.57	15.37	64.48	25	71.10	15.27	64.76
26-50	30	68.16	15.38	64.53	24	71.88	15.44	64.69
51-75	18	65.16	15.51	64.47	15	64.49**	15.41	64.30
76-100	4	60.55*	14.93	64.50	11	62.74**	15.59	64.30
100+	15	59.43**	15.58	64.33	17	60.25**	15.45	64.38
Total	144				144			

* Significant at 5% level of probability.
** Significant at 1% level of probability.

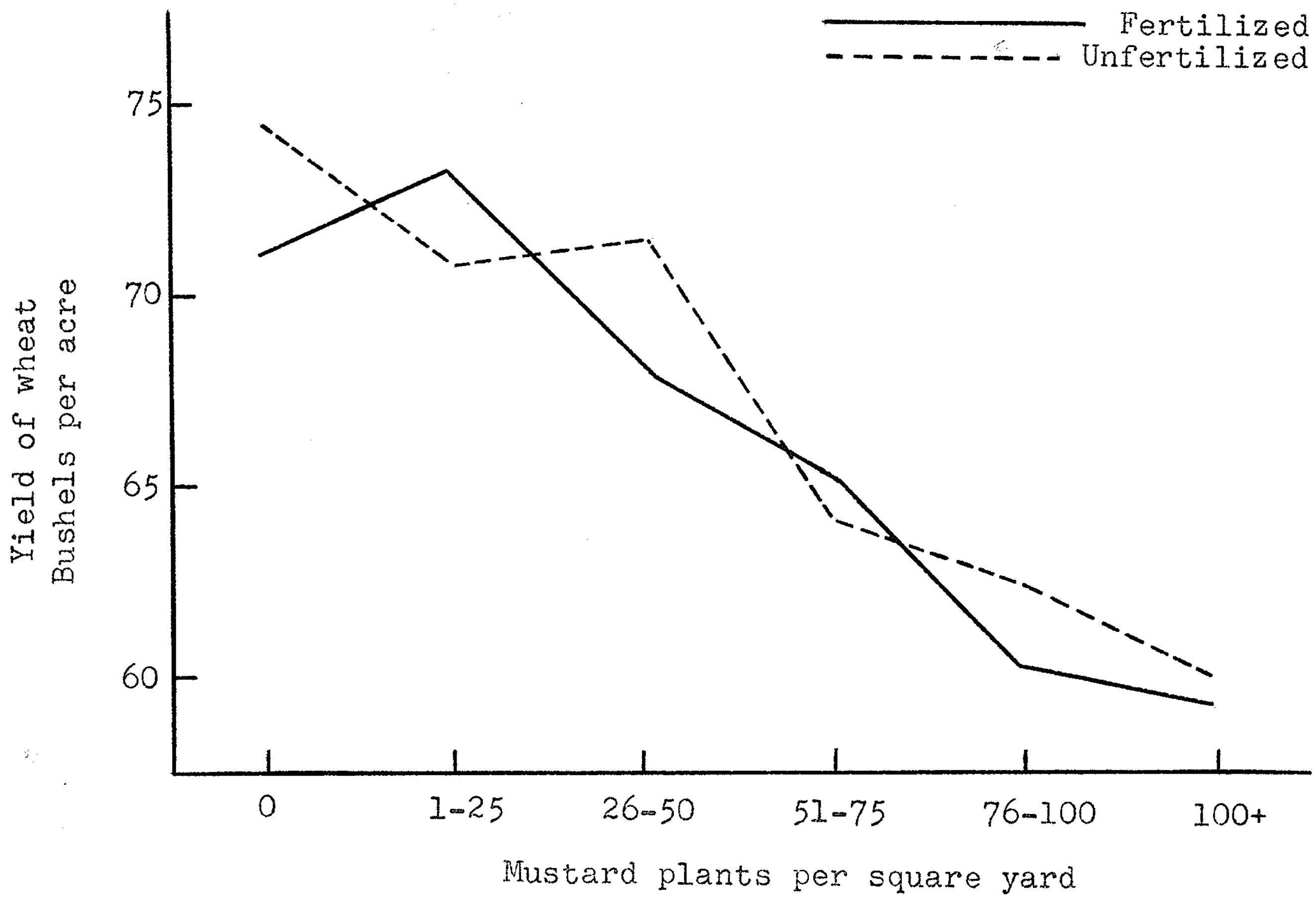
Each category from the fertilized group was compared with the corresponding category in the unfertilized group to determine the influence of fertilizer on yield, protein content and bushel weight of grain samples. Other comparisons were made to study the effect of the various levels of mustard density on yield, protein content and bushel weight of wheat grown under fertilized and unfertilized soil conditions.

Yield of Wheat

Undoubtedly, because of the high level of fertility the fallow land on which the experiment was conducted, variations in yield between fertilized and unfertilized plots with corresponding mustard densities were not significant. However, as illustrated in Figure 1, a general trend towards reduced yield was apparent as the density of wild mustard increased under both fertilized and unfertilized conditions. Yields of wheat were not reduced significantly in unfertilized plots when densities of wild mustard were below 50 to 75 plants per square yard. When the mustard density was 50 to 75 plants per square yard, and higher, reductions in yield were highly significant. These results are quite in agreement with the results of Burrows and Olson (8) who reported that 50 mustard plants per square yard caused significant lowering of yield of wheat under unfertilized soil conditions.

In plots treated with 11-48-0 ammonium-phosphate fertilizer, yield of wheat was reduced significantly when the density of wild mustard was 75 to 100 plants per square yard.

Figure 1. The effect of wild mustard on the yield of wheat grown under two levels of soil fertility.



Under these conditions of increased soil fertility losses in yield of grain were highly significant only where wild mustard density exceeded 100 plants per square yard.

On the basis of the results of this investigation it is apparent that application of a commercial fertilizer with grain sown on weedy land decidedly increased the ability of the grain to compete with weeds. To recapitulate, competition from 50 to 75 mustard plants per square yard in plots where no fertilizer was applied caused highly significant reductions in the yield of wheat. Where a commercial fertilizer was applied at a recommended rate with the grain, significant reductions in yield (5 per cent level) were manifest when 75 to 100 mustard plants per square yard were present. Highly significant reductions in yield (1 per cent level) occurred under fertilized soil conditions only when the density of wild mustard exceeded 100 plants per square yard.

Protein Content and Bushel Weight

Statistical analysis of the data showed that both protein content and bushel weight of wheat were not affected significantly by either fertility treatment or the degree of weediness. Figures 2 and 3, respectively, illustrate no consistent trend in protein content and bushel weight of wheat as a result of fertility treatment or the degrees of weediness studied in this experiment. Probably because of the inherent high fertility of the fallow land on which the experiment was conducted, soil fertility in unfertilized plots was sufficient to maintain protein content and bushel weight of wheat on a par with fertilized plots.

Figure 2. The effect of wild mustard on protein content of wheat grown under two levels of soil fertility.

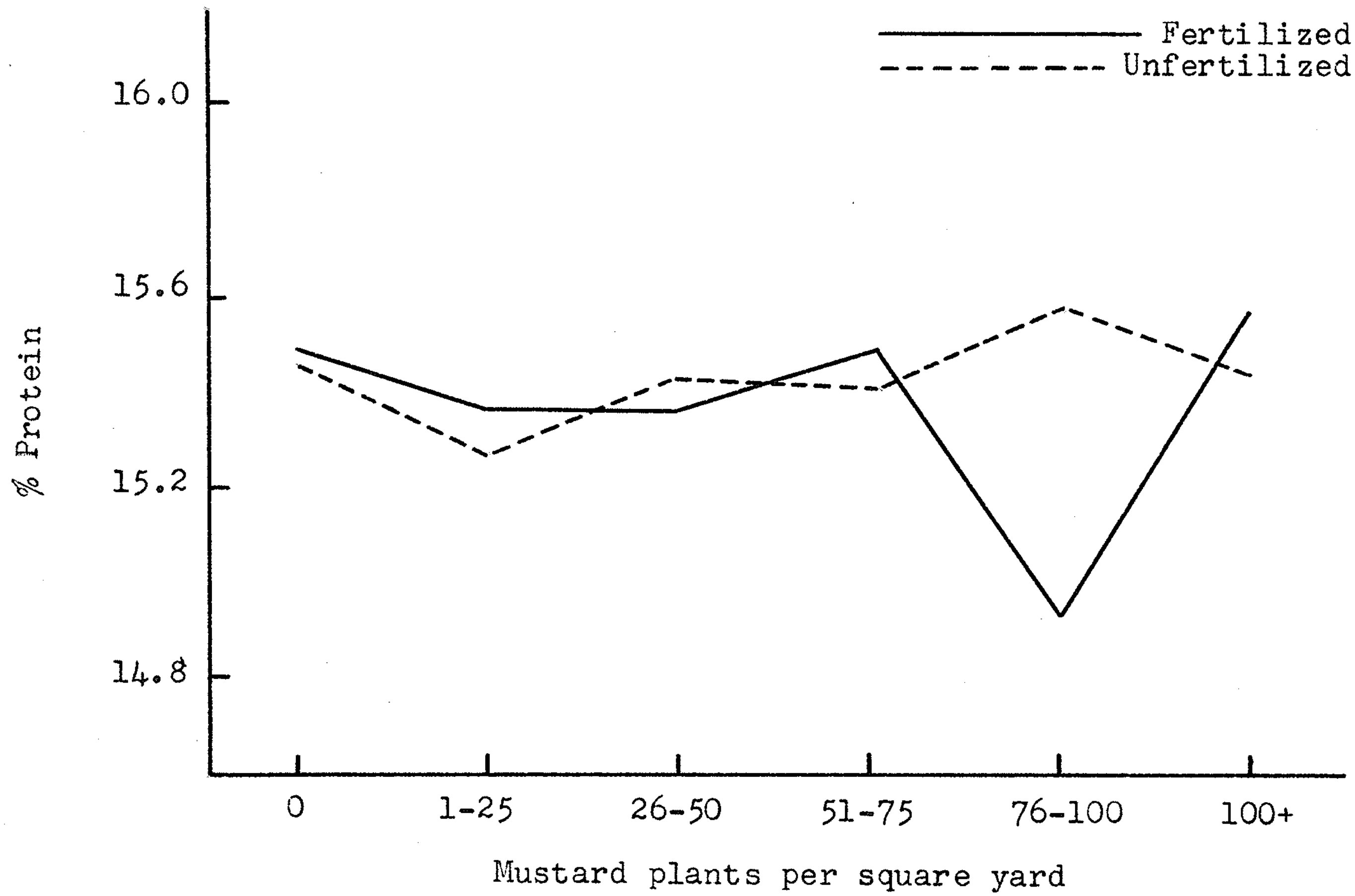
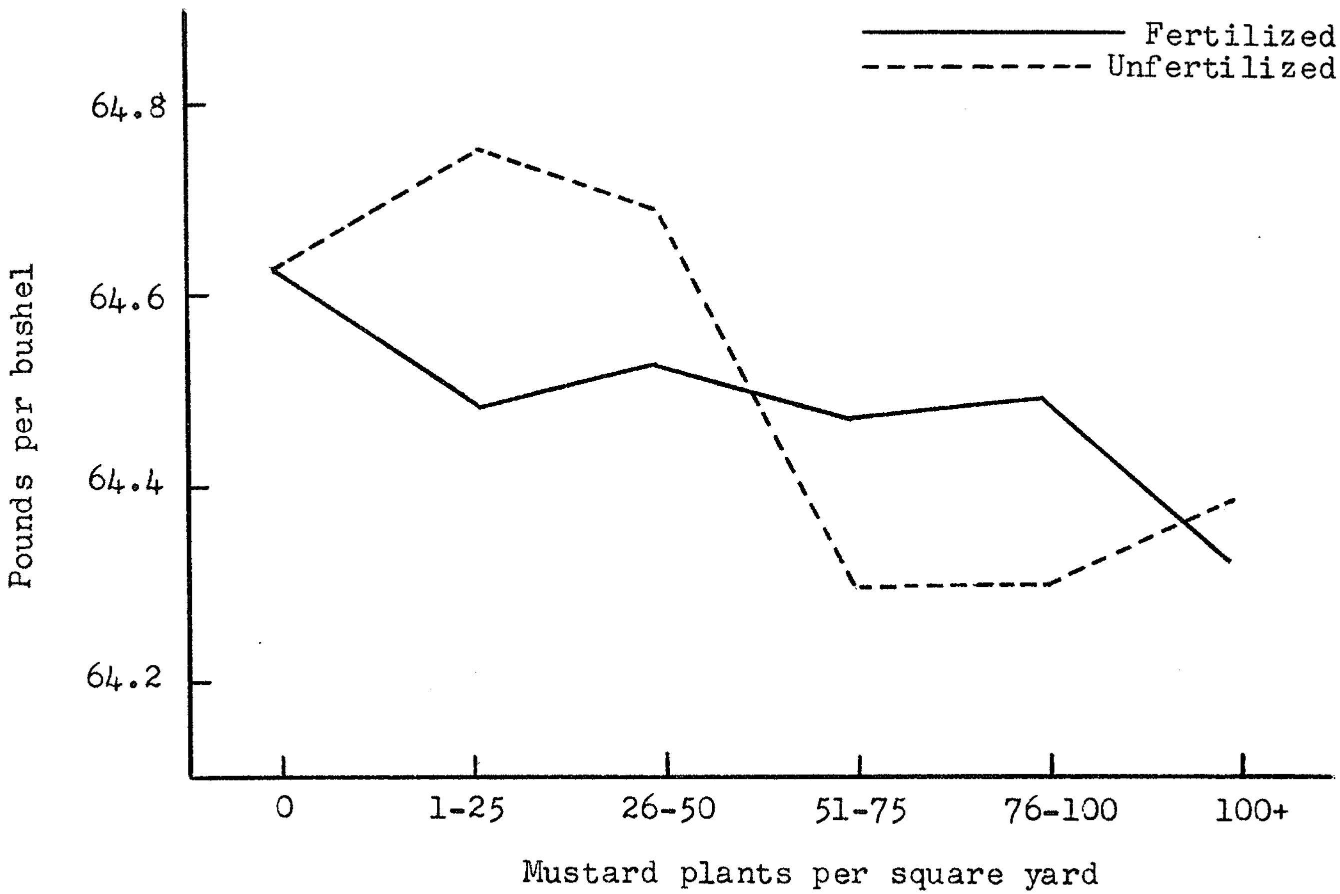


Figure 3. The effect of wild mustard on the bushel weight of wheat grown under two levels of soil fertility.



(b) <u>To determine when, in the growth of wheat, competition from wild mustard becomes apparent under different levels of soil fertility</u>.

As in Experiment (a) of this project, severe drought and wind conditions restricted establishment of the desired mustard density of 100 plants per square yard. As a result of these adverse weather conditions, the density of wild mustard in the weedy plots generally varied between 33 and 55 plants per square yard.

Analysis of variance revealed that yield, protein content and bushel weight of wheat were not influenced significantly by either the application of 11-48-0 ammonium-phosphate fertilizer at the rate of 40 pounds per acre or the stage of crop growth when weed competition was removed with 2,4-D. The absence of any response of wheat to fertilizer treatment certainly reflected the natural high fertility of the land on which the experiment was conducted. In Experiment (a) of this project, yield of wheat was not reduced significantly by wild mustard densities below 50 to 75 plants per square yard under conditions where no fertilizer was applied, or by densities below 75 to 100 plants per square yard under fertilized soil conditions. Protein content and bushel weight of wheat were not affected by mustard densities in excess of 100 plants per square yard under either fertilized or unfertilized conditions. Therefore, on the basis of the results of Experiment (a), significant variations in yield, protein content and bushel weight of wheat in Experiment (b) as a result of fertilizer application and weed removal would not have been anticipated because of the natural high fertility of the soil and because mustard plants were too few, and perhaps too weak, to offer severe competition to the crop.

(c) To evaluate the influence of a commercial fertilizer on weed competition under farm field conditions.

The comparative weed counts under the two levels of soil fertility and their effect on yield and protein content of wheat at each of six locations are presented in Appendices 1 to 24 and summarized in Table 3. The slightly higher average number of weeds in the fertilized portions of most fields as compared to unfertilized portions of the same

Table 3. Weed counts per square yard under two levels of soil fertility. (Summary for 6 locations on farm fields).

	Fertilized			Unfertilized		
Location*	Maximum	Minimum	Average	Maximum	Minimum	Average
1	122	15	56	131	11	54
2	608	12	299	627	24	259
3	6	0	3	11	0	4
4	488	32	148	398	24	95
5	782	96	273	338	88	214
6	1112	351	604	1081	54	573
Average	520	84	231	431	34	200

* Locations 1 to 4 in Roblin area;
locations 5 and 6 in Portage la Prairie area.

fields might imply that weeds may have benefited from fertilizer treatment. This evidence would support the results obtained by Godel (20) who reported that aggressive weeds such as wild oats and wild mustard could derive benefit from fertilizer applied directly with seed. However, because of the wide variations in number of weeds between replicates under either level of soil fertility at most of the locations, it is uncertain whether fertilizer promoted weed germination and growth in these tests.

At all locations, weeds found in the fields were almost exclusively annual species. In the Roblin area (locations 1 to 4) wild oats and wild mustard were the predominant weeds, while in the Portage la Prairie area (locations 5 and 6) wild oats, wild buckwheat and hemp nettle were the most common weeds. Only in a few isolated plots were perennial weeds such as Canada thistle, sow thistle and field horsetail encountered.

In some fields response to fertilizer treatment became apparent as early as the 2- to 3-leaf stage of wheat growth, at which time wheat in fertilized plots, under both weedy and weed-free conditions, was generally about two inches taller than wheat in corresponding plots to which fertilizer was not applied. Although this differential in growth became less apparent during advanced stages of vegetative growth, the response to fertilizer treatment commonly became manifest again at maturity. At locations 4, 5 and 6, fertilized plots matured about 3 days earlier than plots to which fertilizer was not applied, whereas, at location 1 maturity of wheat was advanced by about 6 days as a result of fertilizer treatment. In other fields, locations 2 and 3, response of wheat to fertilizer was not evident at any stage of crop development. Inherent high fertility of the soil at these two latter locations was likely responsible for the absence of response of wheat to fertilizer treatment.

Yield of Wheat

Probably because of the "rolling" topography of the fields in the Roblin area, variations in yield of wheat among replicates were significant at all 4 locations in that area. In the Portage la Prairie area, where the fields were comparatively level, variations in yield amongst replicates were not significant at either of the 2 locations.

Table 4 indicates that at all locations average yields from fertilized plots were consistently higher in comparison to yields of unfertilized plots.* Yields were also consistently higher in weed-free plots as compared with yields of plots from which weeds had not been removed. Increases in yield of wheat resulting from fertilizer treatment were highly significant at the 4 locations (locations 1, 4, 5 and 6) where a favorable response to fertilizer had been observed during the growing season but were not significant at the two

* Complete yield data and analysis of variance appear in Appendices 1 to 12, inclusive.

Table 4. The effect of fertilizer application and weed removal on the yield of wheat.

	Average of weedy and weed-free plots			Average of fertilized and unfertilized plots		
(1) Location	(2) Fertilized bu./ac.	(3) Unfertilized bu./ac.	(2)-(3) bu./ac.	(4) Weed-free bu./ac.	(5) Weedy bu./ac.	(4)-(5) bu./ac.
1	36.8	29.5	7.3**	33.9	32.4	1.5
2	28.5	25.8	2.7	30.4	23.9	6.5**
3	51.4	50.2	1.2	52.3	49.3	3.0
4	33.1	26.5	6.6**	33.3	27.3	6.0**
5	40.9	30.3	10.6**	40.1	31.1	9.0**
6	42.5	31.0	11.5**	40.8	32.8	8.0**
Average	38.9	32.2	6.7	38.5	32.8	5.7

* Significant at 5% level of probability.
** Significant at 1% level of probability.

locations where no response was observed. Increases in yield resulting from weed removal were highly significant at 4 locations. Because of the comparatively low weed counts at locations 1 and 3, increases in yield from weed removal were not significant.

The six locations can be arranged in order of increasing average weed densities as follows: locations 3, 1, 4, 5, 2 and 6. For all practical purposes, location 3 might well be considered weed-free, while location 1 had comparatively low weed counts of 54 weeds per square yard in plots to which fertilizer was not applied, and 56 weeds per square yard in plots which received the benefits of a commercial fertilizer. Competition from these relatively low weed densities did not cause significant reductions in the yield of wheat at either location as shown in Table 4. However, at locations 4, 5, 2 and 6 average weed counts were progressively higher and reductions in yield of wheat as a result of weed competition were highly significant. Of these 4 latter locations, location 4 had the lowest number of weeds, with average weed counts of 95 weeds per square yard in plots where fertilizer was not applied, and 148 weeds per square yard in fertilized plots. A comparison of locations 1 and 4 discloses that significant reductions in yield of wheat may be anticipated when the numbers of annual weeds range between 54 and 95 weeds per square yard under conditions where fertilizer has not been applied, or between 56 and 148 weeds per square yard where a commercial fertilizer has been applied at a recommended rate. Such results agree closely with the results of Experiment (a) of this project, whereby 50 to 75 plants of wild mustard per square yard in unfertilized plots, or 75 to 100 plants of wild mustard per square yard in fertilized plots, were found to cause significant reductions in yield of wheat.

Table 5 illustrates that average yields of wheat were invariably highest in plots where the benefits of fertilizer application and weed removal were combined, and consistently lowest in plots where neither treatment was applied. Plots to which either fertilizer treatment or weed removal was applied were intermediate in yield. The comparative effectiveness of the various treatments on the yield of wheat is expressed on a per cent basis in Table 6.

Table 5. The effect of weeds on the yield of wheat grown under two levels of soil fertility.

	Mean yields (bushels per acre)					
	Fertilized			Unfertilized		
(1) Location	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weed-free	(5) Weedy	(4)-(5)
1	37.4	36.1	1.3	30.4	28.6	1.8
2	31.2	25.8	5.4	29.6	21.9	7.7
3	53.3	49.5	3.8	51.3	49.1	2.2
4	34.9	31.3	3.6	29.7	23.2	6.5
5	44.7	37.0	7.7	35.4	25.1	10.3
6	45.1	39.9	5.2	36.4	25.6	10.8
Average	41.1	36.6	4.5	35.5	28.9	6.6

Table 6. Comparative increases in wheat yields (per cent) as a result of fertilizer application and weed removal.

	Yield increase (per cent)			
			Fertilizer applied and weeds removed	
(1) Location	(2) Fertilizer Applied	(3) Weed Removed	(4) Actual	(2)+(3) Theoretical
1	26.22	6.29	30.77	32.51
2	17.81	35.16	42.47	52.97
3	0.81	4.48	8.55	5.29
4	34.91	28.02	50.43	62.93
5	47.41	41.04	78.09	88.45
6	55.86	42.19	76.17	98.05
Average	30.50	26.20	47.75	56.70

Application of 11-48-0 ammonium-phosphate fertilizer at a recommended rate was, perhaps, slightly more effective in reducing losses in yield from weed competition than was complete weed removal at an early stage of crop growth. At the four locations where fertilizer accelerated the growth of wheat seedlings and hastened maturity, per cent increases in yield which resulted from fertilizer application were greater than per cent yield increases from weed removal. It is interesting to note that at these same locations average weed counts in fertilized plots ranged from 56 to as many as 604 annual weeds per square yard. At locations 2 and 3 where the response of wheat to fertilizer was poor, per cent increases in yield resulting from weed removal were greater than the increases in yield from fertilizer application.

The treatment which combined the effects of both fertilizer and weed removal was decidedly most effective in increasing the yield of wheat. At location 3 where weeds were few and response to fertilizer very slight, or perhaps, absent entirely, increase in yield of wheat as a result of fertilizer treatment and weed removal was only about 8 per cent; at locations such as 5 and 6, where weeds were numerous and response to fertilizer quite favorable, yield increases of almost 80 per cent were obtained.

Protein Content of Wheat

As shown in Table 7, protein content of wheat was consistently lower in those plots from which weeds had not been removed as compared to the protein content of wheat from weed-free plots. However, reductions in protein content

Table 7. The effect of weeds on protein content of wheat grown under two levels of soil fertility.*

	Protein content (per cent)					
	Fertilized			Unfertilized		
(1) Location	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weed-free	(5) Weedy	(4)-(5)
1	13.1	13.3	-0.2	12.9	12.9	0.0
2	11.6	11.0	0.6	11.8	11.2	0.6
3	13.2	13.3	-0.1	13.2	13.0	0.0
4	12.5	12.4	0.1	13.3	12.9	0.4
5	13.2	12.8	0.4	13.2	12.7	0.5
6	14.5	14.2	0.3	15.0	14.6	0.4
Average	13.0	12.8		13.2	12.9	

* The complete data and the analysis of variance for each of the six locations appear in appendices 13 to 24, inclusive.

as a result of weed competition were not significant at locations 1, 3 and 4, but were highly significant at locations 2, 5 and 6. Such results are rather striking for, as shown by Table 3, weeds were most numerous at the three latter locations where significant reductions in protein content occurred. At location 4 yield of wheat was significantly reduced by average weed densities of 148 and 95 weeds per square yard under fertilized soil conditions and under conditions where no fertilizer was applied, respectively. At this same location protein content of wheat was not reduced significantly as a result of weed competition. Significant reductions in protein content occurred at location 5 where the average weed densities were 273 and 214 weeds per square yard under fertilized and unfertilized soil conditions, respectively. At locations 2 and 6 where weed densities were highest for the 6 locations, reductions in protein content as a result of weed competition were accordingly highly significant.

A number of investigators (25, 27, 35) reported that significant increases in yield of wheat from fertilizer application commonly resulted in reductions in protein content except, perhaps, in cases where available soil nitrogen remained adequate for the duration of the entire growing season. Results of the project under discussion appear to support this hypothesis. As shown by Table 8, the average per cent protein at most locations from

Table 8. The effect of fertilizer application and weed removal on the protein content of wheat.

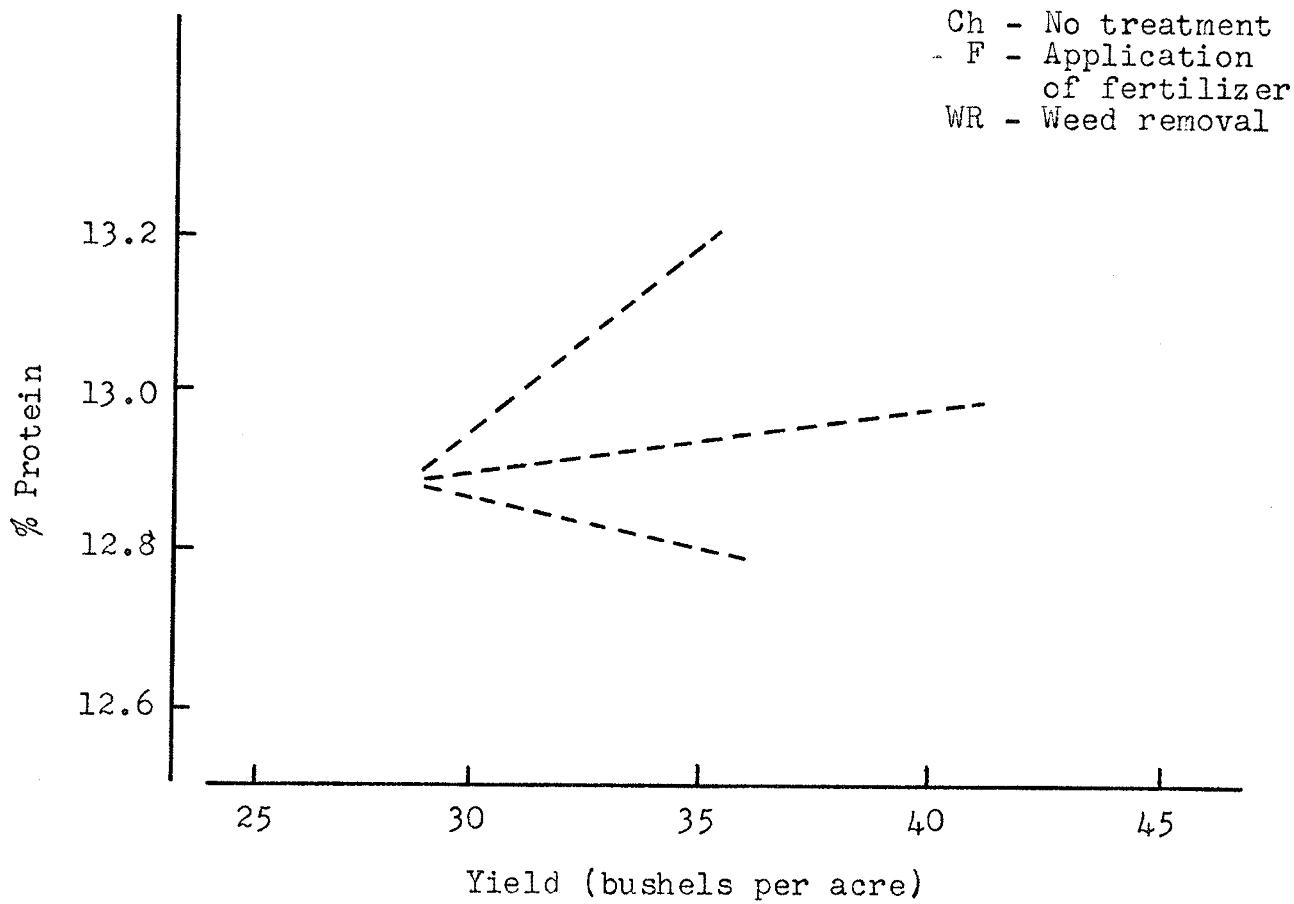
(1) Location	Protein content (per cent) (2) Unfertilized	(3) Fertilized	(2)-(3)	(4) Weed-free	(5) Weedy	(4)-(5)
1	12.9	13.2	-0.3	13.0	13.1	-0.1
2	11.5	11.3	0.2	11.7	11.1	0.6**
3	13.1	13.2	-0.1	13.2	13.1	0.1
4	13.1	12.4	0.7**	12.9	12.6	0.3
5	13.0	13.0	0.0	13.2	12.8	0.4**
6	14.8	14.3	0.5**	14.7	14.3	0.4*
Average	13.1	12.9		13.1	12.8	

* Significant at 5% level of probability.
** Significant at 1% level of probability.

fertilized portions of the fields was generally lower than average per cent protein from portions of the fields where fertilizer had not been applied. At locations 4 and 6, where significant increases in the yield of wheat resulted from fertilizer treatment, protein content of the wheat was reduced significantly. At locations 1 and 5 where fertilizer similarly increased yield of wheat significantly, protein content was not affected probably because of high nitrogen fertility of the soil at these two locations. At locations 2 and 3 where no apparent response to fertilizer had been observed during the growing season, neither yield nor protein content of wheat was affected by fertilizer. Again, as in the case of locations 1 and 5, high natural fertility of the fallow land was believed to be the cause for the apparent lack of response to fertilizer.

Table 6 shows that application of a commercial fertilizer and removal of weeds reduced losses in yield of wheat from weed competition. Figure 4 shows graphically the average yield and protein content of wheat from the 6 locations. From this graph it may be noted that, although fertilizer increased yields of wheat when weeds were present, protein content of wheat was lowered as a result of fertilizer application. These reductions in protein content resulting from the use of fertilizer were highly significant in 2 of the 6 fields sampled. Weed removal, on the other hand, increased yields of wheat and increased protein content of

Figure 4. The comparative effects of fertilizer application and weed removal on the yield and protein content of wheat.



wheat significantly at 3 locations. Stated briefly, it appears that application of 11-48-0 ammonium-phosphate fertilizer at the rate of 40 pounds per acre with wheat on summerfallow generally increased yield of wheat but reduced protein content, while removal of weeds by hand tended to increase both yield and protein content. Under weed-free conditions the depressing effect of fertilizer on the protein content of wheat was not as severe as when weeds were present. Where application of commercial fertilizer and removal of weeds were combined into one treatment, yields of wheat were highest and protein content was maintained at a level somewhat higher than in untreated check plots or plots to which only fertilizer treatment was applied.

Bushel Weight of Wheat

Bushel weight of wheat was not affected by weed competition under either level of soil fertility at any of the six locations. Since average weed densities recorded for the six locations varied from 3 to 604 weeds per square yard when commercial fertilizer was applied, and from 4 to 573 weeds per square yard where fertilizer was not applied, it appears that bushel weight of wheat was not influenced by the degree of weediness under either level of soil fertility. These results agree with the results of Burrows and Olson (8) who reported that bushel weight of wheat was not affected by competition from various densities of wild mustard ranging between 0 and 200 mustard plants per square yard. Although average bushel weight of wheat from fertilized plots was slightly higher than from plots to which fertilizer was not applied, these increases in bushel weight were not significant. Absence of any effect of fertilizer treatment on the bushel weight of wheat is in agreement with the results of McNeil and Davis (34) who reported that bushel weight of a number of varieties of wheat was not affected by various rates of fertilizer application.

SUMMARY AND CONCLUSIONS

The project was designed to study various aspects of weed-crop competition in the three following experiments:

(a) To determine the density of wild mustard that can be tolerated before yield and quality of wheat are reduced significantly under varying levels of soil fertility.

(b) To determine when, in the growth of wheat, competition from wild mustard becomes apparent under different levels of soil fertility.

(c) To evaluate the influence of a commercial fertilizer on weed competition under farm field conditions.

Six densities (0, 1-25, 26-50, 51-75, 75-100, and 100+ plants per square yard) of wild mustard were studied to determine the level of weed population that caused significant reductions in yield, protein content and bushel weight of wheat grown on summerfallow land under two levels of soil fertility. In plots where fertilizer was not applied, yield of wheat was reduced significantly by 51 to 75 plants of wild mustard per square yard, while in plots where 11-48-0 ammonium-phosphate fertilizer was applied at a recommended rate of 40 pounds per acre, yield was not reduced significantly until densities of wild mustard reached 75 to 100 plants per square yard. Protein content and bushel weight of wheat were not affected by the various densities of wild mustard under either level of soil fertility.

In Experiment (b) densities of wild mustard varied between 33 and 55 plants per square yard and, as may be concluded from the results described above, these densities of mustard were generally too low to cause significant reductions in yield and quality of wheat. As a result of the inherent high fertility of the fallow land on which the experiment was conducted, yield and quality of wheat were not affected by 11-48-0 ammonium-phosphate fertilizer applied at a recommended rate of 40 pounds per acre. Because of the absence of significant variations in yield and quality of wheat as a result of weed competition and lack of response of wheat to fertilizer treatment, removal of wild mustard by spraying with butyl ester of 2,4-D at the rate of 4 ounces acid-equivalent per acre at four stages of wheat growth (commencing at the 3-leaf stage of wheat and at intervals of seven days thereafter) did not affect yield, protein content or bushel weight of wheat under either level of soil fertility.

In farm fields where response to fertilizer treatment was favorable, application of 11-48-0 ammonium-phosphate fertilizer at the rate of 40 pounds per acre to wheat on summerfallow was more effective than complete removal of weeds by hand in reducing losses in yield of wheat arising from weed competition. Per cent increases in yield through fertilizer application were higher than per cent increases from weed removal even where average densities of annual weeds were as high as 604 weeds per square yard. Although increases in yield from fertilizer treatment were highly significant at several locations, reductions in protein content were often associated with these increases in yield. In some cases the reductions in protein content resulting from fertilizer treatment were significant.

Weed removal, on the other hand, increased both yield and protein content of wheat. Increases in yield as a result of weed removal were significant when the average densities of annual weeds were 148 and 95 weeds per square yard, or higher, under conditions where fertilizer was and was not applied, respectively. However, the minimum densities of annual weeds which caused significant reductions in yield of wheat were probably somewhere between 56 and 148 weeds per square yard where fertilizer was applied, or somewhere between 54 and 95 weeds per square yard where fertilizer was not applied. Removal of weeds from plots where the average weed densities exceeded 200 annual weeds per square yard increased protein content of wheat significantly.

Yield of wheat was almost invariably highest in those plots to which fertilizer was applied and from which weeds had also been removed. Under the same conditions protein content was comparatively higher than protein content from plots which were fertilized but not "weeded", or plots to which neither fertilizer treatment nor weed removal was applied.

Bushel weight of wheat was not affected by weed competition under either level of soil fertility.

The results of these experiments demonstrated that commercial fertilizer applied directly with seed grain effectively reduces losses caused by weed competition. Profitable response to fertilizer treatment is therefore more likely to occur under weedy conditions than under weed-free conditions. Although reductions in protein content of wheat were often associated with significant increases in yield as a result of fertilizer treatment, these reductions in protein content could be offset, to a certain extent, by weed control. Thus, on the basis of these results, it can be concluded that application of a commercial fertilizer and removal of weeds at a proper stage of crop growth are practices which may be advantageously combined in weed control. It should be pointed out that, although removal of weeds in this study was accomplished through "hand-weeding", similar results would probably be obtained under practical farming conditions when weeds are removed from the crop through a proper application of an appropriate chemical treatment.

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APPENDICES

Appendix 1. Comparison of the effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 1).

Fertilized plots				Unfertilized plots			
	Bushels per acre				Bushels per acre		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
33	41.5	47.7	-5.9	53	30.8	35.6	-4.8
122	40.8	40.2	0.6	131	29.9	26.5	3.4
65	34.4	28.1	6.3	122	22.6	25.3	-2.7
36	52.0	44.5	7.5	28	43.8	37.0	6.8
48	37.7	30.0	7.7	39	33.5	23.7	9.8
20	32.9	34.7	-1.8	36	29.0	25.3	3.7
15	37.7	37.0	0.7	28	28.3	28.1	0.2
59	32.9	35.2	-2.3	32	34.0	31.1	2.9
122	29.9	33.1	-3.2	62	26.3	27.4	-1.1
37	34.4	31.2	3.2	11	26.2	26.3	-0.1
Av. 56	37.4	36.1	1.3	54	30.4	28.6	1.8

Appendix 2. Analysis of variance. The effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 1).

Source of variance	D.F.	M.S.
Replicates	9	101.90**
Fertilizer	1	524.81**
Error (a)	9	10.03
Main plots	19	
Weeds	1	23.75
Weeds x fertilizer	1	0.81
Error (b)	18	10.50
Total	39	

** Significant at 1% level of probability.

Appendix 3. Comparison of the effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 2).

Fertilized plots				Unfertilized plots			
	Bushels per acre				Bushels per acre		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
472	36.1	31.5	4.6	143	34.7	24.9	9.8
608	45.6	27.2	18.4	296	39.2	27.1	12.1
411	33.1	32.6	0.5	334	29.9	20.3	9.6
25	32.9	23.3	9.6	285	30.1	22.6	7.5
357	30.4	28.3	2.1	24	29.0	31.5	-2.5
12	40.1	31.0	9.1	242	34.5	15.7	18.8
197	27.6	23.5	4.1	39	35.8	27.1	8.7
130	23.9	25.3	-1.4	123	21.8	21.9	-0.1
388	19.4	17.4	2.0	480	20.6	12.3	8.3
208	23.3	18.3	5.0	628	21.6	15.8	5.8
Av. 299	31.2	25.8	5.4	259	29.7	21.9	7.8

Appendix 4. Analysis of variance. The effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 2).

Source of variance	D.F.	M.S.
Replicates	9	118.56**
Fertilizer	1	74.04--
Error (a)	9	19.59
Main plots	19	
Weeds	1	435.59**
Weeds x fertilizer	1	14.41--
Error (b)	18	17.10
Total	39	

** Significant at 1% level of probability.

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Appendix 5. Comparison of the effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 3).

Fertilized plots				Unfertilized plots			
	Bushels per acre				Bushels per acre		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
2	54.8	53.0	1.8	2	64.6	53.2	11.4
3	60.2	56.2	4.0	2	54.5	65.8	-11.3
2	56.1	51.4	4.7	3	51.4	49.3	2.1
6	59.3	56.1	3.2	2	68.7	67.5	1.2
6	51.8	46.3	5.5	0	45.6	51.3	-5.7
0	50.2	47.6	2.6	6	37.6	39.7	-2.1
2	52.9	48.1	4.8	4	51.6	54.3	-2.7
5	68.7	64.8	3.9	0	62.1	52.5	9.6
2	42.9	39.7	3.2	11	42.9	40.4	2.5
2	36.1	31.4	4.7	1	33.6	26.0	7.6
Av. 3	53.3	49.5	3.8	4	51.3	50.0	1.3

Appendix 6. Analysis of variance. The effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 3).

Source of variance	D.F.	M.S.
Replicates	9	390.39**
Fertilizer	1	5.63- -
Error (a)	9	39.93
Main plots	19	
Weeds	1	65.03*
Weeds x fertilizer	1	87.29**
Error (b)	18	8.84- -
Total	39	

* Significant at 5% level of probability.
** Significant at 1% level of probability.
- -

Appendix 7. Comparison of the effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 4).

Fertilized plots				Unfertilized plots			
	Bushels per acre				Bushels per acre		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
54	31.5	32.4	-0.9	83	29.7	21.4	8.3
488	32.4	29.7	2.7	398	27.2	24.4	2.8
331	36.0	32.0	4.0	96	29.9	24.7	5.2
55	35.8	41.1	-5.3	48	29.4	21.4	8.0
60	41.3	28.8	12.5	68	30.2	21.2	9.0
32	31.0	31.7	-0.7	30	24.0	20.8	3.2
299	37.6	27.8	9.8	110	34.2	17.3	16.9
65	31.7	23.9	7.8	61	23.0	13.2	9.8
47	31.9	33.6	-1.7	24	28.1	25.5	2.6
52	40.0	32.0	8.0	36	40.8	23.7	17.1
Av. 148	34.9	31.3	3.6	95	29.7	21.4	8.3

Appendix 8. Analysis of variance. The effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 4).

Source of variance	D.F.	M.S.
Replicates	9	35.85**
Fertilizer	1	578.36**
Error (a)	9	7.19--
Main plots	19	
Weeds	1	354.62**
Weeds x fertilizer	1	987.51**
Error (b)	18	17.21--
Total	39	

** Significant at 1% level of probability.
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Appendix 9. Comparison of the effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 5).

Fertilized plots				Unfertilized plots			
	Bushels per acre				Bushels per acre		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
158	38.1	31.5	6.6	338	32.9	29.4	3.5
172	32.8	29.4	3.4	108	31.7	24.9	6.8
418	49.0	30.4	18.6	88	38.6	19.2	19.4
158	58.9	43.6	15.3	306	37.9	24.0	13.9
237	37.7	36.3	1.4	198	39.0	35.6	3.4
181	45.0	40.4	4.6	250	40.2	22.0	18.2
393	45.7	53.9	-8.2	225	39.3	32.6	6.7
96	38.8	25.5	13.3	225	26.0	21.7	4.3
139	53.2	41.1	12.1	199	36.7	24.2	12.5
782	47.5	37.7	9.8	203	31.2	17.8	13.4
Av. 273	44.7	37.0	7.6	214	35.4	25.1	10.2

Appendix 10. Analysis of variance. The effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 5).

Source of variance	D.F.	M.S.
Replicates	9	90.14
Fertilizer	1	1119.40**
Error (a)	9	48.04
Main plots	19	
Weeds	1	801.00**
Weeds x fertilizer	1	15.81
Error (b)	18	24.48
Total	39	

** Significant at 1% level of probability.

Appendix 11. Comparison of the effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 6).

Fertilized plots				Unfertilized plots			
	Bushels per acre				Bushels per acre		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
484	40.0	32.4	7.6	739	34.9	30.3	4.6
396	34.5	30.3	4.2	680	33.5	25.6	7.9
573	52.0	31.7	20.3	361	40.9	19.8	21.1
1112	40.2	37.4	2.8	1081	40.9	32.8	8.1
351	58.4	45.4	13.0	54	39.7	24.9	14.8
498	48.2	41.8	6.4	623	42.4	22.6	19.8
525	48.4	53.6	-5.2	371	41.5	33.8	7.7
353	40.8	45.0	-4.2	517	27.4	22.4	5.0
637	56.4	42.5	13.9	417	38.6	25.3	13.3
719	50.0	39.0	11.0	406	32.6	18.5	14.1
Av. 604	46.9	39.9	7.0	573	37.2	25.6	11.6

Appendix 12. Analysis of variance. The effect of weed competition on the yield of wheat grown under two levels of soil fertility. (Location 6).

Source of variance	D.F.	M.S.
Replicates	9	67.91
Fertilizer	1	1435.30**
Error (a)	9	47.75
Main plots	19	
Weeds	1	866.62**
Weeds x fertilizer	1	54.38
Error (b)	18	24.65
Total	39	

** Significant at 1% level of probability.

Appendix 13. Comparison of the effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 1).

Fertilized plots				Unfertilized plots			
	Per cent protein				Per cent protein		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
33	11.4	12.4	-1.0	53	11.3	12.2	-0.9
122	14.0	14.2	-0.2	131	13.7	12.9	0.8
65	11.0	11.8	-0.8	122	10.5	10.4	0.1
36	13.5	14.2	-0.7	28	13.0	13.6	-0.6
48	12.2	12.6	-0.4	39	12.2	11.7	0.5
20	13.0	12.4	0.6	36	12.5	12.6	-0.1
15	13.9	13.9	0.0	28	14.1	14.1	0.0
59	14.4	14.1	0.3	32	14.3	13.9	0.4
122	13.6	13.6	0.0	62	13.7	14.1	-0.4
37	13.5	13.5	0.0	11	13.9	13.8	0.1
Av. 56	13.1	13.3		54	12.9	12.9	

Appendix 14. Analysis of variance. The effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 1).

Source of variance	D.F.	M.S.
Replicates	9	4.53**
Fertilizer	1	0.55
Error (a)	9	0.20
Main plots	19	
Weeds	1	0.13
Weeds x fertilizer	1	0.12
Error (b)	18	0.13
Total	39	

** Significant at 1% level of probability.

Appendix 15. Comparison of the effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 2).

Fertilized plots				Unfertilized plots			
	Per cent protein				Per cent protein		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
472	11.8	10.9	0.9	143	13.0	12.6	0.4
608	11.2	10.3	0.9	296	11.6	10.8	0.8
411	12.7	12.1	0.6	334	12.4	12.9	-0.5
25	11.6	10.9	0.7	285	12.3	11.3	1.0
357	11.1	10.8	0.3	24	10.9	10.8	0.1
12	11.5	11.7	-0.2	242	11.4	10.9	0.5
197	10.8	10.1	0.7	39	10.8	10.6	0.2
130	12.6	11.7	0.9	123	12.7	11.1	1.6
388	11.3	10.8	0.5	480	11.2	10.9	0.3
208	11.1	10.7	0.4	628	11.4	10.4	1.0
Av. 299	11.6	11.0		259	11.8	11.2	

Appendix 16. Analysis of variance. The effect of weed competition on the protein content of wheat under two levels of soil fertility. (Location 2).

Source of variance	D.F.	M.S.
Replicates	9	1.61**
Fertilizer	1	0.45--
Error (a)	9	0.28
Main plots	19	
Weeds	1	3.07**
Weeds x fertilizer	1	0.02--
Error (b)	18	0.12
Total	39	

** Significant at 1% level of probability.

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Appendix 17. Comparison of the effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 3).

Fertilized plots				Unfertilized plots			
	Per cent protein				Per cent protein		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
2	11.2	11.8	-0.6	2	11.3	11.0	0.3
3	13.0	12.6	0.4	2	13.6	13.0	0.6
2	11.4	11.2	0.2	3	11.6	11.3	0.3
6	12.9	13.7	-0.8	2	13.4	14.0	-0.6
6	13.7	13.9	-0.2	0	13.4	13.4	0.0
0	14.7	14.8	-0.1	6	15.3	14.8	0.5
2	13.8	13.3	0.5	4	12.7	12.7	0.0
5	13.1	12.8	0.3	0	12.0	11.7	0.3
2	14.3	13.7	0.6	11	14.7	14.4	0.3
2	14.2	14.7	-0.5	1	14.1	13.7	0.4
Av. 3	13.2	13.3		4	13.2	13.0	

Appendix 18. Analysis of variance. The effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 3).

Source of variance	D.F.	M.S.
Replicates	9	5.67**
Fertilizer	1	0.17--
Error (a)	9	0.35
Main plots	19	
Weeds	1	0.07
Weeds x fertilizer	1	0.16
Error (b)	18	0.09
Total	39	

Appendix 19. Comparison of the effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 4).

Fertilized plots				Unfertilized plots			
	Per cent protein				Per cent protein		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
54	13.6	12.8	0.8	83	12.7	12.4	0.3
488	11.7	12.5	-0.8	398	12.8	12.9	-0.1
331	13.7	13.4	0.3	96	14.2	13.1	1.1
55	13.0	13.0	0.0	48	14.4	13.8	0.6
60	13.9	13.2	0.7	68	14.0	14.2	-0.2
32	13.1	13.1	0.0	30	14.5	14.1	0.4
299	11.7	11.8	-0.1	110	12.0	12.9	-0.9
65	12.1	12.6	-0.5	61	14.2	13.3	0.9
47	11.7	11.3	0.4	24	13.2	11.9	1.3
52	10.3	9.8	0.5	36	10.8	10.6	0.2
Av. 148	12.5	12.4		95	13.3	12.9	

Appendix 20. Analysis of variance. The effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 4).

Source of variance	D.F.	M.S.
Replicates	9	4.76**
Fertilizer	1	0.55
Error (a)	9	0.36
Main plots	19	
Weeds	1	0.60
Weeds x fertilizer	1	0.13
Error (b)	18	0.18
Total	39	

** Significant at 1% level of probability.

Appendix 21. Comparison of the effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 5).

Fertilized plots				Unfertilized plots			
	Per cent protein				Per cent protein		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
158	13.5	12.9	0.6	338	13.5	12.5	1.0
172	13.5	13.9	-0.4	108	13.5	13.3	0.2
418	14.5	14.1	0.4	88	14.9	14.6	0.3
158	12.5	12.2	0.3	306	12.6	12.6	0.0
237	15.5	15.5	0.0	198	15.3	15.2	-0.1
181	11.0	10.1	0.9	250	11.5	11.4	0.1
393	11.6	10.2	1.4	225	11.6	10.5	1.1
96	12.9	12.6	0.3	225	13.0	12.7	0.3
139	13.1	12.3	0.8	199	12.4	12.3	0.1
782	13.7	13.4	0.3	203	13.8	13.2	0.6
Av. 273	13.2	12.7		214	13.2	12.8	

Appendix 22. Analysis of variance. The effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (L9cation 5).

Source of variance	D.F.	M.S.
Replicates	9	7.64**
Fertilizer	1	0.39
Error (a)	9	0.15
Main plots	19	
Weeds	1	1.75**
Weeds x fertilizer	1	0.04
Error (b)	18	0.10
Total	39	

** Significant at 1% level of probability.

Appendix 23. Comparison of the effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 6).

Fertilized plots				Unfertilized plots			
	Per cent protein				Per cent protein		
(1) Weeds per sq. yd.	(2) Weed-free	(3) Weedy	(2)-(3)	(4) Weeds per sq. yd.	(5) Weed-free	(6) Weedy	(5)-(6)
484	14.2	13.9	0.3	739	14.0	14.4	-0.4
396	14.7	14.0	0.7	680	14.9	14.5	0.4
573	13.4	13.8	-0.4	361	14.5	14.8	-0.3
1112	14.7	13.8	0.9	1081	15.7	14.5	1.2
351	15.0	15.3	-0.3	54	14.8	15.5	-0.7
498	14.1	13.7	0.4	623	14.5	13.5	1.0
525	15.1	14.2	0.9	371	15.8	14.0	1.8
353	15.8	15.3	0.5	517	15.6	15.8	-0.2
637	14.8	14.5	0.3	417	15.5	15.0	0.5
719	13.2	13.2	0.0	406	14.3	13.6	0.6
Av. 604	14.5	14.2		573	15.0	14.6	

Appendix 24. Analysis of variance. The effect of weed competition on the protein content of wheat grown under two levels of soil fertility. (Location 6).

Source of variance	D.F.	M.S.
Replicates	9	1.52**
Fertilizer	1	1.81**
Error (a)	9	0.13
Main plots	19	
Weeds	1	1.33*
Weeds x fertilizer	1	0.00
Error (b)	18	0.21
Total	39	

* Significant at 5% level of probability.
** Significant at 1% level of probability.