STUDIES ON COMPETITION BETWEEN WHEAT (TRITICUM AESTIVUM L. EM. THELL.) AND WILD OATS (AVENA SPP.).

by

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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Abstract

Two experiments were carried out in the Kabete Field Station, Faculty of Agriculture, University of Nairobi to study the effect of wild oats (Avena spp.) in competition with short maturing "Kiboko" and long maturing "Kenya Bongo" varieties of wheat on well drained friable red clay soils. Two spacings of wheat, (18 x 2.5)cm and (18 x 5.0) cm, were used and wild oats were planted between the rows after dehusking and soaking in tap water for forty eight (48) hours to enhance germination in both experiments. Experiment I was carried out in the short rains of 1978 without the benefit of fertilizer and wild oat populations were 0, 9, 18, 27 and 54 plants per m^2. Experiment II was carried out in the long rains of 1979 with adequate Diammonium phosphate fertilizer applied at the rate of 100 kg/ha before planting.

In the first experiment, only the effect of wild oat competition on vegetative growth of "Kiboko" was examined due to bird damage to the grains. In addition to vegetative growth, the effect of competition on yield per plant and yield components of "Kenya Bongo" were also studied. The influence of both crops on the vegetative growth of wild oats were examined in both experiments.

The results of experiment I showed that height

of wheat variety "Kiboko", stem dry weight, number of tillers and leaves per plant were significantly depressed by increasing wild oat densities, whereas leaf dry weight and total dry weight per plant, though decreased with increasing wild oat densities, the reductions were not significant. The presence of the crop did not affect these vegetative components in a consistent trend in wild oats.

In experiment II, the height of "Kenya Bongo" variety of wheat was significantly increased in the initial stages of growth and significantly depressed at the final harvest when wild oat densities increased. The number of tillers and green leaves, stem and leaf dry weight per plant were significantly depressed by the presence of wild oats. The ratio between green and senesced leaf was also significantly decreased as wild oat density increased. The number of fertile tillers, ear dry weight, number of grains and grain yield per plant were reduced by increases in wild oat population without affecting 1000 grain weight and grain weight per ear. Wild oats did not suffer any systemic trend in vegetative growth as result of competition from the crop.

In both experiments the influence of wheat spacing was relatively minor. Although the parameters examined were increased at wider intra-row spacing, the number of tillers per plant was the only parameter significantly increased.

CHAPTER 1

INTRODUCTION

Modern bread wheats have exclusively evolved from hexaploid species known botanically as *Triticum aestivum* L. em Thell. not known to exist as such in the wild state (Purseglove, 1972).

Although the nutritional value of wheat protein is limited by its short supply of essential amino acids, namely, lysine, methionine and theonine in that order, (Inglett,1974; Johnson, Whited, Mattern and Schmidt, 1968), amongst World's cereal crops wheat is pre-eminent both in regard to its antiquity and importance as most widely cultivated food crop of mankind (Percival, 1974; Agrawal and Ramakrishna, 1972), giving one third of cereal production closely followed by rice, mainly in the temperate regions (Purseglove, 1972). On account of its physical and chemical qualities, wheat makes palatable and better bread than any other cereal due to its unique protein gluten which holds the carbon dioxide produced by the fermenting yeast (Percival, 1974; Purseglove, 1972). Wheat proteins are well digested even by infants but a small minority of humans suffer from coeliac disease as a result of eating gluten (Carpenter, 1975). Among cereal crops wheat flour is similar in its net protein value to rice, maize, and potatoes and much superior to cassava and plantains.

In Kenya, and the developing world at Large, there is tendency for eating bread especially among urban population. This suggests that the role of wheat as food crop will continue and even increase. It is therefore benefitting that the Food and Agricultural Organization of the United Nations has chosen as its emblem an ear of wheat surrounded by letters of its name with the Latin inscription "FIAT PANIS" (Let there be bread) appearing below.

Wheat was first introduced into Kenya by various missionaries who grew small patches in the highlands for their own consumption at the beginning of the twentieth century (Dixon, 1960). Later on, the earlier settlers turned their attention to the possibility of wheat production (Schouten, 1957), and one of the first attempts at extensive commercial wheat production was made by Lord Dalamere in 1907 in Njoro area (Guthrie and Pinto, 1970; Purseglove, 1972). Since then the wheat hectarage has been expanding mainly in areas between 2,000m and 3000m above sea level and generally receiving 750-1200mm of annual rainfall (Hafiz, 1965; Guthrie and Pinto, 1970). However, though the largest hectarage in this region is in Uasin Gishu plateau, the area with the greatest potential is the wetter parts of Masailand extending from Mau Narok to Narok (Acland, 1971).

Generally, wheat yields have declined in the last couple of years as a result of wild oat infestation, bad weather and diseases (Anonymous, 1978b). Nevertheless, the main policy objective of Kenya Government is to achieve self-sufficiency in wheat production with any excess exported without loss to the Government. According to economic survey in 1978, a total of 170,000 tonnes of wheat were produced in 1977 (Anonymous, 1978a). Consumption in the same year was 158,400 tonnes of wheat flour. It was however estimated that Kenya's national annual requirement was over 200,000 tonnes of wheat equivalent. In the following year wheat deliveries to Wheat Board declined by 10.5 per cent. Because of high demand for wheat, Kenya has consistently imported part of the domestic requirements. For instance, a total of 24,000 tonnes was imported in 1977 valued at Ksh. 89,096,000 (Anonymous, 1978b).

Since its introduction into Kenya, the principal problem in wheat production has always been the constant struggle against stem rust (*Puccinia graminis*) and yellow rust (*Puccinia striiformis*)

(Guthrie and Pinto,1970; Thorald, 1973; Savile, Thorpe, Collings-Wells and Peers, 1958). However, it has been realized of late that wheat production in Kenya is also being threatened by wild oat infestation (Mulamula, personal communication, 1978).

Haddow (1978) and Paterson (1967) have reported wild oats to have risen from its relative obscurity a generation ago to a position of the most important single weed of cereals in temperate regions. It is now almost everywhere cereals are grown. Coffman (1961) quoted by Holm et al. (1977) listed a total of about 50 oat species, most of them having originated in the old world. About 1,000 varieties of cultivated oats have been named. Only the varieties from two species Avena sativa L. and A. byzantina C. Koch are of much economic importance; the rest are wild oats.

As a weed, wild oats contaminates high valued crops grown for seed and the presence of its seeds increases seed drying and tranport costs for the farmer (Bowler, 1973). Not only do wild oats contaminate crops but also reduce crop yields considerably due to competition. Several workers have shown that there is severe competition leading to severe crop loss due to infestation by wild oats in barley (Selman, 1970; Hoepfner, 1969; and Thurston, 1969) wheat (Parlychenko and Harrington, 1934;

Friesen and Shebeski, 1960) and in peas (Gargouri and Seely, 1972).

Where agricultural practices are conducive to the growth of wild oats, they will enter fields with scarcely any regard for the type of crop (Holm et al., 1977). It is particularly damaging to grains because it thrives in a particular cropping system and sequence, difficult to control chemically (Thurston, 1962) and infests the soil with seeds which survive for 4-6 years (Chepil, 1946; Gates, 1917; Banting, 1966).

Because of the menacing nature of wild oats, its occurence in high altitude wheat growing areas of Kenya is a matter of concern to wheat farmers. It is thought that wild oats was introduced into Kenya at the turn of twentieth century initially confined to isolated areas in Narok, Molo and Mau Summit. With change of land ownership after independence the new owners were unaware of the seriousness of the weed. Today, the weed has spread to many areas in Narok, Uasin Gishu, Nyandarua, Nakuru and Laikipia districts infesting a total of about 31,000 - 42,000 hectares of potential wheat/barley land (Mulamula, personal communication, 1978). Owino (1974) listed Avena fatua L., Avena ludoviciana Dur., Avena maxima L. and Avena sterilis L. as the existing species present in Kenya and usually found together in wheat/barley fields. Nevertheless, intermediary crosses between these and *Avena sativa* L. may also be present.

Work in temperate areas (Thurston, 1962, Chancellor and Peters, 1974, Bowden and Fiesen, 1967) have attempted to study the effect of wild oat competition against cereal crops. However, the extent of damage which wild oat infestation causes to wheat in Kenya has never been investigated. Therefore an experiment was designed with the following objectives:-

1. To study the vegetative growth of wheat in competition with different densities of wild oats.
2. To study the vegetative growth of wild oats when grown in association with wheat.
3. To investigate the competitive ability of wheat and wild oats when wheat spacing is varied.
4. To explore the wild oat density level which will reduce wheat yields significantly.

CHAPTER 2

2. LITERATURE REVIEW

The growth of plants in a multispecific community is typically influenced at some or all stages of development by biological and physical processes which are frequently referred to as competition (Baldwin, 1976; Hall, 1974). This is conditioned by the proximity of the plants to each other, such that the poorer competitors suffer reduction in the yield of various products (Lee, 1959). Competition develops around the primary factors of which water, light and nutrients are highly important (Donald, 1963; Pavlychenko and Harrington, 1934; Lucas and Milbourn, 1976). Any of these may be a limiting factor if it is present in an amount insufficient for the needs of plants growing in association (Donald, 1957). Similarly, Clements, Weaver and Hanson,(1929) maintain that competition arises from the reaction of one plant upon the physical factors about it and upon its competitors. In other words, two plants do not compete with each other as long as the water content; the nutrient material and light are in excess of the needs of both. When the immediate supply of any of these necessary factors falls below the combined demands of these plants, competition begins. Pavlychenko and Harrington (1934) argue that plant competition is not known to take place where the plants are spaced so far apart that their root systems do not meet underground, but its effects may be observed as soon as the spacing between the neighbouring plants is reduced to the extent that their root systems commence to occupy the same feeding grounds. They observed over a period of several years in a weed nursery at Saskatchwan that competition between overlapping root systems took place before the tops began to shade one another. The relative time of emergence of a weed and crop is also important in determining competitive ability. The earlier emerging weed species establish earlier, cover the ground and develop better root and shoot systems than the crop. If the weeds are particularly aggressive, competition reduces vigour and consequently yield of the crop (Godel, 1935; Carson, 1975). The depression of crop growth by weed competition varies greatly depending partly on the adequacy of growth factors, partly on the stage of growth of the crop when the weeds appear, but mainly on the competitive ability of the crop relative to that of the weed population. This in turn is influenced by the habit, growth rate and the density of the crop and weeds especially in early stages of development (Harris and Lazenby, 1974; Harold and Barnes, 1944).

Plant competition can be arbitrarily divided into two:-

2.1. Shoot competition

The principal factors of the environment for which shoot competition may occur are:-

2.1.1. Light

Competition for light has long been regarded as the central factor in the establishment of plant communities and in determining the ultimate size and growth rate of different communities (Clements et al. 1929, Donald, 1951). However, actual interest in light relations in plant communities has only developed in recent years.

Monsi and Saeki (1953) showed that many herb communities in Japan cast shade quite as deep as forest conopies. Their stratified clip-technique clearly illustrated the light gradient in plant communities and the competition of plants for light. It has now become an acceptable fact that in a plant community of various species or the same species, competition for light occurs when leaves of one species shade the leaves of another species or the same species. Competition also occurs within a single plant where upper leaves shade the lower leaves. The ultimate ability of such species to produce dry matter therefore depends on the degree to which they can exploit the light falling on them, (Donald, 1951) and the plant or species which displays its leaves in an advantageous position for light interception will have a better chance to utilize the light and suppress its dwarf neighbour competitors. This fact was recognized by Godel (1935) and Pavlychenko and Harrington (1934) who reported that crops grown densely establish earlier and smother competitive weeds by shading.

The ability of a crop or weed to intercept more light than its neighbour in proximity depends on the following plant characteristics:-

(a) Plant height

Jensen (1932) quoted by Saeki (1963) pointed out that plant height was a very important factor in competition for light and that plants of high stature commanded more light and dominated plants of lower stature. Much evidence is now available on the role of light and height in interspecific and interplant competition (Donald, 1961). The stratified-clip technique introduced by Monsi and Saeki (1953) provided a clear picture of plant height competition for light. They followed the seasonal development of lowland grass communities in Japan. The profiles of relative light intensity and of leaf mass clearly illustrated that the development of Sanguisorba tenuifolia L. was suppressed by that of Phragmites communis L., whose large reserves and inherent character made it possible to project shoots over those of the former in early vegetative period. Similarly, Iwaki (1959) found that maximum photosynthetic activity and dry matter production were much the same in Fagopyrum spp. and Phaseolus spp. in pure stands. However, in mixed stands of both species, Fagopyrum spp. was much superior competitor and markedly reduced the dry matter of Phaseolus spp. because the former attained more rapid growth in height. Results obtained with subterranean clover (Trifolium subterraneum L.) showed that the length of petioles can also be as important as plant height in plant competition for light(Black, 1958; 1960). When large and small seeds of subterranean clover (Trifolium subterraneum L.) were mixed in equal numbers and grown together, the plants developed from the former dominated those from the latter. Plants derived from the large seeds developed larger and longer petioles (Black, 1958). One variety of subterranean clover, Yarloop, which had the longest petioles yielded more than Bacchus Marsh or Tallarook in mixed stands, while Bacchus Marsh, which dominated Tallarook, had longer petioles than Tallarook (Black, 1960).

Therefore certain genotypic characters such as rate of growth in height may be of little or even of negative value in pure stands, but may be the decisive factor in the competition for light in mixed stands or weedy stands (Saeki, 1963) with the result that the suppressed plants may ultimately die if competition is severe.

(b) Leaf arrangement and Angle

Tanner and Stoskopf (1967) laid heavy emphasis on the idea that broad and lax-leaved varieties of crops were selected in early years to assist in shading weeds, though more erect leaf types were the more efficient photosynthesizers. This underlines the fact that broad horizontal leaves intercept more light and subsequently prevent the growth of species underneath.

De Wit (1965) and Ross and Nilson (1967) described the frequency distribution of leaf angles for a number of species. Species such as clover and beans were described as being "planophile", with preponderance of leaves at small angles to the horizontal. Sugar beet was "plagiophile", with fairly uniform distribution of leaf angles from 0 to 90^{o}. Ryegrass was "erectophile" in early growth when more than half of its leaves had leaf angles exceeding 60^{o}. In mixed stands, tall plants with planophile canopy would effectively intercept more light and shade understorey foliage more than those plants with erectophile canopy. The way in which direct sunlight penetrates a canopy depends on the distribution of gaps in the foliage which is determined by leaf angle (Monteith, 1969 ; Mitchell, 1979). Sakamoto and Shaw (1967) have shown that if the leaves of soya bean crop were oriented horizontally, light penetrated only 30 centimeters down the canopy. Broughman (1960) has also shown that clover with nearly horizontal leaves transmitted 50 per cent of the incident light while ryegrass with vertically disposed leaves transmitted 74 per cent of the incident light per unit leaf area. For sugar beets grown in spaced plant tests, the growth of prostrate leaf types was superior to that of an erect leaf type, but the erect leaf type gave greater growth under conditions of competition (Oshima, 1962). This was because the erect leaf allowed more light penetration into the canopy as competition began due to increased plant population. Leaf thickness and number of branches or tillers in case of cereals may also be of importance in the degree of shading.

Observations like these have led to the proposal that a nearly vertical orientation of the upper leaves of a canopy with the lower leaves approaching the horizontal might be efficient in radiation intercepted and the rate of dry matter production in pastures increased with leaf area development and approached a maximum at high leaf area indices.

An increase in L beyond a maximum will result into mutual shading of leaves and reduction of growth rate (Donald and Black, 1958). A plant species which attains high L earlier in the season will intercept more radiation and will possess better competitive ability (Black, 1963). Haizel (1971) reported that although wild oat was relatively slow in expanding its leaves when grown in mixed populations of barley and white mustard (Sinapsis alba L.) it developed largest L later in the growth period, suggesting that its competitive ability may be greater than those of the other species.

(d) Efficiency of light utilization

Light intensity has been recognized to affect growth of plants. The rate of photosynthesis per unit L at high light intensities in normal air has been known to differ with plant species (Black, Chen and Brown, 1968). At high light intensities Hesketh (1963) and Hesketh and Moss (1963) reported that maize, sugar cane and sorghum which are C_4 plants had higher photosynthetic rates than tobacco and sugar beet which are C_3 plants. These differences in photosynthetic rates prompted Black *et al.* (1968) to suggest that most aggressive weeds may belong to the former group of plants; their competitive ability increases as the intensity of light increases as a result of increased photosynthesis. These weeds grow more luxuriantly than the crop. *Amaranthus* and *Digitaria* spp. belong to this group of weeds. It may be possible that wild oats similarly fall into this group of weeds. Work by Cannell (1967) and Thurston (1959) indicated that Net assimilation rate in *Avena fatua* L. and *Avena Ludoviciana* Dur. in early stages of growth was greater than in cultivated spring barley, winter oats and wheat.

2.1.2. Carbon dioxide (CO_2)

Although it is not readily obvious how to enrich the carbon dioxide supply under field conditions, the wind does play a key role in stirring the air which enhances photosynthesis by renewing the supply of air containing a normal carbon dioxide content next to the leaf. Wind does not allow air to accumulate near a leaf which had its carbon dioxide content depleted. An uneven crop surface resulting from species of different heights may have merit in enhancing mixing (Mitchell, 1970). Actual plant competition for carbon dioxide does not therefore exist at least not for very prolonged periods.

However, plants have different abilities for fixing the available atmospheric carbon dioxide into their tissues for photosynthesis (Zelitch, 1970). Carbon dioxide uptake rates play an important role in competition among plants. Species which fix more carbon dioxide at a given light intensity would have higher growth rate than those which fix less. Black, et al. (1968) suggested that a plant became a serious weed because of its ability to fix carbon dioxide at a higher rate than the crop.

2.2 Root competition

The health and survival of a plant depends on proper water and nutrient balance. Any degree of imbalance will produce proportionately deleterious deviation in physiological activity of the plant. The root system is well adapted to the absorption of nutrients. When plants are sufficiently far apart to avoid overlapping of their root absorption zones, there will be no competition between roots (Eddowes, 1969). Competition begins as soon as the root system of one plant invades the feeding area of the roots of another plant (Aspinall, 1960) as well as if supplies of water or nutrients become limiting (Brouwer, 1965). Under such conditions, the success of a plant will depend on the magnitude of the competition as determined by the following factors:

(i) Variation in root systems

Environmental factors may modify root growth (Mitchell,1970) but the basic difference between root systems in plants is genetically determined (Troughton and Whittington, 1968). Differences also occur within varieties or species of plants determining the competitive ability. The productivity of plants may therefore depend largely on the development of a root system adequate to support it during the period of maximum stress or competition (Russell, 1977). Widely spreading roots are said to absorb moisture and nutrients vigorously whereas deep roots may be of value where reserves of water occur at considerable depths (Troughton and Whittington, 1968). May and Milthorpe (1962) pointed out that extension in depth of a root system is important to provide access to a potentially large supplies of water and nutrients and lateral extension is important in its utilization. Lee (1960) found that the barley variety Atlas 46 was able to withstand competition because at the time of internode elongation it produced a dense mat of roots from the crown which was efficient at gathering nutrients from a limited volume of soil. The variety Vanghn which did not produce such a root system was more susceptible to competition. Nye (1966), however, showed that thin roots covered with abundant root hairs would be more efficient per unit mass for the absorption of relatively slow diffusing ions like phosphorous and potassium than thicker roots thinly covered with root hairs. Strictly speaking, it is the root hairs which make contact with the soil particles and Troughton and Whittington (1968) considered that the greater the surface area per unit mass of root, the greater the contact of root hairs with the moisture around the soil particles.

The root characteristics of wild oats in relation to cereal crops have been described by many workers. Pavlychenko and Harrington (1934) planted Marquis wheat and Hannchen barley at 15 cm rows and wild oats between the rows to give an average field infestation by this weed and found that competition was very great between Marquis wheat and wild oats, 22 days after emergence of the shoot when the total root lengths were 55.2m and 35m respectively. It was less in case of barley where the root lengths totalled 117m and those of the weed 24m. This competitive ability of the root system was determined not only by the extent but also by the natural distribution of the roots. Those of the barley were concentrated near the surface than those of wheat which were thinly and evenly distributed. Pavlychenko and Harrington (1935) explained that the success of plants in field competition depended mainly on prompt and uniform germination. Under adverse moisture conditions ability to develop a large and efficient assimilating surface in early seedling stage, and the possession of a root system with a large mass of fibres close to the surface with the main roots penetrating deeply, would be advantageous.

(ii) Difference in water and nutrient uptake

Different plants species take up different amounts and proportions of nutrients and water from the soil (Russell, 1973). For example, cereals absorb less mineral nutrients than any other crop although they give a large amount of dry matter per hectare. Root crops, on the other hand, all take up large amounts of nutrients. Thus the success of certain weeds in competition with crops may partly be attributed to their different requirements for nutrients. Such differences may arise from varying abilities of plant species to make contact with and to absorb, translocate and utilize ions (Viets, 1972).

(iii) Efficiency of utilization

Efficiency is the amount of dry matter produced per unit of water or mineral absorbed.

Efficiency is more important than the actual amount absorbed (Troughton and Wittington, 1968). Crops and weeds which use water and nutrients efficiently are therefore expected to yield more under competition when these elements are limiting than those which do not. Black *et al*. (1968) have shown in their study that weeds which use water very efficiently are serious weeds in crops during periods of drought. Similarly, Shantz and Piemeisel (1927) working on the efficiency of water use by crops and weeds at Akron, Colorado, U.S.A., reported that crops and weeds which had high yields and possessed high competitive ability had low water requirements.

2.3. Effect of weed competition on cereal growth

The relationship between plant growth or yield and plant density has thoroughly been discussed for wheat (Puckridge and Donald, 1966; Puckridge and Rotkowsky, 1971; Holliday 1960; Hudson, 1941; Puckridge, 1968). Fischer and Wilson (1975) discussed similar relationship in sorghum while Bunting (1975), Allison (1969) and Eddowes (1969) dealt with density/growth relationship in maize. In addition to showing the form of growth/population relationship, they examined various yield components in cereals such as the number of vegetative and fertile tillers, weight of seed per ear and dry matter production. They showed that the yield components decreased with increasing density. Similar effects have been observed on the growth of cereals in competition with weeds (Godel, 1935; Pavlychenko and Harrington, 1934). Weeds growing in a crop community increase the population of the stand resulting in intra and interspecific competition for environmental resources, subsequently affecting the developmental stages of the crop.

Burrows and Olson (1954) showed that increasing the density of wild mustard from 0 to 400 plants per m^2 with constant wheat density decreased the number of wheat culms per m^2. In another experiment, where wheat density was also varied at 50, 100 and 180 kg/ha, they reported similar results and decreasing dry weight of the weed as wheat density increased. However, the effect of the weed on grain weight was not consistent. For instance, in one year the 1000 grain weight was not affected while in another year it was affected by both wheat and weed density. Environmental differences such as temperature and rainfall might have been responsible for the variation.

In a similar experiment conducted at Rutherglen station, Australia, over a three year period on a loam soil, Rees (1975) reported that the number of fertile wheat tillers was reduced by 46 per cent due to presence of ryegrass (Lolium rigidum Gaud.). In pot experiments in a glasshouse Smith and Levick (1974) planted 4 wheat and 6-4 ryegrass plants per pot. They found that competition for nitrogen (N) markedly reduced tiller number, shoot weight, wheat height and total grain weight with no reduction in grain weight per ear. However, when Barrett and Campbell (1973) planted 6, 9 and 12 wheat plants and 6 ryegrass plants per pot, under similar conditions, they found no reduction in wheat tiller numbers and dry matter though there was 26 and 60 per cent reduction in ryegrass tiller numbers when there was competition for nitrogen and both for nitrogen and light respectively. Wheat can therefore compete successfully with ryegrass but no measurements were made with populations of the weed greater than wheat or with ryegrass which emerged and became established before the wheat. It might be expected that with either situations, the competitive superiority of wheat would be reduced or even lost. On the other hand, competition for nitrogen between wheat and skeleton weed (Chondrilla juncea L.) drastically reduced the dry matter yield of the crop (Myers and Lipsett, 1957). Similar competition study was carried by Kock (1967) on the effect of charlock (Sinapsis arvensis L.) on oats and that of wild oats (Avena fatua L.) on barley in a green house in pots at different nitrogen levels. He found 10-15 per cent decrease in cereal weight, the greatest reduction occuring before shooting stage. Blackman and Templeman (1937) observed reduced tiller numbers and fertile shoots in barley due to competition with (Brassica arvensis L.) He reported similar results with spring oats when there was competition from Raphanus raphanistrum L.

Trenbath and Harper (1973) and Trenbath (1974) compared neighbour effects in the genus Avena. They planted indicator species at constant density at row width of 17cm with 7.5cm spacing within the row. Within the row, weed species A. fatua L., A. ludoviciana Dur. and indicator species were added. They found that A. ludoviciana Dur. caused a near significant increase in internode length of A. strigosa L. while A. fatua L. caused a highly significant decrease in the number of mature panicles per plant. Midway through the growth cycle A. fatua L. had the greatest leaf area and its height superiority suggested that it was an efficient competitor for light.

In three separate experiments Evetts and Burnside (1973) studied the effect of deep rooted perennial common milkweed (Asclepias syriaca L.) on dryland sorghum. They harvested paired samples of sorghum from infested and non-infested areas and found that the number of sorghum heads/ha and grain weight/head were significantly reduced by competition with the weed. However, the 500-seed weight was unaffected. The reduction in sorghum heads/ha was observed to be due to the reduction in sorghum stand rather than reduced tillering or barren plants. The effect of the weed on seed weight appeared to be during head development possibly reducing the number of grains, but the fewer grains compensated for the loss by attaining greater weight. This finding was confirmed in Tanzania by Enyi (1973) when he combined sorghum weeding with no weeding after sowing. His findings indicated that weeding increased sorghum height , number of ears per stand, number of grains per ear and weight per unit length of the ear. In maize, weed competition reduced maize height by 36 per cent and yields by 26 per cent when the weeds were left in the crop between 30-60 days after germination (Blanco, Oliveira and Araujo, 1973), and when weeds were left growing throughout the growing cycle, maize yields fell by 91 per cent of the potential yield (Jorge Nieto, Brondo and Gonzalez, 1968). However, Thomas (1974) grew 2 maize plants and 10 Rottboellia exaltata L. plants together in pots and applied sufficient nutrient solution. He found no effect on dry weight of both maize and the weed up to the 4th week compared with controls, but in field experiments, maize remaining with the weed up to 12 weeks after germination suffered yield reductions, the magnitude of which he did not indicate.

Although weeds affect crop growth, competition from the crop similarly affects the growth of the weeds in association. A number of workers have reported the effect of crops on weeds. Kees (1975) reported that in a survey of wild oat infestation ranging from 1 to 205 plants per m^2 in cereals throughout Southern Bavaria, weed tillering was influenced more by intra-specific competition than by competition from the crop. With all cereals the influence on tillering increased with increasing stand density, but winter wheat and spring barley had more competitive ability than spring wheat. Kock and Rademacker (1966) found that the development of Alopecurus mysuroides Huds. and wild oats alone and in competition with cereals showed that although competition did not significantly affect the pattern of development it caused some reduction in the weight of the two weed species. Similarly, Aspinall and Milthorpe (1959) and Aspinall (1960) described the relationship between the growth of barley and of white persicaria (Polygonum lapathifolium (L.)in pure and mixed populations. The growth of persicaria was greatly restricted when associated with barley whereas barley was little influenced by the presence of persicaria even at high densities. Barley was found to intercept more light than persicaria when grown at the same density (Aspinall, 1960).Harold and Barnes (1944) also reported that at constant amount of weediness with spurry (Spergula arvensis L.) and mayweed (Matricaria indora L.), an increase in barley plants diminished the injurious effect of the weeds.

2.4. Wild oat density

There is some evidence that varying the density of weed population has, within limits, relatively little effect on crop yield. Shadbolt and Holm (1956), for example, found the variation in the density of weed population had relatively little effect on the yield of carrots and onions. Nevertheless, Naylor (1972) showed that the depression of yield in winter wheat was linearly related to the logarithm of the density of Alopecurus mysuroids Huds. Each ten fold increase in weed density reduced crop yield by about 25 per cent.

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Dew (1972) described the relationship between the yield of a given crop and population density of a competing weed, for estimating crop loss, by the following equation:-

$$Y = a + bx$$

where Y = yields

x = measure of the weed population

b = regression coefficient and is the index of competition for specific crop weed situation.

a = Intercept on Y - axis.

He used wild oats as a weed to describe this relationship and found that competition index of wild oats was higher with wheat than with barley. Several workers including (Friesen and Shebeski, 1960; Pavlychenko and Harrington, 1934) have suggested that competitive effects may be quite severe and that considerable yield losses occur even with light infestations of this weed. In a survey of the world's worst weeds, Holm et al.(1977) pointed out that one might find losses ranging from 15 to 85 per cent due to wild oats depending on the crop, the area and the level of infestation. In Britain, yield depressions from 10 to 50 per cent varying with cereal crop and the level of infestation, has also been reported (Thurston, 1961). In Western Europe in general Haddow (1978) reported that crop

yield losses due to wild oats depended on several factors but that moderate densities of about 700 panicles per m^2 caused yield depressions of 10 to 15 per cent in spring barley and 15 to 20 per cent in winter wheat, while in very heavily infested crops, yields had often been more than halved. Loubaresse, Mouillac and Lejeune (1975) determined the threshold level of infestation of wheat by wild oats and found it to be very low, only 20 panicles per m^2.
In moderate infestations of wild oats of 52 plants per m^2 compared with 528 and 211 plants per m^2 of barley and wheat, Dew (1973) found barley and wheat yield reductions of 14 and 22 per cent, respectively. Chancellor and Peters (1974), working with natural infestation of wild oats in wheat removed the weed at intervals during early stages. Only three sites out of seven showed any significant yield reduction due to the presence of wild oats and all these had populations of 150 stems or more per m^2 at harvest. No significant yield reductions occurred at lesser densities of 20-100 stems per m^2. In Manitoba wheat and flax fields, Bowden and Friesen (1967) found that from 12-47 wild oats plants per m^2 were sufficient to cause significant yield reductions in wheat when grown on summer fallow land or when sulphate of ammonia was added to stubble land. Without the fertilizer

treatment, however, 82-117 wild oat plants per m^2 were needed to suppress the wheat yields significantly. They suggested that on stubble land, soil fertility was a more important factor than moderate densities of wild oats in determining eventual crop loss. Fertilizer treatment increased the general vigour of the weed more than it did for the crop making it more competitive. Only 12 wild oat plants per m^2 were sufficient to reduce flax yields on summer fallow and stubble land except in one instance when flax grown on both summer fallow and stubble land were not affected by densities less than 47 plants per m^2. Bell and Nalewaja (1968) found that 99 wild oat plants per m^2 reduced flax yields by 60.1 per cent in one year and 178 plants per m^2 reduced it by 82.1 per cent in another.

Yield reductions due to wild oats have also been reported in barley but there are indications that barley is more competitive than wheat. In a survey at Rothamsted Experimental Station, Thurston (1969) planted barley with upright and prostrate habits in rows spaced at 12.5 cms and 25 cms apart and 0, 53 and 108 wild oats pre-germinated seeds were sown per m^2 after drilling. The results suggest that only wild oat populations much denser than 108 plants per m^2 would appreciably reduce barley yields significantly. In pot experiments Thurston (1954) found that wild oats were more productive in competition with wheat than with barley. Hoepfner (1969) found yield reductions of 15 and 24 per cent with densities 15 and 37 wild oat plants per m^2 respectively at harvest when barley was planted in rows 6cm apart, but 75 ~~wild oat~~ plants ~~per~~ m^2 were required to reduced barley yields by 15 per cent when the row spacing was 8 or 22 cm apart. However, Selman (1970) found yield depressions at wild oat densities down 10 plants per m^2 with barley while in one instance an infestation of 170 plants per m^2 reduced barley yields by 40 per cent. Bate, Elliott and Wilson (1970) assessed the reaction of wild oats to various levels of competition from spring barley. They found the effects of weed on crop to be minor compared with those of crop on weed. They attributed this to the fact that barley had better developed root systems and was more efficient in the use of water than wild oats. In Kenya, however, the reduction of yield due to high infestation of wild oats in wheat growing areas has not been experimentally investigated. Nevertheless, Owino (1974) estimated the yield reduction to range from 5-7 per cent with instances of complete crop loss based on non-experimental data.

Not only do wild oats reduce crop yields but also contaminate high value seed crops.

Holm et al. (1977) reported that a survey in Bavaria in Germany in the decade following 1949 revealed that more than 25 per cent of the fields which had been planted to produce certified cereal seed were rejected because too many wild oat plants were present in the fields. Surveys in Argentina in the same period reported by the same authors showed that wild oat was one of the contaminants of cereal seed stock. Bowden (1971) reported wild oat to be a menance in the Canadian prairies; he estimated that Canadian farmers paid freight on 109 thousand tonnes of worthless wild oat seeds each year. In Western Australia, Paterson (1967) estimated that of 3,527 million tonnes of wheat received by the co-operative in one season, some 90 million tonnes were subject to dockage for wild oat content. An examination of weed seeds present in 52 samples of wheat seeds grown in the Eldoret, Nakuru, Njoro, Rongai, Mau Narok, and the Kinangops areas in Kenya revealed that wild oat was one of the most serious contaminants of seed (Bogdan, 1965). The Seed Quality Control Service in Kenya has therefore set standards for wheat grown for seed- a single plant of wild oat is not required in a single plot (Mulamula, personal communication). Apart from seed contamination Friesen and Shebeski (1960) observed that wild oats resulted in crop lodging. He reported that high wild oat densities resulted in increased wheat lodging in the Canadian prairies. This implies that a wheat field with too many wild oat plants would not be harvested by combine very efficiently since a greater proportion of the crop would lodge, leading to severe crop losses in the field.

It is clearly evident from the literature therefore, that wild oats have a great ability to compete with cereal crops thereby affecting growth and yield of the cereals. On the other hand, while yield reductions may not be spectacular, the ability to contaminate the seed remains predominant. In view of this, the spread of wild oats in wheat growing areas of Kenya has prompted the Ministry of Agriculture to make funds available for research in its control. The fact that wheat yields in Kenya have declined in the last decade is partly attributed to infestation by wild oats. This clearly indicates that wild oat is already becoming a major problem for wheat farmers. Because of this, experiments were carried out to investigate the effect of competition between wild oats and wheat under Kenyan conditions.

CHAPTER 3

3. MATERIALS AND METHODS

3.1. Experimental site

Experiment I was carried out at the Kabete Field Station of the Faculty of Agriculture, University of Nairobi, which lies within latitudes 1^{o} 14' 20" to 1^{o} 15' 15" South and longitudes 36^{o} 44' to 36^{o} 45' 20" East and altitude 1815m. On a broad scaled map, Gethin-Jones and Scott (1958) placed the farm under one soil type, namely, red to strong brown friable clay with laterite, while Scott (1961) placed it under a red friable clay. However, in a detailed soil survey of the farm, Nyandat and Michieka (1970) described the site of the first experiment as having dark reddish brown clay overlying a dark red clay; deep and well drained with top soil pH ranging between 5.2 to 7.2 and subsoil pH in the range of 5.2 to 7.7. The land, which is fairly even, had been under fallow for three consecutive years followed by crops of beans, maize and beans in that order.

Experiment II was carried out in the same Field Station but the actual experimental site was different from that of the first experiment. Nyandat and Michieka (1970) described the site as having a deep well drained soil with top and subsoil pH ranging from 5.2 to 6.6 and 4.8 - 6.5 respectively. The site was fallow in the long rains of 1977 while in the short rains of the same year it was under beans followed by a crop of kale in 1978.

3.2. Land preparation

The land was ploughed with a disc plough, harrowed once, clods broken and the plot levelled using ordinary hoes (jembes) to give a fine seedbed for experiment I. For experiment II, the land was prepared in the same manner. The site was, however, heavily infested with *Oxalis latifolia* L. whose bulbs were removed as much as possible during seedbed preparation.

3.3. Treatments and Design

Treatment combinations for experiment I were as follows:-

W_1D_o, W_1D_1, W_1D_2, W_1D_3, W_1D_4, W_2D_o, W_2D_1, W_2D_2, W_2D_3 and W_2D_4.

Where W_1 and$_2$ = Intra-row wheat spacing.

D_{0-4} = Wild oat density per m^2 in ascending order.

A total of ten treatments were randomized in blocks, replicated three times with the two wheat spacings and five wild oat densities in a factorial arrangement. The planned spacings for wheat were 18 x 2.5 cm and 18 x 5.0 cm, giving plant populations of 222 and 111 plants/m^2, respectively. Hereafter, the narrow and wider wheat spacing will be referred to as W_1 and W_2 respectively. Wild oats were planted between rows to give populations of 0, 9, 18, 27 or 54 plants per m^2, hereafter referred to as D_0, D_1, D_2, D_3 and D_4, respectively. The size of each plot was 2.16m x 2.0m with 12 wheat rows and the wild oats located between the rows.

Similar treatment combinations, design, replications and wheat spacing were used for experiment II. The wild oat densities thereafter referred to as Z_0, Z_1. Z_2, Z_3 and Z_4 were, however, 0, 10, 20, 30 and 60 plants per m^2, respectively. Pure stands of wild oats were not included in both experiments because of lack of seed.

3.4. Planting

Experiment I was carried out in the short rains of 1978 which began in October but became exceptionally long after a spell of dry period.

The variety of wheat planted was 'Kiboko', an early maturity variety which takes 70-120 days to mature. Prior to planting, wild oat seeds were cleaned, dehusked and soaked in tap water at room temperature for 48 hours to enhance germination. Wheat was planted in 2-4 cm deep furrows made by small sharpened wooden sticks. It was then thinned to the required intra-row spacing 10-14 days after germination. However, the experiment had to be replanted on

9th December 1978, almost towards the temporary close of short rains, following bird damage.

Experiment II was planted on 22nd April 1979 in the long rains which commenced in the second week of April. The wheat variety used was "Kenya Bongo" instead of "Kiboko" to test competitive ability of a late maturing variety of wheat with wild oats. Planting was carried out in the same way as in Experiment I.

Seeds of both varieties of wheat were obtained from Njoro Plant Breeding Station. Wild oats (Avena spp.) seeds were obtained from a farm at Mau Narok where wild oats are currently threatening commercial wheat farming. The combination of species planted were the same in both experiments because seeds from only one farm were planted.

3.5. Fertilizer application

No fertilizer was applied in experiment I. However, in experiment II, a granular form of Diammonium phosphate (D.A.P.) which consists of 15 per cent nitrogen and 45 per cent P_2O_5 was applied at the rate of 100 kg/ha in accordance with the current recommendation in the country. The fertilizer was broadcast and then worked into the soil using a fork jembe.

3.6. Weeding

The site of the first experiment was only slightly infested with broad leaved weeds, and therefore it was not necessary to spray with any herbicides. Hand pulling was sufficient. All plots were clean weeded by hand when weeds appeared. In the second experiment, Oxalis latifolia L. seriously infested the experimental site. Nevertheless, no known chemical has been recommended for the effective control of this weed in wheat. As a result, hand picking was done at weekly intervals until the 8th week after crop germination when the crop had attained a full canopy which had smothered the oxalis by shading.

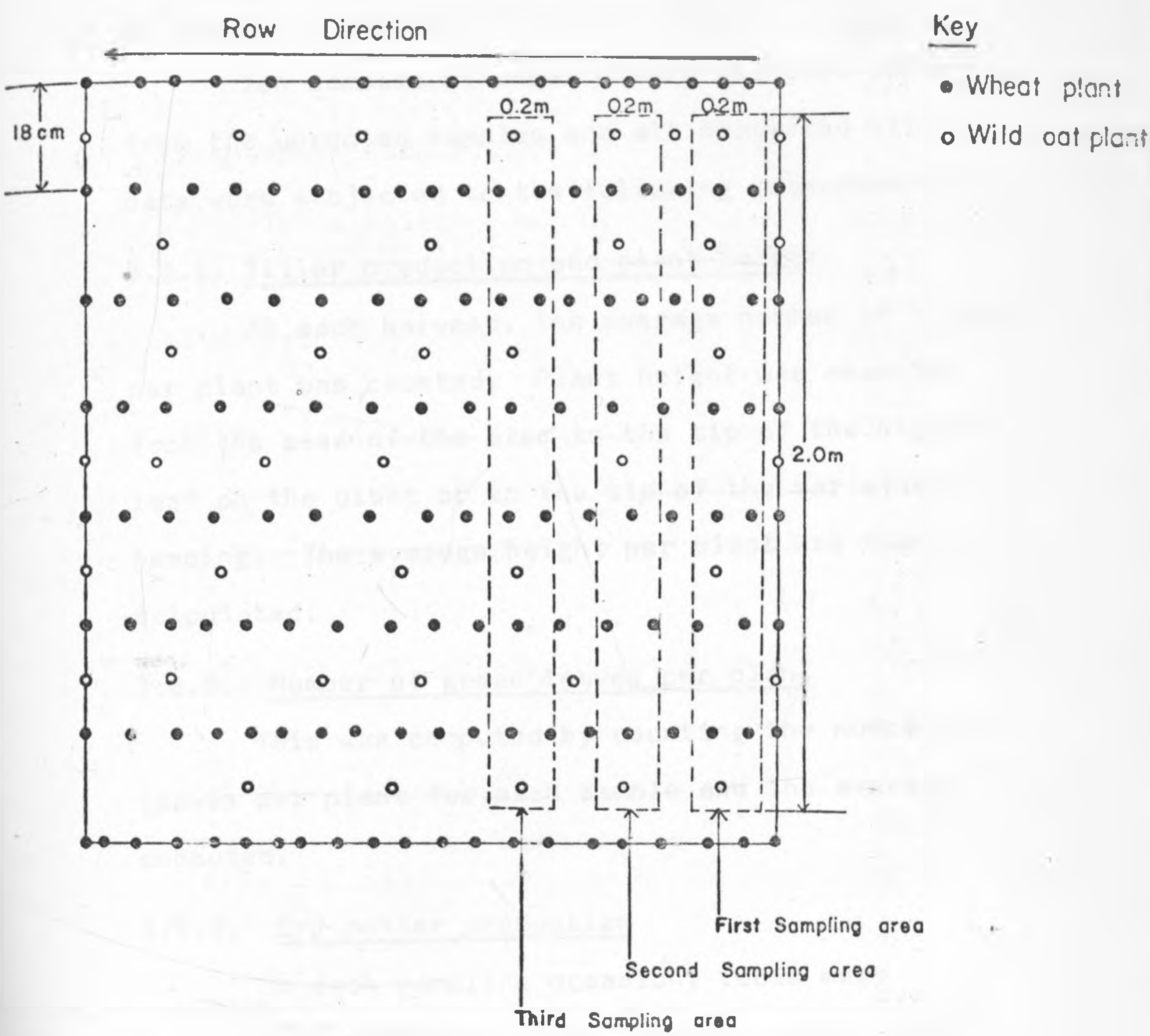
3.7. Irrigation

In experiment I, the short rains came to a halt two weeks after crop germination. It was therefore necessary to supply irrigation water liberally. This was done by delivering the water by a plastic hose pipe from a tank of water mounted on a tractor. When the wheat was at boot stage irrigation was stopped because unexpected rains began again. Experiment II received ample rainfall. Sprinkler irrigation was used four times during the growth period of the crop, twice at the vegetative stage on 20th May 1979 and on 15th June 1979. At the beginning of the reproductive phase irrigation was applied on 2nd July 1979 followed by another on 18th July 1979.

3.8. Sampling procedure

In Experiment I, sampling was done at random from an area measured systematically. Sampling at 2 weeks intervals started 45 days after planting. However due to bird damage only two samplings were done. A final straw dry matter yield was taken at day 80 after planting. On each sampling occasion, 20 wheat plants selected at random from the central rows in the sampling area were gently uprooted leaving the outer rows as discards. For wild oats, 2, 3, 4 and 5 plants in ascending densities were similarly selected from the sampling area and harvested. The sampling area was determined by measuring a distance of 20cm along each side of the plot and the area (0.2m x 2m) gave the sampling area as indicated in a plot in Fig. 1.

Figure 1: Sampling Procedure



During subsequent sampling, one(1) wheat plant and one(1) wild oat plant (where applicable) adjacent to the area previously sampled were left as guard in each row.

Ten samples of wheat plants selected randomly from the uprooted samples and all harvested wild oats were subjected to the following measurements:-

3.8.1. Tiller production and plant height

At each harvest, the average number of tillers per plant was counted. Plant height was measured from the base of the stem to the tip of the highest leaf on the plant or to the tip of the ear after heading. The average height per plant was then calculated.

3.8.2. Number of green leaves per plant

This was computed by counting the number of leaves per plant for each sample and the average computed.

3.8.3. Dry matter production

On each sampling occasion, roots were carefully trimmed from each uprooted plant. The stems leaves and leaf sheaths, and reproductive parts were separated, bulked and dried at 90°C to constant weight and their dry weights determined. Dry weights of whole wild oat plant was determined without separating them into various organs. The total dry weight of wheat was computed by adding the dry weights of the component parts.

In Experiment II, sampling was started 50 days after planting. Subsequent harvests were taken at 14 days intervals upto 106 days after planting after which a final harvest was done at day 158. The sampling procedure was similar to that of Experiment I except that the sampling area was (0.1 m x 2.0 m), half as much as in Experiment I on each sampling period. The number of wheat plants uprooted on each sampling occasion was ten per plot. Plant height, tiller, green leaf and stem dry matter production per plant were determined by the method used in Experiment I. Senesced leaves were separated and dried. The ratio of green/senesced leaves was calculated. The number of wild oat plants harvested on each occasion were the same as in Experiment I. However, they were separated into leaves and stems, bulked and the dry weights of the component parts determined.

3.6.4. Grain yield

At the final harvest, the number of fertile tillers per plant were computed in addition to the number of total tillers. Mean number of ears per plant were calculated. Ear dry weight was determined after drying at 40°C to constant weight. After threshing, 1000 grain weight, grain yield per plant, grain weight per ear and the number of grains per ear were determined.

3.9. Pests

The cardinal pest of wheat at Kabete Field Station are birds of various species. The first experiment was devastated when the crop was at the milky stage of grain formation. It was possible to take yield data in the second experiment because the bird scarers were more reliable. The second manace was mice cutting the tender stems of both wheat and wild oats. Rodenticide (Rodene) was used to kill the mice from the plots using bread and tomatoes as baits.

3.10. Statistical analysis of data

Analysis of variance of the data was computed according to the method in Steel and Torie (1960) for each plant component at each sampling period in Experiment I. Similar computation was done for wheat component parts in Experiment II but for wild oats only the data of the first and 5th sampling periods were computed. Test of significance was conducted by an F-test and Duncan's multiple range test method was used to compare the significant differences between treatment means. Tables of mean square values are given in Appendix A-E for both experiments.

CHAPTER 4

4. RESULTS

4.1. Effect of competition on growth of "Kiboko" wheat variety and wild oats (Avena spp.).

4.1.1. General observations

In Experiment I, "Kiboko" wheat variety germinated 3-5 days after planting whereas wild oats started to germinate 7 days after sowing and germination was completed after 14 days. Both plant species started tillering a week after germination. Flowering in wheat started about 45 days after planting while wild oats began flowering 45 days afterwards. At the period of wild oat flowering wheat could have already been harvested, had it not been for bird damage to the grain.

4.1.2. Plant height

Table 1 shows mean heights for "Kiboko" wheat variety and wild oats in Experiment I. At the first sampling period, 45 days after planting, the height of wheat decreased with increasing wild oat density but the effect was not significant. The height decrease, however, became significant (P = 0.05) 60 and 80 days after planting. Increasing wild oat density from D_1 to D_4 did not have significant effect on wild oat heights grown with wheat at W_1 and W_2 spacing. There was also no significant difference between heights of wheat at W_1 and W_2 spacing.

4.1.3. Tiller production per plant

Mean tiller production per plant of wheat and wild oats for Experiment I are presented in Table 2. There was a significant different (P = 0.05) in tiller production in wheat with increasing wild oat density for both W_1 and W_2. However, increasing wild oat density from D_1 to D_2 and D_3 to D_4 did not affect tillering significantly. Tiller production between W_1 and W_2 wheat spacing were significant in weedfree plots (P = 0.05). Wild oats did not suffer any apparent reduction in tiller numbers per plant at all levels of density. However, the superiority of wild oats in producing abundant tillers is evident. It had produced 8.8 and 14.6 overall number of tillers per plant at 1st and 2nd harvests respectively compared to 3.6 and 4.8 tillers per plant of wheat (Table 2).

4.1.4. Number of green leaves per plant

Increasing wild oat density generally decreased the number of green leaves per plant of wheat at day 45 and 60 as presented in Table 3.

There was significant difference (P = 0.05) between D_0 and all levels of wild oat density. No significant difference was found between D_1 and D_2. Similarly, there was no significant difference between D_3 and D_4 in depression of wheat leaf number per plant. Wheat spaced at W_2 produced more number of leaves than in W_1. The differences were significant at wild oat densities D_2 and D_4.

4.1.5. Dry weight per plant

Dry matter accumulation in the leaves and stems of wheat are presented in Table 4. Table 5 indicates the mean total dry matter production per plant of wheat and wild oats. It can be observed that leaf and stem dry matter per plant decreased with increasing wild oat density for both W_1 and W_2 wheat spacings. Whereas decreasing leaf dry matter had no significant difference at all wild oat densities, stem dry matter attained significant difference (P = 0.05) between D_0 and all wild oat densities for day 45 and 60. There was however, no significant difference in stem dry matter yield of wheat grown at wild oat densities D_1, D_2, D_3 and D_4. The straw dray matter yield at day 80 showed similar trend.

Wheat spacing had little influence on leaf and stem dry matter. Wheat planted at W_2 produced more dry matter than that planted at W_1 but the difference was not significant.

Total dry matter production per plant of wheat followed similar pattern as leaf and stem dry matter. Although it decreased with increasing wild oat density, there was no significant difference. Wild oats total dry matter did not follow a systematic trend with increasing density of its own species and wheat spacing had no apparent influence. Although total dry matter decreased with increasing wild oat density, there was no significant difference.

TABLE 1. Mean height (cm) of shoots of wheat and wild oats grown at different densities in mixed stand.

SES and C.V.	Days from planting	Wheat spacing (cm)	WHEAT: Wild oat density per m^2 0	9	18	27	54	WILD OATS: Wild oat density per m^2 9	18	27	54	SES and C.V.
SE(W)=1.215		2.5	33.1^{a}	28.6^{a}	28.4^{a}	27.5^{a}	26.7^{a}	13.9^{c}	23.1^{c}	20.2^{c}	14.7^{c}	SE(D)=1.848
SE(D) =1.929	45											SE(W)=1.168
CV = 16%		5.0	35.5^{a}	28.3^{a}	29.9^{a}	26.0^{a}	25.3^{a}	19.8^{c}	21.9^{c}	19.0^{c}	17.9^{c}	C.V. = 24.1%
SE(D)=1.880		2.5	69.7^{c}	60.0^{d}	60.2^{d}	53.8^{e}	48.7^{e}	33.8^{b}	29.9^{b}	27.0^{b}	33.3^{b}	SE(D) = 1.430
SE(W)=1.189	60											SE(W) = 1.011
C.V.=7.56%		5.0	68.5^{c}	60.9^{d}	60.2^{d}	60.3^{d}	50.6^{d}	31.7^{b}	33.7^{b}	31.6^{b}	28.0^{b}	C.V. = 11.23%
SE(D)=1.381		2.5	70.1^{a}	65.6^{bc}	62.5^{bc}	62.9^{bc}	60.9^{bc}	67.8^{p}	75.8^{p}	67.2^{p}	82.3^{p}	SE(D)= 4.141
SE(W)=0.874	80											SE(W)= 2.928
C.V.=5.38%		5.0	67.3^{a}	63.9^{bc}	60.4^{bc}	58.5^{bc}	56.3^{bc}	74.2^{p}	71.8^{p}	72.8^{p}	79.4^{p}	C.V. = 13.73%

Means in the same column at a particular date from planting and followed by the same subscript letters are not significantly different ($P = 0.05$).

SE(D) = Standard error of wild oat density.

SE(W) = Standard error of wheat spacing.

C.V. = Coefficient of variation.

TABLE 2. Effect of competition mean tiller number per plant of wheat and wild oats grown at different densities in mixed stands.

SES and C.V.	Days from planting	Wheat spacing (cms)	Wheat: Wild oat density per m^2 0	9	18	27	54	Wild oats: Wild oat density per m^2 9	18	27	54	SES and C.V.
SE(D)=0.217		2.5	4.3^{b}	3.2^{bc}	3.2^{c}	3.3^{c}	2.5^{c}	8.7^{d}	8.4^{d}	8.9^{d}	8.2^{d}	SE(D) = 0.778
SE(W)=0.137	45											SE(W) = 0.550
C.V. = 14.61%		5.0	5.7^{a}	3.7^{bc}	3.4^{c}	3.2^{c}	3.2^{c}	9.1^{d}	8.2^{d}	10.8^{d}	7.8^{d}	CV = 21.64%
SE(D)=0.239		2.5	5.9^{a}	4.1^{b}	4.3^{b}	3.4^{c}	3.2^{c}	15.7^{b}	18.9^{b}	12.7^{b}	11.9^{b}	SE(D) = 1.214
SE(W)=0.151	60											SE(W) = 0.858
C.V. = 12.78%		5.0	6.9^{d}	4.8^{b}	4.4^{b}	4.4^{c}	4.3^{c}	16.0^{b}	18.8^{b}	12.1^{b}	10.9^{b}	C.V. = 20.36%
SE((D)=0.560		2.5	6.4^{h}	4.5^{pc}	4.4^{p}	4.9^{p}	3.4^{p}	30.7^{a}	35.2^{a}	30.9^{a}	16.9^{a}	SE(D) = 2.405
SE(W) =0.354												SE(W) = 1.700
C.V. = 26%		5.0	7.4^{q}	6.5^{pc}	5.5^{p}	5.4^{p}	4.1^{p}	39.0^{a}	25.6^{a}	25.4^{a}	24.5^{a}	C.V. =21.04%

Means in the same column at a particular date and followed by the same subscript letters are not significantly different (P = 0.05).

SE(D) = Standard error of wild oat density.

SE(W) = Standard error of wheat spacing.

C.V. = Coefficient of variation.

Effect of competition on mean number of leaves per plant of wheat and wild oats grown at different densities.

		WHEAT					WILD OATS				
Days from planting	Wheat spacing (cm)	Wild oat density per m^2					Wild oat density per m^2				SES and C.V.
		0	9	18	27	54	9	18	27	54	
45	2.5	21.3^{a}	17.7^{b}	15.1^{b}	15.1^{c}	14.7^{c}	34.6^{d}	31.5^{d}	34.8^{d}	33.5^{d}	SE(D) = 0.771
											SE(W) = 0.302
	5.0	22.9^{a}	17.4^{bd}	16.8^{bd}	17.4^{q}	16.1^{q}	35.2^{d}	32.9^{d}	33.8^{d}	30.9^{d}	C.V. = 5.7%
60	2.5	17.2^{c}	13.9^{d}	11.9^{d}	11.4^{p}	9.5^{p}	75.2^{b}	66.1^{b}	59.9^{b}	55.2^{b}	SE(D) = 5.241
											SE(W) = 3.703
	5.0	19.3^{c}	15.4^{bd}	13.4^{bd}	12.4^{z}	12.1^{z}	69.0^{b}	76.1^{b}	53.2^{b}	48.6^{b}	C.V. = 20.4%

the same column at a particular data and followed by the same subscript letters are not antly different (P = 0.05).

) = Standard error of wild oat density.

) = Standard error of wheat spacing.

= Coefficient of variation.

TABLE 4. Effect of competition on mean leaf and stem dry weight (g) per plant of wheat grown at 2 densities and five wild oat densities in mixed stands.

SES and C.V.	Days from planting	Wheat spacing (cm)	LEAF DRY WEIGHT (g) Wild oat density per m^2 0	9	18	27	54	STEM DRY WEIGHT (g) Wild oat density per m^2 0	9	18	27	54	SES and C.V.
SE(D)=0.168		2.5	0.73^{b}	0.53^{b}	0.53^{b}	0.43^{b}	0.27^{b}	0.41^{b}	0.22^{c}	0.19^{c}	0.20^{c}	0.12^{d}	$SE(D_o)=0.033$
SE(W)=0.106	45												$SE(D_w)=0.021$
C.V. =6.53%		5.0	1.03^{b}	0.73^{b}	0.73^{b}	0.73^{b}	0.57^{b}	0.39^{d}	0.25^{c}	0.25^{c}	0.18^{d}	0.17^{d}	C.V. =34.09%
$SE(D_o)=0.90$		2.5	0.89^{c}	0.79^{c}	0.78^{c}	0.72^{c}	0.60^{c}	0.95^{a}	0.54^{c}	0.51^{c}	0.26^{c}	0.16^{d}	$SE(D_o)=0.110$
$SE(D_w)=0.057$	60												$SE(D_w)=0.70$
C.V. =31.21%		5.0	1.13^{c}	0.87^{c}	0.69^{c}	0.64^{c}	0.58^{c}	1.30^{b}	0.69^{c}	0.63^{c}	0.62^{c}	0.47^{b}	CV = 44.0%
		2.5						4.20^{p}	2.73^{q}	2.80^{q}	2.80^{q}	2.03^{z}	$SE(D_o)=0.355$
	80												$SE(D_w)=0.224$
		5.0						4.60^{p}	3.70^{c}	3.20^{cq}	2.50^{cq}	2.40^{cz}	C.V.=28.13%

Means in the same column of a particular date and followed by the same subscript letters are not significantly different (P = 0.05).

SE(D) = Standard error of wild oat density.

SE(W) = Standard error of wheat spacing.

C.V. = Coefficient of variation.

TABLE 5. Mean total dry weight (g) per plant of wheat and wild oats grown at different densities in mixed stands.

SES and C.V.	Days from planting	Wheat spacing (cm)	WHEAT Wild oat density per m^2					WILD OATS Wild oat density per m^2				SES and C.V
			0	9	18	27	54	9	18	27	54	
SE(D)=0.537		2.5	1.40^{p}	1.08^{p}	0.97^{p}	0.82^{p}	0.49^{p}	0.30^{b}	0.67^{b}	0.82^{b}	0.59^{b}	SE(D) = 0.137
SE(W)=0.340	45											SE(W) = 0.069
C.V. =12.29%		5.0	1.52^{p}	1.32^{p}	1.30^{p}	0.90^{p}	0.89^{p}	0.60^{b}	1.03^{b}	0.74^{b}	0.76^{b}	C.V. = 13.54%
SE(D)=0.244	60	2.5	1.35^{q}	1.17^{q}	1.30^{q}	1.13^{q}	0.98^{q}	1.57^{d}	1.78^{d}	1.89^{d}	1.85^{d}	SE(D) = 0.370
SE(W)=0.155												SE(W) = 0.262
C.V. =46.04%		5.0	1.95^{q}	1.50^{q}	1.39^{q}	1.15^{q}	1.05^{q}	2.50^{d}	3.17^{d}	2.60^{d}	1.37^{d}	C.V. = 43.40%
		2.5	-	-	-	-	-	24.46	32.15	33.36	22.33	
	80											
		5.0	-	-	-	-	-	32.07	29.51	28.05	35.57	

Means in the same column, at a particular date, followed by the same subscript letters are not significantly different (P = 0.05).

SE(D) = Standard error of wild oat density.

SE(W) = Standard error of wheat spacing.

C.V. = Coefficient of variation.

4.2. Effect of competition on the growth of "Kenya Bongo" variety of wheat and wild oats (*Avena spp.*) grown in association.

4.2.1. General observations

In Experiment II, wheat attained even germination 5 days after planting, while wild oats completed germination in 10 days. Although several wild oat seeds failed to germinate, the number of seedlings established were close to the required densities of 10, 20, 30 and 60 plants per m^2. Wild oats at Z_3 and Z_4 suffered severe lodging after about 106 days of growth when the crop was at boot stage resulting in some wheat lodging as well. Flowering in wheat began about 106 days after planting and by day 120, flowering was completed. Wild oats, on the other hand started to flower two weeks before wheat. However, at final harvest some tillers were still flowering. The first primary tillers had already matured by this period and some seeds had fallen off.

4.2.2. Plant height

Table 6 shows mean heights of wheat and wild oats for six sampling periods for Experiment II. At day 50, wild oat density had significant effect on the height of wheat. The height of wheat increased with increasing wild oat density, but the differences were only significant (P = 0.05) at high wild oat densities (Z_3 and Z_4). In subsequent sampling period, 64 days after planting wheat height increased with increasing wild oat density but the differences were not significant (P = 0.05). At day 78, and until final harvest, this situation was reversed. Wheat height tended to decrease with increasing wild oat density. However, the heights were not significantly different.

Wheat spacing significantly affected height at day 50 (P = 0.05). Wheat spaced at W_1 was taller than that at W_2 but the differences were only significant at wild oat densities Z_2, Z_3 and Z_4. From day 64 until final harvest, wheat spacing had no significant effect on height although wheat grown at W_2 spacing was slightly taller than that spaced at W_1.

There was no consistent trend in height of wild oats as density increased in all sampling periods.

TABLE 6. Mean height (cm) of shoots of wheat and wild oats grown at different densities in mixed stands.

SEs and C.V.	Days from planting	Wheat spacing (cm)	WHEAT Wild oat density per m^2 0	10	20	30	60	WILD OATS Wild oat density per m^2 10	20	30	60	SEs and C.V.
SE(D)=1.295		2.5	48.2[a]	51.6[a]	51.6[ad]	53.4[d]	57.1[c]	63.4[b]	53.4[b]	62.4[b]	59.5[b]	SE(D) = 4.186
SE(W)=0.819	50											SE(W) = 2.960
C.V. = 6.20%		5.0	46.4[a]	49.2[a]	49.9[ak]	50.7[k]	53.6[d]	50.3[b]	61.2[b]	56.4[b]	61.4[b]	C.V. = 17.47%
SE(D)=1.166		2.5	59.8[g]	59.9[g]	60.3[g]	61.5[g]	61.1[g]	71.2[c]	68.0[c]	78.6[c]	83.8[c]	
SE(W)=0.737	64											
C.V. = 4.72%		5.0	59.2[g]	60.0[g]	60.3[g]	61.2[g]	61.3[g]	70.9[c]	83.5[c]	74.2[c]	78.9[c]	
SE(D)=1.925		2.5	74.3[q]	74.1[q]	73.5[q]	72.5[q]	70.5[q]	85.2	86.7	82.7	92.5	
SE(W)=1.217	78											
C.V. =6.38%		5.0	76.9[q]	76.1[q]	75.1[q]	75.1[q]	70.1[q]	82.7	90.7	84.5	96.8	

Table 6 (Contd...)

SE(D)=1.722												
SE(W)=1.186	92	2.5	98.4^{c}	91.6^{c}	90.5^{c}	90.0^{c}	89.2^{c}	99.2	104.0	98.3	103.8	
C.V.=4.54%		5.0	95.8^{c}	95.3^{c}	94.0^{c}	92.0^{c}	90.8^{c}	97.9	100.0	103.7	118.7	
SE(D)=2.224												
SE(W)=1.047	106	2.5	103.6^{d}	102.7^{d}	100.1^{d}	97.5^{d}	96.3^{d}	115.9	116.4	114.1	117.1	
C.V.=5.37%		5.0	106.4^{d}	104.7^{d}	102.7^{d}	100.1^{d}	99.8^{d}	108.2	111.9	108.6	121.7	
SE(D)=1.337												
SE(W)=0.846	158	2.5	118.8^{b}	115.9^{b}	114.2^{b}	112.5^{c}	108.9^{c}	158.0^{m}	162.0^{m}	165.4^{m}	162.8^{m}	SE(D)=2.181
		5.0	119.5^{b}	116.9^{b}	115.3^{b}	113.0^{c}	110.2^{c}	168.8^{m}	159.8^{m}	155.1^{m}	164.3^{m}	SE(W)=1.542
C.V.=2.87%												C.V.=4.68%

Means in the same column at a particular date, followed by the same subscript letters are not significantly different = (P = 0.05).

SE(D) = Standard error of wild oat density..

SE(W) = Standard error of wheat spacing .

C.V. = Coefficient of variaton.

4.2.3. Tiller production per plant

Results for tiller production per plant of wheat and wild oats are presented in Table 7. It can be seen that increasing wild oat density significantly depressed wheat tillering at all sampling periods ($P = 0.05$). From day 50 to day 78, Z_2, Z_3 and Z_4 significantly reduced tiller production per plant of wheat, while Z_1 had insignificant effect. From day 92 until final harvest, Z_1 also affected tiller production significantly.

Doubling intra-row wheat spacing significantly increased tillering in wheat but there was no significant difference between wild oat free plots at all sampling periods. From day 50, until final harvest, Z_3 and Z_4 depressed tillering significantly more at W_1 than at W_2 ($P = 0.05$).

Tiller production in wild oats increased with time reaching maximum at day 92, but increasing density had no consistent effect on tillering. However, it possessed the ability to produce more tillers than wheat at all levels of density.

TABLE 7. Effect of competition on mean tiller numbers per plant of wheat and wild oats grown at different densities in mixed stands

SEs and C.V.	Days from planting	Wheat spacing (cm)	WHEAT: Wild oat density per m^2 0	10	20	30	60	WILD OATS: Wild oat density per m^2 10	20	30	60	SEs and C.V.
SE(D)=0.389												
SE(W)=0.247	50	2.5	8.4^{a}	7.7^{a}	6.5^{a}	5.1^{c}	4.1^{d}	8.0^{b}	7.9^{b}	7.2^{b}	10.2^{-}	SE(D) = 0.588
		5.0	8.5^{a}	7.4^{a}	7.4^{b}	6.4^{d}	5.1^{e}	7.0^{b}	9.2^{b}	7.6^{b}	9.7	SE(W) = 0.416
C.V. = 14.33%												C.V. = 17.02%
SE(D)=0.693												
SE(W)=0.438	64	2.5	8.6^{a}	7.9^{a}	6.7^{b}	5.2^{q}	4.2^{p}	10.8	8.8	12.3	12.2	
C.V.=24.45%		5.0	8.8^{a}	8.1^{a}	7.7^{ba}	6.7^{cb}	6.4^{q}	9.2	10.0	12.2	11.9	
SE(D)=0.359												
SE(W)=0.227	75	2.5	8.5^{a}	7.9^{a}	6.4^{c}	4.9^{b}	4.3^{g}	10.2	9.3	10.7	12.5	
C.V. = 12.87%		5.0	9.1^{a}	8.0^{a}	7.1^{c}	6.4^{c}	5.7^{d}	10.3	11.8	10.0	12.5	

Table 7. (Contd...)

SE(D)=0.397												
SE(W)=0.247	92	2.5	8.2^{a}	7.0^{cf}	6.7^{f}	4.3^{d}	3.9^{b}	12.7	11.5	11.2	13.0	
C.V.		5.0	8.4^{a}	7.3^{cf}	7.1	6.1^{f}	5.6^{d}	12.3	12.3	13.2	14.3	
SE(D)=0.533												
SE(W)=0.337	106	2.5	8.6^{a}	6.8^{cf}	6.7^{f}	5.5^{bd}	5.2^{b}	11.8^{b}	11.9^{b}	11.7^{b}	13.2^{b}	SE(D) = 0.684
		5.0	8.4^{a}	7.9^{cf}	7.7^{f}	6.6^{df}	6.4^{d}	12.4^{b}	14.1^{b}	13.2^{b}	13.3^{b}	SE(W) = 0.434
C.V.=18.76%												C.V. = 5.63%
SE(D)=0.336		2.5	7.7^{a}	6.9^{cf}	6.1^{f}	5.4^{c}	4.7^{b}	12.1	11.4	11.2	10.4	
SE(W)=0.213	158	5.0	8.2^{a}	8.1^{af}	6.9^{cf}	6.0^{ep}	5.4^{p}	9.8	10.9	10.9	10.0	
C.V.=12.39%												

Means in the same column at a particular date, followed by the same subscript letters are not significantly different (P = 0.05).

SE(D) = Standard error of wild oat density.

SE(W) = Standard error of wheat spacing.

C.V. = Coefficient of variation.

4.2.4. Number of green leaves per plant

Table 8 shows the mean number of green leaves per plant of wheat and wild oats during five sampling periods. It can be seen that increasing wild oat density significantly reduced the number of green leaves per wheat plant. At Z_1 wild oats had no significant effect on number of leaves of wheat, Wild oat densities Z_2, Z_3 and Z_4 significantly depressed the number of green leaves of wheat, compared with wild oat free plots (P = 0.05). However, there was no significant differences among Z_2, Z_3 and Z_4. This trend continued from day 50 to 92. At day 106, Z_4 reduced the number of green leaves of wheat significantly more (P = 0.05) than Z_2 and Z_3.

The influence of doubling intra-row wheat spacing was relatively minor on the number of green leaves produced per wheat plant.

The production of green leaves per wild oat plant was not affected in a consistent manner neither by increases in density nor wheat spacing. In all sampling periods, however, wild oats had more number of green leaves than wheat.

TABLE 8. Mean number of green leaves per plant of wheat and wild oats grown at different densities in mixed stands.

			WHEAT					WILD OATS				
SES and C.V.	Days from plan-ting		Wild oat density per m^2					Wild oat density per m^2				
			0	10	20	30	60	10	20	30	60	SES and C.V.
SE(D)=1.577		2.5	33.5^{a}	28.9^{a}	25.5^{b}	24.1^{b}	20.6^{b}	37.2^{a}	35.2^{a}	36.8^{a}	36.5^{a}	SE(D)=3.294
SE(W)=0.998	50											SE(W)=2.329
C.V.=13.9%		5.0	36.8^{a}	30.8^{a}	28.9^{b}	25.1^{b}	23.6^{b}	36.3^{a}	44.5^{a}	36.7^{a}	44.8^{a}	C.V. = 23.4%
SE(D)=2.014		2.5	33.0^{a}	31.0^{a}	25.8^{b}	23.5^{b}	20.8^{b}	38.9	36.2	32.9	37.1	
SE(W)=1.274	64											
C.V.=17.7%		5.0	35.0^{a}	30.7^{a}	30.1^{b}	24.6^{b}	23.4^{b}	31.2	34.8	37.2	46.3	
SE(D)=0.600		2.5	28.2^{a}	24.7^{b}	24.2^{b}	22.3^{b}	20.3^{b}	36.6	36.4	32.5	37.5	
SE(W)=0.379	78											
C.V.=6.1%		5.0	29.4^{a}	25.0^{b}	23.9^{b}	21.7^{b}	21.2^{b}	31.9	39.0	37.7	33.1	

Table 8 (Contd...)

SE(D)=0.93												
SE(W)=0.555	92	.5	20.3	19.8[a]	18.9[b]	17.2[b]	16.5[b]	36.4	38.1	25.9	21.0	
C.V.=11.8%		5.0	22.0[a]	29.0[a]	19.9[b]	18.7[b]	18.1[b]	33.5	28.8	35.7	30.8	
SE(D)=0.759												SE(D)=3.594
SE(W)=0.481	106	2.5	20.3[a]	19.1[a]	17.8[b]	17.2[b]	14.7[c]	33.5[b]	31.7[b]	23.2[b]	18.5[b]	SE(W)=2.541
C.V.=10.7%		5.0	20.3[a]	19.2[a]	16.2[b]	15.0[b]	14.1[c]	31.8[b]	26.4[b]	31.2[b]	28.1[b]	C.V.=3.17%

Means in the same column at a particular date and followed by the same subscript letters are not significantly different ((=0.05).

SE(D) = Standard error of wild oat density.
SE(W) = Standard error of wheat spacing.
C.V. = Coefficient of variation.

4.2.5. Leaf and stem dry matter production per plant

The mean leaf dry matter per plant of wheat and wild oats are presented in Table 9, and Fig. 2 and 3. Table 10, and Fig. 4 and 5 show stem dry matter production for the two species in Experiment II.

Taking leaf dry matter first, it can be seen that there was a tendency for wheat leaf dry weight per plant to decrease as wild oat density increased (Table 9). From day 50 to day 78, Z_1 and Z_2 decreased leaf dry weight but not significantly. Only when the density reached Z_3 and Z_4 was leaf dry weight significantly reduced. However, this trend disappeared at day 106 when all levels of wild oat density significantly affected leaf dry weight.

Although doubling intra-row spacing of wheat increased leaf dry weight per plant, the increase did not differ significantly at all levels of density ($P = 0.05$). For example at day 50, wheat accumulated 1.57g and 2.02g of leaf dry matter at W_1, and W_2 respectively in plots kept wild oat free while at day 106, at similar spacing it had accumulated 7.75g and 7.77g per plant. The depression of leaf dry weight per plant at day 106 were 26.8, 34.8, 40.5 and 57.7 per cent for W_1 and 11.0, 19.9, 39.5 and 47.5 per cent for W_2 in order of ascending densities in both cases.

Wild oats produced more leaf dry matter per plant than wheat during its growth cycle but density did not influence it in any particular pattern at day 50 and 106.

Stem dry weight per plant of wheat followed a similar trend as leaf dry weight. However, formation of stem started later in the growth period. At the 1st and 2nd sampling periods, wheat only produced leaves and leaf sheaths. Stem formation started at about the 3rd harvest and thereafter dry matter accumulated per plant increased until 5th harvest. The effect of increasing wild oat density decreased stems dry weight with no significant difference until day 78. At day 92 and 106, only the highest densities (Z_3 and Z_4) had significant effect (0=0.05). Stem formation in wild oats started two weeks earlier than the crop. However, the differences were not significant at day 50 and 106 when density increased. By day 106, stem dry weight per plant of wild oats had doubled that of wheat.

TABLE 9. Effect of competition on mean leaf dry weight (g) per plant of wheat and wild oats grown at different densities in mixed stands

SES and C.V.	Days from planting	Wheat spacing (cm)	WHEAT: Wild oat density per m^2 0	10	20	30	60	WILD OATS: wild oat density per m^2 10	20	30	60	
SE(D)=0.183												SE(D)=0.331
SE(W)=0.116	50	2.5	1.57^{a}	1.40^{a}	1.15^{a}	0.92^{b}	0.59^{b}	3.3^{q}	2.3^{q}	2.7^{q}	2.1^{q}	SE(W)=0.234
C.V.=36.59%		5.0	2.02^{a}	1.55^{a}	1.33^{ad}	0.93^{bd}	0.77^{bd}	2.3^{q}	2.5^{q}	2.1^{q}	2.6^{q}	C.V. =3.12%
SE(D)=0.283												
SE(W)=0.179	64	2.5	2.82^{p}	2.55^{p}	2.14^{p}	1.09^{q}	1.19^{q}	5.2	4.5	6.2	6.5	
C.V.=32.52%		5.0	3.53^{p}	2.74^{p}	2.46^{pq}	1.40^{gq}	1.16^{gq}	5.1	6.2	7.2	5.8	
SE(D)=0.305												
SE(W)=0.193	78	2.5	3.89^{b}	3.39^{m}	3.17^{m}	2.50^{n}	1.93^{n}	12.3	16.7	16.3	17.5	
C.V. =23.04%		5.0	4.30^{m}	4.10^{m}	3.92^{mp}	2.74^{pn}	2.00^{pn}	17.7	15.9	11.0	15.1	

Table 9. (Contd...)

SE(D) = 0.332												
SE(W) = 0.209	92	2.5	7.24^{a}	5.85^{c}	5.11^{c}	4.28^{c}	3.16^{b}	21.0	18.4	19.5	17.7	
C.V. = 15.69%		5.0	7.70^{a}	6.40^{c}	5.80^{p}	4.45^{pc}	3.87^{d}	11.0	16.2	14.6	24.4	
SE(D)=0.449		2.5	7.75^{a}	5.67^{c}	5.05^{c}	4.61^{c}	3.28^{b}	24.0	22.1	20.2	19.0	SE(D)=2.275
SE(W)=0.284	106											
C.V. =19.87%		5.0	7.77^{a}	6.88^{c}	6.22^{p}	4.70^{pc}	4.08^{d}	12.1	14.9	15.6	24.4	C.V.=29.9%

Means in the same column at a particular date, followed by the same subscript letters are not significantly different (P = 0.05).

SE(D) = Standard error of wild oat density.

SE(W) = Standard error of wheat spacing.

C.V. = Coefficient of variation.

Figure 2: Effect of wild oat density on wheat leaf dry weight (g) per plant.

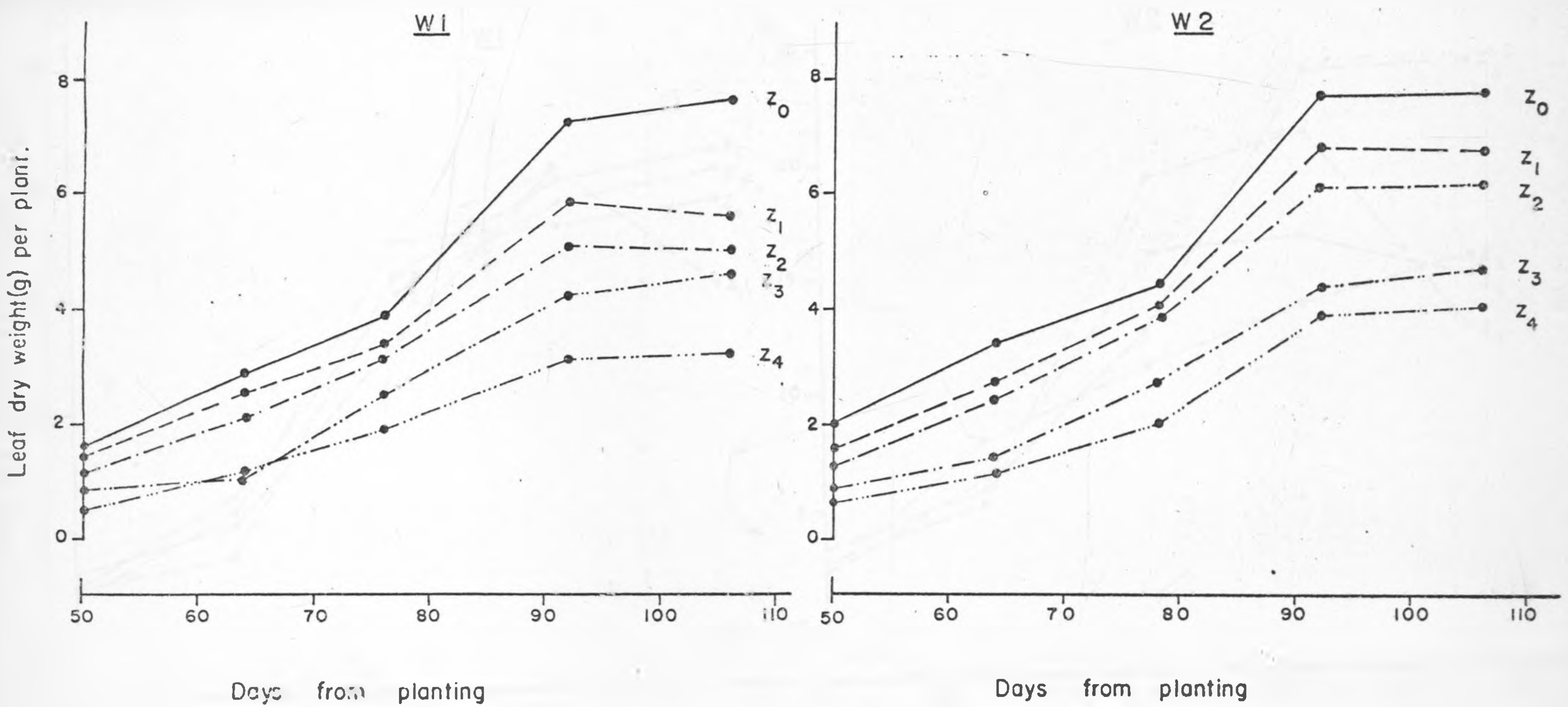


Figure 3: Effect of competition on leaf dry weight (g) per plant of wild oats (Avena spp.)

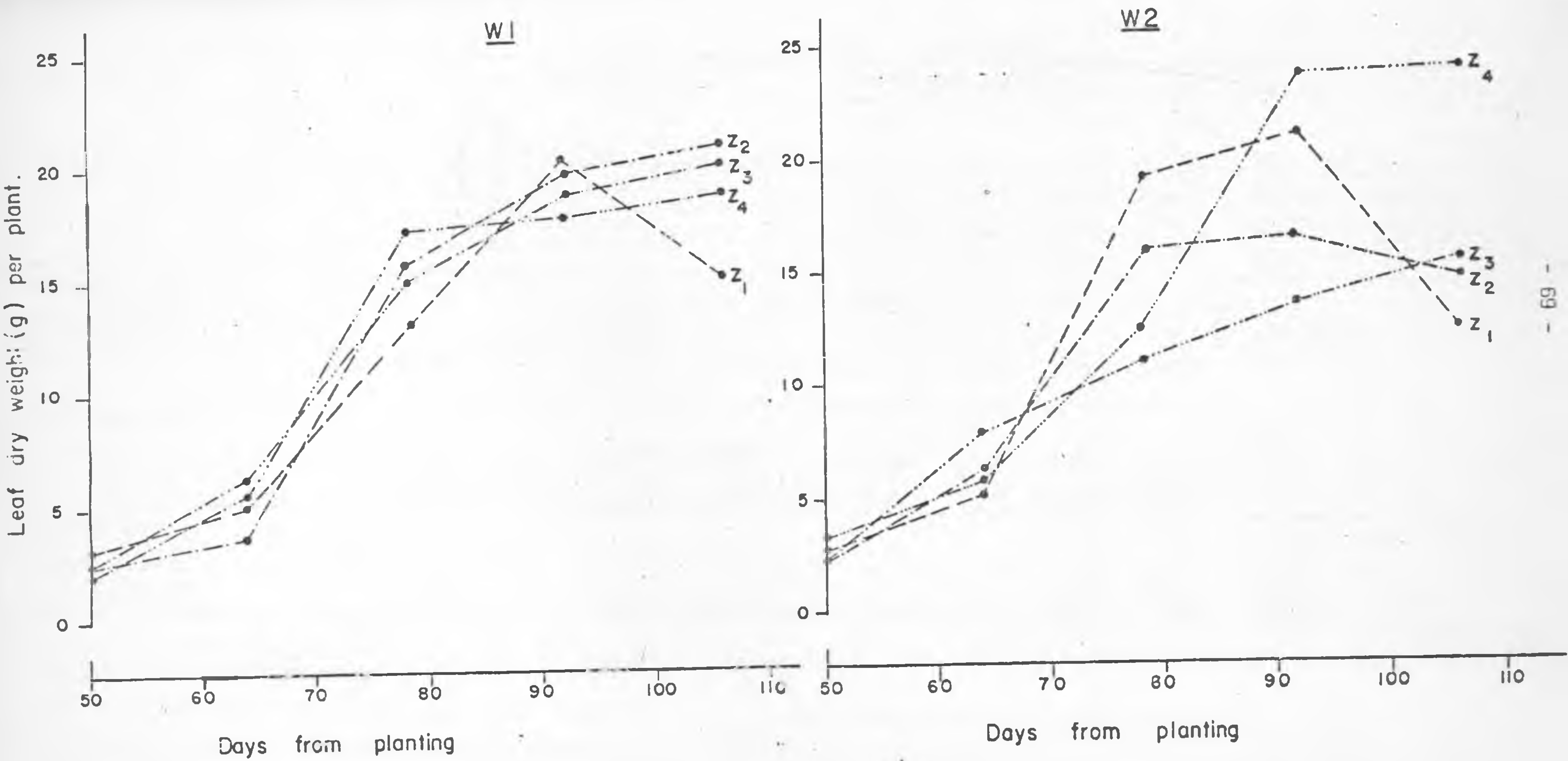


TABLE 10. Mean stem dry weight (g) per plant of wheat and wild oats grown at different densities in mixed stand.

SES and C.V.	Days from planting		WHEAT: Wild oat density per m^2 0	10	20	30	60	WILD OATS: Wild oat density per m^2 10	20	30	60	SES and C.V.
	64	2.5	-	-	-	-	-	0.30	2.27	0.87	0.20	SE(D)=0.217
		5.0	-	-	-	-	-	0.23	0.87	0.40	0.47	SE(W)=0.153 C.V. =11.81%
SE(D)=0.174	78	2.5	0.33^{b}	0.34^{b}	0.32^{b}	0.30^{b}	0.15^{b}	2.33	1.30	1.97	2.73	
SE(W)=0.110												
C.V.=14.2%		5.0	0.35^{b}	0.31^{b}	0.31^{b}	0.27^{b}	0.25^{b}	1.30	2.33	1.07	2.03	
SE(D)=0.139												
SE(W)=0.088	92	2.5	1.56^{a}	1.39^{a}	1.16^{a}	1.13^{ac}	0.57^{d}	2.67	3.30	3.60	3.93	
C.V.=27.74%		5.0	1.81^{a}	1.44^{a}	1.30^{a}	1.10^{ac}	0.70^{d}	2.57	3.70	2.33	4.13	
SE(D)=0.410												SE(D)=1.195
SE(W)=0.259	106	2.5	4.31^{p}	3.65^{p}	2.86^{p}	2.10^{pq}	2.09^{n}	6.77	8.33	8.70	7.40	SE(W)=0.845
C.V. =29.28%			5.27^{p}	4.49^{p}	3.87^{p}	3.25^{pq}	2.41^{n}	6.37	7.63	6.07	8.40	C.V. =39.24%

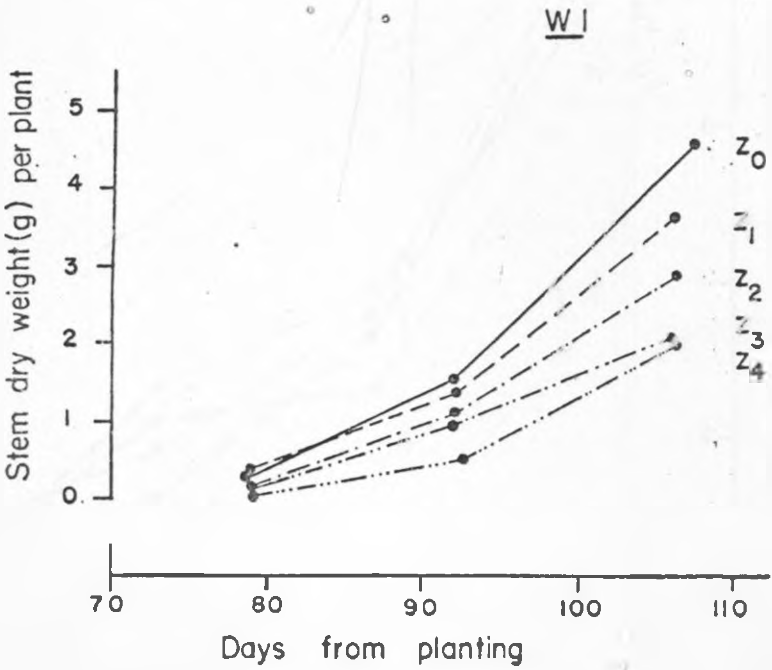
Means in the same column at a particular date, followed by the same subscript letters are not significantly different (P=0.05).

SE(D) = Standard error of wild oat density.

C.V. = Coefficient of variation.

SE(W) = Standard error of wheat density.

Figure 4: Effect of wild oat density



on wheat stem dry weight (g) per plant.

W2

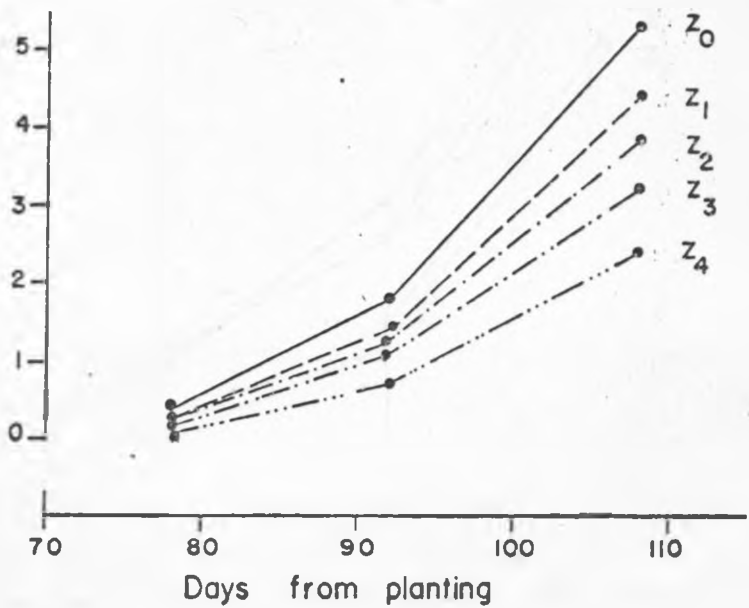
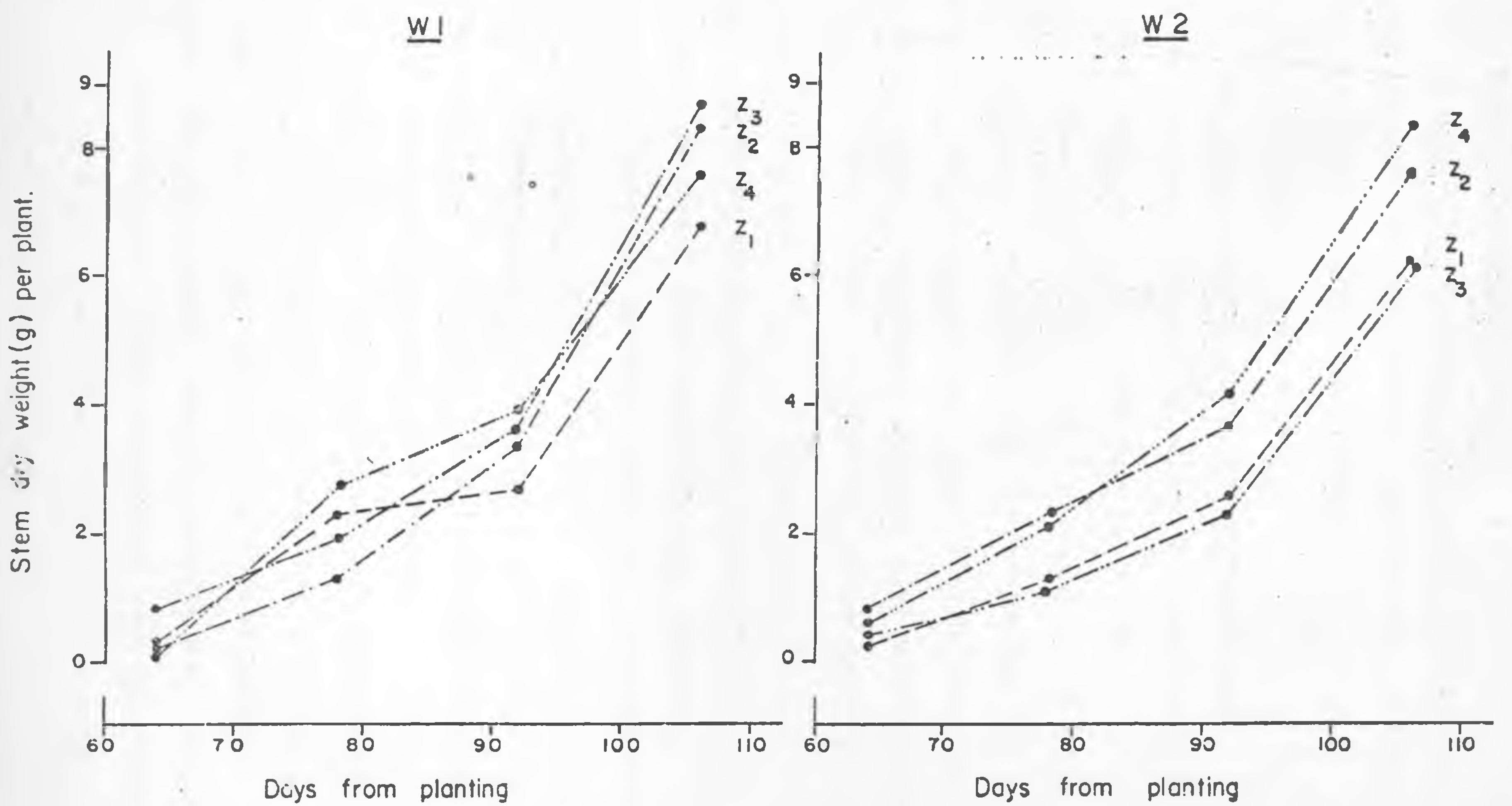


Figure 5: Effect of competition on stem dry weight (g) per plant of wild oats (Avena spp.)



4.2.6. Effect of competition on the ratio between green and senesced leaf.

Leaves were considered senescent if they were apparently brown or had general loss of green colour. Leaves with most of the blades brown, dying or dead were also considered as senescent.

The ratio between green and senesced leaf are shown in Table 11 and Fig. 6 and 7 on dry weight per plant basis for both wheat and wild oats. Generally, the ratio progressively decreased with time (Fig. 6 and 7). Leaf senescence first started in plants sown with high wild oat densities but as the weeds grew bigger, the lowest density also experienced senescence. From day 50 to day 106, wheat spacing had little effect on the ratio, although wheat at W_2 maintained higher ratios than that grown at W_1. In both cases, however, there was a general decrease in the ratio as wild oat density increased. The difference reached significant levels (P=0.05) at Z_2, Z_3 and Z_4. There was however no significant difference between the ratios of Z_2, Z_3 and Z_4. This trend was maintained until the last sampling period at day 106.

Wild oats, on the other hand, maintained high ratios than wheat throughout the sampling period. Although ratios at high density levels decreased at progressively higher rate, the differences were slight (Table 11 and Fig. 7). Leaf senescence started 4 weeks later with wild oat plants when senescence in wheat was somehow levelling off (Fig 6 and 7).

TABLE 11. Mean ratio between Green and senesced leaf (on dry matter basis) of wheat and wild oats grown at different densities in mixed stands.

SES and C.V.	Days from planting		WHEAT: Wild oat density per m^2 0	10	20	30	60	WILD OATS: Wild oat density per m^2 10	20	30	60	SES and C.V.
SE(D)=0.690												
SE(W)=0.437	50	2.5	10.1[a]	9.8[a]	8.6[q]	7.5[q]	5.8[q]	-	-	-	-	
C.V. =18.96%		5.0	12.7[a]	10.2[a]	9.0[a]	8.6[q]	6.7[q]	-	-	-	-	
SE(D)=0.536												
SE(W)=0.239	64	2.5	7.4[a]	7.3[a]	6.2[b]	5.1[b]	4.0[b]	-	-	-	-	
C.V.=14.84%		5.0	8.7[a]	8.2[a]	6.8[b]	4.8[b]	4.0[b]	-	-	-	-	
SE(D)=0.267												
SE(W)=0.187	78	2.5	2.9[p]	2.6[p]	2.2[q]	2.1[q]	1.6[q]	13.3[b]	14.4[b]	15.5[b]	15.0[b]	SE(D) = 1.084
C.V.=19.49%		5.0	3.3[p]	3.0[p]	2.5[q]	2.2[q]	1.4[q]	15.2[b]	16.4[b]	14.7[b]	14.0[b]	SE(W) = 0.767; C.V. =17.94%

Table 11. (Contd...)

SE(D)=0.600												
SE(W)=0.380	92	2.5	2.2^{z}	2.0^{z}	1.8^{y}	1.6^{y}	1.2^{y}	11.5	13.0	15.0	12.6	
C.V. =81.25%		5.0	2.4^{z}	2.1^{z}	1.6^{y}	1.7^{y}	1.5^{y}	13.6	14.5	12.7	12.7	
SE(D)=0.930												SE(D)=1.195
SE(W)=0.588	106	2.5	1.8^{a}	1.4^{a}	1.2^{b}	1.1^{b}	0.9^{b}	9.6^{d}	10.5^{d}	10.7^{d}	9.0^{d}	SE(W)=0.845
C.V. =162.72%		5.0	2.3^{a}	1.7^{a}	1.4^{b}	0.9^{b}	0.8^{b}	9.2^{d}	10.3^{d}	9.5^{d}	8.0^{d}	C.V. = 33.26%

Means in the same column at a particular date, and followed by the same subscript letters are not significantly oifferent (P=0.05).

SE(D) = Standard error of wild oat density.
SE(W) = Standard error of wheat spacing.
C.V. = Coefficient of variation.

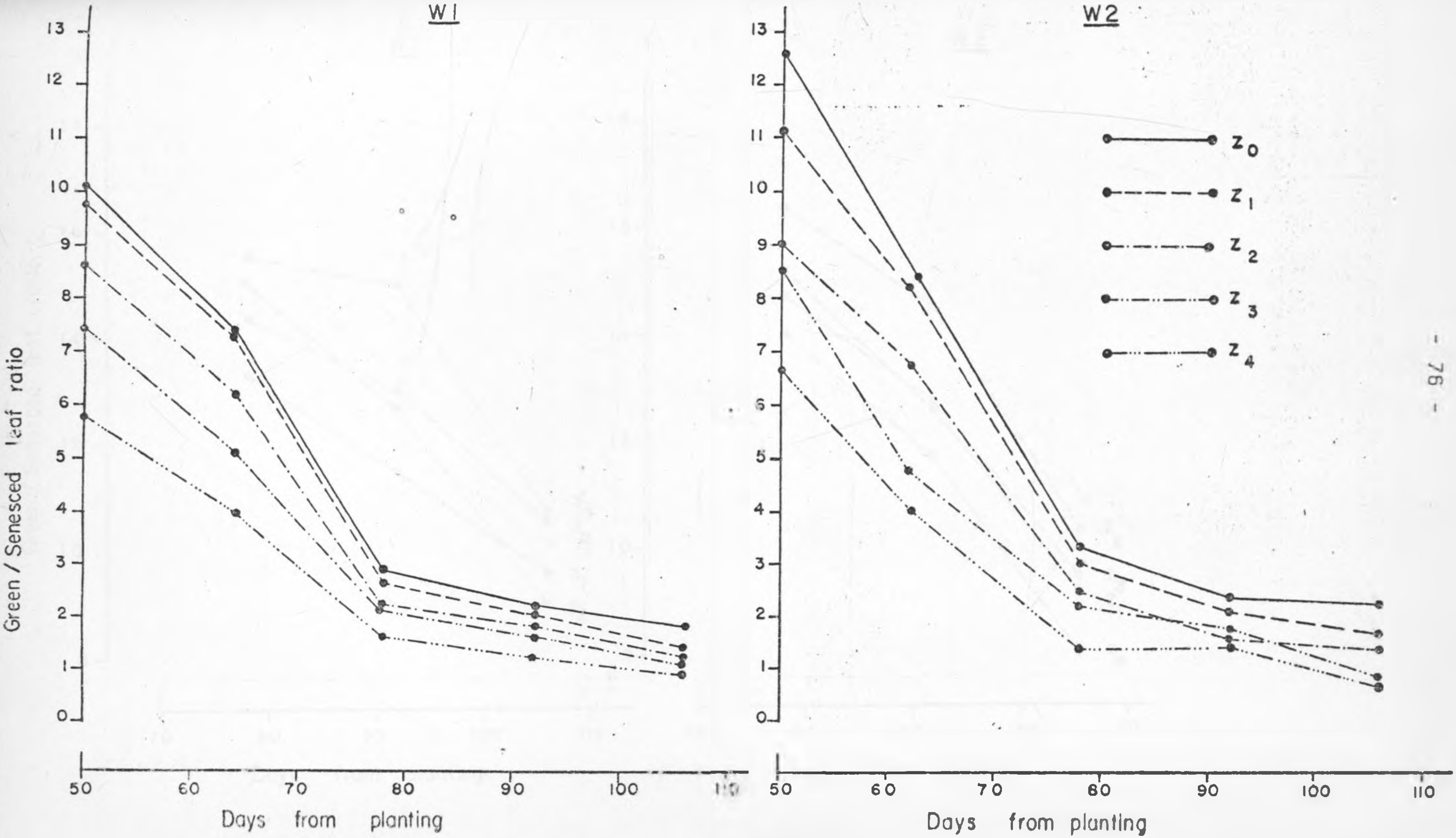
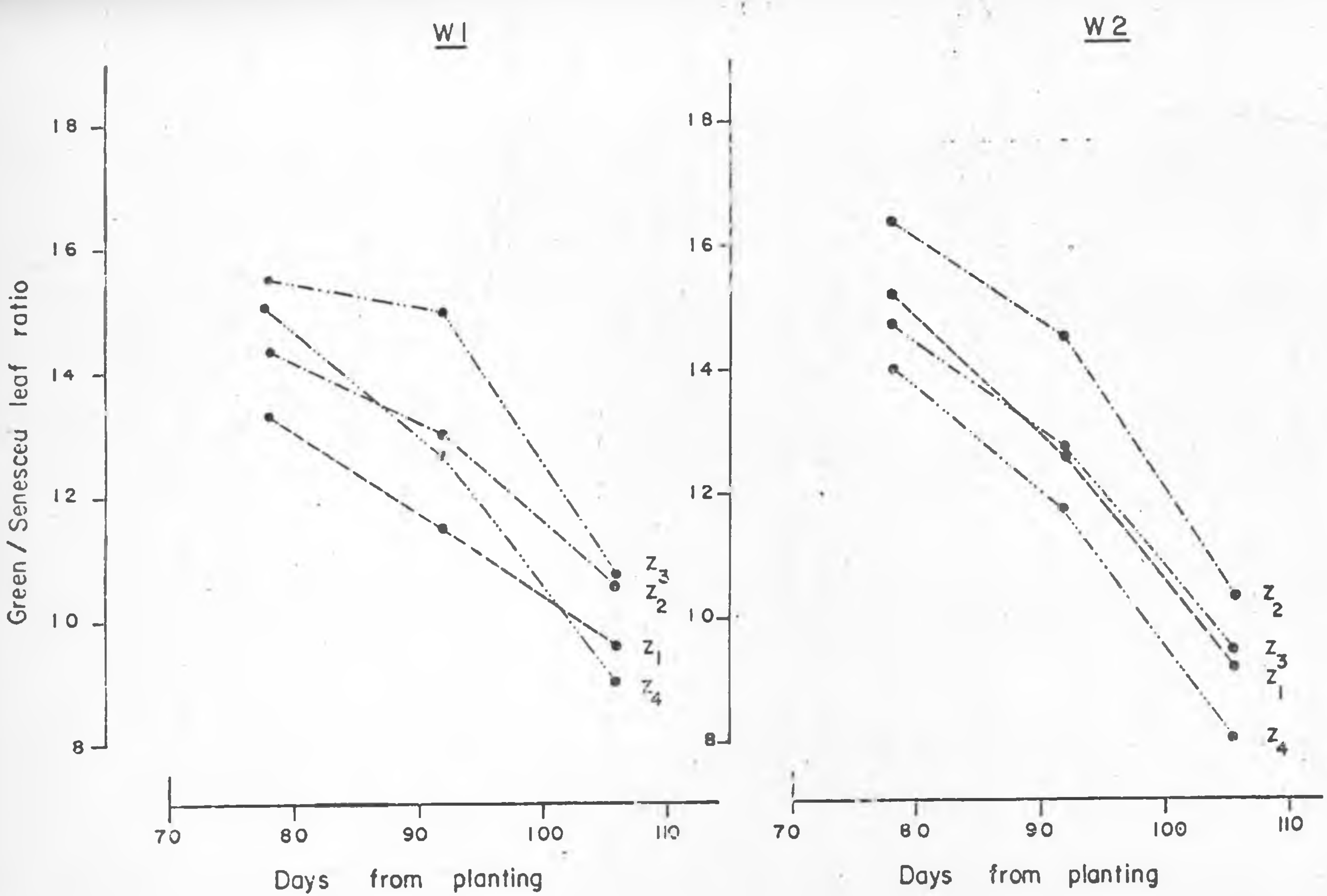

W1
W2
Green / Senesced leaf ratio
Days from planting
Z0
Z1
Z2
Z3
Z4

Figure 7: *Effect of competition on Green/Senesced leaf ratio of wild oats (Avena spp.) on dry weight basis.*



4.2.7. Effect of wild oat density on yield and components of yield.

Table 12 shows components of yield at final harvest. The effect of increasing wild oat density on production of fertile tillers per plant of wheat was to diminish the number of fertile tillers significantly (P = 0.05). At W_1 the number of fertile tiller were reduced by 6.9, 16.3, 32.6 and 51.2 per cent at wild oat densities Z_1, Z_2, Z_3 and Z_4 respectively. When wheat spacing was W_2 fertile tiller numbers per plant were reduced by 2.1, 16.7, 37.5 and 50 per cent at similar wild oat densities. Wheat spacing apparently had no significant effect on number of fertile tillers produced although at W_2, slightly more fertile tillers were produced.

Ear dry weight per plant progressively decreased with increasing wild oat density and the differences were significant (P = 0.05). Doubling wheat spacing did not affect ear dry weight although at W_2 ear dry weights were higher at all levels of wild oat density than the equivalents at W_1.

The pattern of grain yield per plant followed that of ear dry weight. Although grain yield decreased as density increased, increasing density from Z_3 to Z_4 depressed the yield but not significantly. At W_1 grain yields per plant were reduced by 18.9, 28.0, 36.1 and 44.5 per cent at wild oat densities Z_1, Z_2, Z_3 and Z_4, respectively. At W_2 the reductions were 17.8, 28.7, 32.1 and 43.7 per cent at the respective wild oat densities. Wheat spaced at W_2 had more yield that at W_1 and the difference was significant ($P = 0.05$).

Wild oat density and wheat spacing had no effect on the wheat grain weight per ear. However, they affected the number of seeds. Seed number per ear decreased as wild oat density increased and wider spaced wheat produced more seeds. 1000 grain weight was not affected by both wild oat density and wheat spacing.

TABLE 12. Effect of wild oat density on mean grain yield and components of grain yield.

ATTRIBUTES	Wheat spacing (cm)	Wild oat density per m^2 0	10	20	30	60	SEs and C.V.
No. of fertile Tillers/plant	2.5	4.3^{a}	4.0^{b}	3.6^{b}	2.7^{b}	2.1^{c}	SE(D) = 0.267
	5.0	4.8^{a}	4.7^{pb}	4.0^{pb}	3.0^{bq}	2.4^{cq}	SE(W) = 0.169 C.V. = 17.7%
Ear dry Weight (g) per plant	2.5	5.57^{a}	5.43^{q}	4.13^{mn}	3.87^{pn}	2.86^{p}	SE(D) = 0.476 SE(W) = 0.301
	5.0	6.67^{a}	5.53^{qn}	4.80^{mn}	4.13^{pn}	3.93^{p}	C.V. = 25.4%
Grain yield (g) per plant	2.5	4.07^{a}	3.30^{b}	2.93^{cd}	2.60^{de}	2.26^{e}	SE(D) = 0.173 SE(W) = 0.110
	5.0	4.67^{a}	3.84^{b}	3.33^{cd}	8.17^{de}	2.63^{e}	C.V. = 13.3%
No. of grains per ear	2.5	42^{a}	38^{ab}	36^{ab}	34^{ab}	32^{b}	SE(D) = 2.577 SE(W) = 1.630
	5.0	46^{a}	40^{ab}	37^{ab}	35^{ab}	33^{b}	C.V. = 16.9%
1000 grain weight (g)	2.5	23.23^{b}	21.80^{b}	21.63^{b}	21.16^{b}	21.76^{b}	SE(D) = 0.745 SE(W) = 0.471
	5.0	22.23^{b}	23.86^{b}	22.46^{b}	21.86^{b}	22.43^{b}	C.V. = 8.2%
Grain weight (g) per ear	2.5	0.88^{q}	0.90^{q}	0.81^{q}	0.76^{q}	0.69^{q}	SE(D) = 0.217 SE(W) = 0.137
	5.0	0.88^{q}	1.11^{q}	0.84^{q}	0.72^{q}	0.90^{q}	C.V. = 6.8%

Means in the same column at a particular date, followed by the same subscript letters are not significantly different (P = 0.05).

SE(D) = Standard error of wild oat density.
SE(W) = Standard error of wheat spacing.
C.V. = Coefficient of variation.

CHAPTER 5

5. DISCUSSION

5.1. Plant height

As shown in Table 1, experiment I and Table 6 experiment II, increasing wild oat density generally increased intra and interspecific competition resulting into decrease in wheat height at final harvest. It seems clear that wild oats have inhibitory effect on nearby wheat plants. They offer substantial competition for light, moisture and nutrients. Earlier work in Australia (Smith and Levick, 1974) indicated that wheat height decreased with increasing ryegrass (*Lolium rigidum* Gaud.) density when both species competed for nitrogen. Similarly, Blanco *et al.* (1973) working in Sao Paulo, found that weed competition reduced maize height by 36 per cent at final harvest.

In experiment I height of wheat variety "Kiboko" was reduced by 6.4, 10.8, 10.3 and 13.1 per cent at wild oat densities D_1, D_2, D_3 and D_4 respectively at W_1 wheat spacing. At W_2, densities D_1, D_2, D_3 and D_4 reduced the height by 5.1, 10.3, 13.1 and 16.3 per cent respectively. Although wild oat seeds germinated later and the plants failed to catch up with early maturing wheat plants, they were tall enough to shade many of the leaves of wheat. This, prevented the wheat plants from manufacturing enough photosynthates. This agrees with the findings of Thomas (1974) who grew maize with the weed R. exaltata L. at different densities in pot experiments and found that although R. exaltata L. were shorter than maize, they were able to shade most of the lower maize leaves.

In the present experiment, the greater competitiveness of wild oats suggested that it had the ability to exploit its environment better than its competitor. This could be explained by its higher tillering ability indicating that it absorbed and utilized more nitrogen than wheat, since nitrogen promotes tillering in cereals (Smith and Levick, 1974).

When "Kenya Bongo" a long maturing variety with high tillering ability than "Kiboko" was grown in experiment II, wild oat plants kept pace with it in growth in the initial stages until day 50 (Table 6). After this height superiority of wild oats became evident. At the initial stages of growth, the increasing height of both species with increasing densities can be explained in terms of light utilization. Denser stands initially have more rapid growth because they display more photosynthetic surface per unit area of ground following germination and thus synthesize more material. However, this situation did not persist. In subsequent growth period, this was reversed; wheat height decreased with increasing wild oat density and the latter gained superiority in height. This could suggest that the relative growth rate of plants in dense stands fell below that of sparse stands at an early growth stage and progressively declined thereafter. Donald (1951) similarly observed that as density increased, the growth stage at which competition became operative was relatively earlier. In this experiment competition began with the highest wild oat densities and later in the growth period the lowest densities became operative.

It is suggested that the height superiority of wild oats, subjected the community to competition for light. In a survey in Tunisia it was found that wild oats grew higher than wheat and competed successfully with them for light and nutrients (Anon, 1975). Similarly, Trenbath (1974) found wild oat height superiority over Avena strigosa L. In the present experiment, the greater number of leaves (27.5) and leaf dry weight (17.79g) per plant of wild oats compared to 17.4 leaves and 5.60g of leaf dry weight per wheat plant, for instance at day 106 as the overall average (Table 8 and 9) showed that wild oat plants had densely disposed leaves over wheat canopy and half way into the canopy. The leaves were possibly of greater area than those of wheat, thus achieving full exploitation of light. Black (1958) suggested that the domination by large seed subterranean clover (Trifolium subterraneium L.) swards over small seeded plants was due to competition for light because the former developed longer petioles and their leaves were held in advantageous position at a greater height, thus shading the small plants. The greater height of wild oat plants coupled with greater leaf number suggest that it successfully competed for moisture and nutrients particularly nitrogen, as abundant amount of both elements absorbed by plants promote luxuriant vegetative growth.

5.2. Tiller production per plant

Competition with wild oats reduced tiller numbers per plant of wheat as indicated in Table 2 and Table 7 for experiment I and experiment II respectively. This is in agreement with Burrows and Olson (1954) who found that wheat tiller numbers per plant decreased when wild mustard density was increased from 0 to 400 plants per m^2. Similarly, Blackman and Templeman (1937) reported reduced tiller numbers per plant of barley due to competition with Brassica arvensis L.

In experiment I, mean tiller production per plant of wheat continued to increase with time during the period of study. This might have been the effect of a wet period after a dry spell which promoted tillering. Nevertheless, the production of fewer tillers at high wild oat densities could possibly be explained by competition for nitrogen and light. The work of Aspinall (1961) showed that tillering in barley was directly related to the supply of nitrogen if water supply is not limiting. Similarly, Smith and Levick (1974) explained that the reduction of tiller numbers in wheat due to competition with Wimmer grass (Lolium rigidum Gaud.) was because of low nitrogen levels. On the other hand, the depressing effect of shading from wild oat plants reducing the amount of photosynthates manufactured by the leaves could not be ruled out. Reduction in tillering at high wild oat densities might have arisen directly from the shading of the lower portion of the culm. As can be expected, wheat spacing W_1 and W_2 had significant effect on the tillering ability of "Kiboko". At W_2, more tillers were produced than at W_1 in all wild oat free plots. Wild oat densities D_3 and D_4 depressed tillering more at W_1. The fewer plants per m^2 at W_2 in wild oat free plots was compensated by production of more tillers as a result of less intraspecific competition. The high reduction of tillers at W_1 with increasing wild oat densities is in agreement with the results of several workers (Puckridge and Donald, 1966; Puckridge and Rotkowsky, 1971 ; Puckridge, 1968) who reported decreased wheat tillering with increasing density. Puckridge (1968) found that when wheat was grown at high density, 1150 plants per m^2 with adequate nutrients and water the plants produced no tillers. He suggested that this was an effect of intraspecific competition for light. The results in the present study suggested that wheat grown at W_1 suffered both intra and interspecific competition for water, nutrients and light depressing tiller production per plant.

In the second experiment, however, "Kenya Bongo", a more tillering variety than "Kiboko" was grown with adequate fertilizer. Increasing wild oat density depressed the tillering of this variety (Table 7) and the severity of competition increased with time. For example at day 92, and afterwards wheat tillering was depressed by wild oat density even as low as 10 plants per m^2. The onset of competition was earlier with high wild oat densities. This agrees with Weaver and Clements (1938) who reported that the onset of competition for light in sunflower was earlier at high densities. It is suggested that the height superiority of wild oat plants discussed earlier, subjected the wheat plants to severe competition for light, shading the wheat plants. Friend (1965) artificially shaded wheat plants and showed that reduced tillering was a result of increased shading.

The effect of wheat spacing (W_1 and W_2) on tillering was significant only when wild oat density reached Z_3 and Z_4 in both cases. At W_2, wheat produced significantly more tillers at Z_3 and Z_4. Although at W_2 wheat had more tillers at low wild oat densities Z_1 and Z_2 and in wild oat free plots, the differences were not spectacular in all sampling periods. The high tillering ability of "Kenya Bongo" resulted in early intra-plant competition for light, moisture and nutrients depressing tiller production. This was intensified by interplant competition in wheat grown at W_1.

Wild oats in both experiments appeared to suffer little as density increased (Table 2 and 7). Wild oat density did not have consistent influence on its tillering ability. This might be due to the arrangement of the wild oat plants in the community. The inter-row position of the wild oat plants in respect to wheat could have permitted the feeder roots to spread laterally. They therefore exploited the environment more efficiently before the roots met with the roots of the neighbouring wild oat and wheat plants. Kees (1975) showed that wild oat tillering was more influenced by intraspecific competition if they were closely spaced than by competition from the crop.

5.3. Dry weight per plant

Competition reduced leaf, stem and total dry weight of wheat but wild oats did not suffer any specific pattern of dry weight change in experiment I (Table 4 and 5). A similar trend was followed in experiment II for stem and leaf dry weight (Table 8, 10; Fig. 2 and 3). As with plant height discussed earlier, decreased dry matter production could have been due to competition for light, nutrients and water. The interactions of competition for environmental resources enables the successful species to acquire a continuously increasing share of each factor to increase its dry matter yield. When wild oats competed with wheat, it probably had its prime effect through reducing the concentration of light,nutrients and water to the weaker competitor. Alternatively, absorption ability and efficiency of utilization of resources available for the two species might differ even if mineral nutrient and water content of the soil were adequate. Bowden (1971) reported that wild oats absorbed up to three times as much water and utilized about twice the amount of nitrogen and phosphate compared with cultivated oats. It is possible that wilt oats in these experiments had similar effects while competing against wheat. This may be due to the possibility that wild oats might have interfered with root development and mineral nutrition of the crop, and in later stages hindered sunlight interception due to increased plant density. Pavlychenko and Harrington (1935) compared the growth of wheat sown at ordinary rates free from weeds, with wheat seeded in drills and wild oats planted between rows as in the present experiments. Root systems were excavated at 5, 22, 40 days and at maturity. The results showed that wild oats suppressed root development of the cereal. The ability of the crop to attain maximum dry matter may have therefore been impared. The success of wild oats in accumulating dry matter rapidly would also be due to the efficiency of its photosynthetic surface. The slow rate of wild oat leaf senescence compared to wheat (Table 11, Fig. 6 and 7) implied that it had a longer duration of leaf surface able to photosynthesise and consequently greater ability to compete for growth factors. Thurston (1959) found that net assimilation rate of wild oats in early stages of growth was greater than that of cultivated cereals. She suggested that this made the plants to accumulate dry matter more rapidly than other cereals. On the other hand, Cannell (1967) reported that although wild oats had a higher net assimilation rate than cultivated oats, it did not catch up with the dry matter attained by cultivated oats. He attributed this to the fact that the cultivated oats did not suffer intraspecific competition, and therefore were not restricted in growth. This suggests that different crop species can resist the effects of a weed species to different extents.

5.4. Ratio between green and senesced leaf

The deteriorative processes which naturally terminate the functional life of plant leaves is called senescence. The higher the rate of senescence the lower is the ratio between green and senesced leaf.

The effect of wold oat density of wheat was to reduce the ratio of green to senesced leaf (Table 11 and Fig. 6). This indicated that there was faster leaf senescence at high than at low wild oat densities. This could have been a direct effect of the shading of wheat plants by wild oats which were superior in height and had numerous leaves as mentioned earlier. Because of the insufficient amount of sunlight they received, the photosynthetic rates of the shaded wheat leaves were possibly reduced below their respiration rates resulting in senescence. Wheat spacing appeared to have little effect on leaf senescence although at W_1 leaf senescence in wheat was slightly higher than at W_2 due intra-plant competition. The insignificant effect of spacing could have been as a result of increased tillering at W_2 which compensated for the fewer number of plants, resulting in increased shading within the plant, thereby increasing the rate of senescence to a level similar to that of W_1.

The situation was different with wild oat plants. The pattern of leaf senescence was not consistent with increasing density. The later commencement of leaf senescence in wild oat plants and maintenance of high ratio between green and senesced leaf showed that they were less subjected to shading (Table 11 and Fig. 7). It might be because of the inter-row position of the wild oats in respect to wheat plants which reduced shading of lower leaves at the initial stages of growth. Only when both species grew bigger and complete canopy was established, did leaf senescence start in wild oat plants.

5.5. Effect of wild oat density on the yield and yield components of wheat variety "Kenya Bongo"

Grain yield depends on the number of fertile tillers and grain number per head a cereal crop can produce. The weight of grains so formed determines the eventual yield per plant. When environmental resources are adequate without competing plants for the same resources in the neighbourhood, the plant will approach the potential yield. As competition sets in, the yield of the plant decreases in proportion to the intensity of the competition.

In the present study as indicated in Table 12, the number of fertile tillers, ear dry weight, number of grains and grain yield per plant of wheat variety "Kenya Bongo" decreased with increasing wild oat density. The grain weight per ear and 1000 grain weight were, however, not affected as competition from wild oats increased. Rees (1975) concluded that the yield of wheat per plant was reduced by presence of annual ryegrass (Lolium rigidum Gaud.)mainly by reducing the number of fertile tillers. Blackman and Templeman (1937) observerd similar effects when barley competed with Brassica arvensis L. Wild oat competition with wheat in this experiment appeared to affect wheat yield mainly during head formation, reducing the number of fertile shoots, ear dry weight and finally grain yield per plant. It seems clear that photosynthetic assimilates were probably not sufficient to cater for head formation. Partitioning of the limited assimilates among tillers gave rise to severe competition within the plant unit itself thereby rendering some tillers infertile. Similarly, ear dry weight was reduced. It was also observed that plants grown at high wild oat densities produced smaller heads and fewer grains per head. However, the grain weight per ear and 1000 grain weight were not affected possibly because the fewer grains per ear received greater share of photosynthetic assimilates and compensated for the loss by attaining greater weight. These results are in agreement with the work of Enyi (1973) who found that weeding increased the number of grains and weight per unit length of ear of sorghum. Similarly, Evetts and Burnside,(1973) reported that when sorghum competed with milkweed (Asclepia syriaca L.), grain number per head was significantly affected with no effect on 500-seed weight. It should be recognized that reducing intra-specific competition among wheat plants by double spacing increased the number of fertile tillers, ear dry weight, grain yield per plant and number of grains per ear but did not have any significance at all levels of wild oat density. Many crop scientists including (Friesen and Shebeski, 1960; Pavlychenko and Harrington, 1934; Chancellor and Peters, 1974) have reported yield reductions in cereal crops due to the presence of wild oats. Their findings revealed that the level of density at which cereal yields were significantly depressed varied with soil type, nutrient status of the soil and type of crop. Bowden and Friesen (1967) found that 12-47 wild oat plants per m^2 were sufficient to cause significant yield reductions in wheat grown in summer fallow land or when fertilizer was added to stubble land. Without the fertilizer treatment 82-117 wild oat plants per m^2 were required to suppress wheat yields significantly. It may therefore be speculated that application of fertilizer in the present experiment improved the general vigour of the wild oats so that as low as 10 plants per m^2 significantly reduced wheat yield per plant by 18.9 and 17.8 per cent for W_1 and W_2 spacing respectively. The severity of reduction in the yield was possibly intensified by shortage of growth factors available for the crop. This suggests that fertilizer should be banded rather than broadcast, so that only the rows of wheat receive the fertilizer. This would decrease the vigour of wild oat growth.

5.6. Other effects of wild oats

Besides affecting wheat growth and yield, wild oats have other undesirable characteristics. When wild oats were grown with "Kiboko", a short maturing wheat variety, the crop would have been harvested before the wild oats started flowering had it not been for bird damage. This would have hampered mechanical harvesting by combine on large scale farms. The greenness of the wild oats at the stage of harvest could prevent efficient drying of the grains, consequently resulting in reduced quality and down grading of the seeds.

In experiment II, at final harvest, the earlier wild oat seeds to mature had already fallen to the ground. A general observation by Holm et al. (1977) showed that wild oat seeds often fell to the ground before cereal crops were harvested. Such a behaviour of wild oat seeds can give a seed return to the soil to give heavy infestations during the next crop season. Haddow (1978) reported that in the United Kingdom the heaviest infestations of wild oats could give a seed return to the soil of up to 60,000 seeds per m^2. Apart from soil infestation by seeds, harvesting by combine would heavily contimate wheat grains amounting to rejection of the grains if grown for seed.

Lastly, lodging reported earlier at wild oat densities Z_3 and Z_4 would result to severe field losses.

CHAPTER 6

6. SUMMARY AND CONCLUSIONS

The experiments were designed to study the effect of varying wild oat densities on two varieties of wheat; "Kiboko" and "Kenya Bongo". In each experiment two spacings were used for wheat plants.

Generally, the results of the experiments indicated that the growth of both wheat varieties decreased with increasing wild oat density at both wheat spacings and the onset of competition was earlier in plants grown with high wild oat densities. However, some growth parameters were more affected than others. For instance, in experiment I, wheat height, tillering, leaf number and stem dry weight were significantly reduced while total and leaf dry weight were reduced but not significantly.

Wild oats density though reduced wheat height in experiment II, had no significant adverse effect until final harvest when its effect became significant but reduced tiller numbers, leaf numbers, stem and leaf dry weight per plant and the ratio of green to senesced leaf. Competition significantly reduced grain yield per plant as a result of reduced ear weight and number of grains per ear. Nevertheless, 1000 grain weight was unaffected by competition.

The effect of varying wheat spacing was less pronounced. Widely spaced wheat suffered less reduction in growth. Tillering, as would be expected, was the only growth parameter significantly affected in both experiments.

Growth performance of wild oats in competition with wheat was not consistent with increase in its own density. It appeared to withstand population pressures and to compete for environmental resources better than wheat, at least within the limits of densities examined in both experiments. The greater height, numerous leaves and tillers it produced compared to wheat plants, possibly because of its greater competitiveness, might have limited light penetration into the wheat canopy, resulting in earlier senescence of wheat leaves.

Owing to its ability to compete better for nutrients, moisture and light than wheat, thereby reducing yileld, it appears that wild oats, if not concentrolled, is likely to limit wheat farming in Kenya in the near future. Worse still, its undesirable effects of contaminating grain would certainly impede wheat growing for seed, which demands a high standard of purity.

CHAPTER 7

7. SUGGESTIONS FOR FURTHER RESEARCH

Wild oat is a noxious weed of cereal crops such as wheat, barley and oats. It is only becoming a problem in these crops in Kenya during five years or so and has therefore not received the attention of many research workers. The present research has just looked into an aspect of wild oat competition with two varieties of wheat commonly grown in Kenya. It is therefore suggested that the following still remain fertile area for further research work:-

(a) Species identification

Apparently, wild oat species presently existing in wheat farming areas of Kenya are not known. It is therefore appropriate to identify and know which species are more prevalent and more adapting to the Kenyan conditions so that one knows what species one is dealing with.

(b) Photosynthetic efficiency, nutrient and water absorption ability

Further research into photosynthetic efficiency, nutrient and water absorption ability of wild oats as compared to various varieties of wheat in Kenya could elucidate the competitive ability of wild oats.

(c) Productivity of wild oats in pure and mixed stands

The present research did not seek to find the productivity of wild oats in pure stands as compared to that in mixtures. Whether wheat has any effect on wild oat seed production ability and to what degree it is liable to intraspecific competition would be elucidated by further research.

(d) Other crops in rotation

It is of more practical value to gear research on the possibility of controlling wild oats. Rotation is one of the cultural practices for weed control. It is suggested that after two or three consecutive wheat crops, such crops like rapeseed could be tried in rotation.

(e) Research in wheat growing areas

Climatic conditions in Kenya are diverse even in wheat growing areas moisture regimes vary. Further research on wild oats should also be tried in high altitude areas where most wheat is grown.

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APPENDIX A

EXPERIMENT I. Analysis of variance for mean square values of various biological characters of wheat plant grown at 2 densities and 5 wild oat densities.

Days from planting	Source of variation	Degrees of freedom	Plant height	No. of tillers/ plant	Leaf dry wt/plant	Stem dry wt/plant	No. of leaves/ plant	Total dry wt/plant
	Total	29						
	Block	2	157.552	0.56[illegible]4	0.079	0.0206	4.8324	0.2549^{NS}
	Treatment	9	19.0332^{NS}	2.0212**	0.1329^{NS}	0.3194*	21.8972*	0.2973^{NS}
45	Wild oat density	4	35.3755^{NS}	3.3282**	0.1678^{NS}	0.5762**	42.6858*	0.538^{NS}
	Wheat spacing	1	0.9013^{NS}	2.7378**	0.507^{NS}	0.4941*	14.5604*	0.406^{NS}
	Interaction	4	7.2233^{NS}	0.5351^{NS}	0.0045^{NS}	0.0189^{NS}	2.9426^{NS}	0.0292^{NS}
	Error	18	22.1505	0.2814	0.094	0.0730	6.8290	1.7299
	Total	29						
	Block	2	44.72	2.4223	0.1332	0.0099	2.197	1.7025
60	Treatment	9	59.8359 *	3.5992**	0.0808^{NS}	0.0289	26.049**	0.2410^{NS}
	Wild oat density	4	117.1768*	6.783**	0.1518^{NS}	0.0613*	48.7825**	0.3211^{NS}
	Wheat spacing	1	2.4633^{NS}	4.408**	0.0413^{NS}	0.0073^{NS}	22.707*	0.3991^{NS}
	Interaction	4	16.8383^{NS}	0.2133^{NS}	0.0198^{NS}	0.002^{NS}	4.1512^{NS}	0.1214^{NS}
	Error	18	21.1982	0.3420	0.0491	0.0067	4.1922	0.3582

* = Significant at 5% level.　　NS = Non significant.

** = Significant at 1% level.　　These apply to all subsequent Anova tables.

Appendix A.(Contd...)

			Plant height	No. of tillers/ plant	Stem dry wt/ plant
	Total	29			
	Block	2	12.10	6.727	1.084
	Treatment	9	50.6467*	4.578*	2.0599*
80					
	Wild oat density	4	93.8625**	7.7055*	4.0889*
	Wheat spacing	1	72.387^{NS}	8.533**	0.9720^{NS}
	Interaction	4	1.9958^{NS}	0.4626^{NS}	0.3028^{NS}
	Error	18	11.4500	1.8840	0.7555

APPENDIX B

EXPERIMENT I. Analysis of variance for mean square values of various biological characters of wild oats (*Avena* spp.) grown at 5 densities mixed with 2 densities of wheat.

Days from planting	Source of variation	Degrees of freedom	Plant height	No. of tillers/ plant	No of leaves/ plant	Total dry wt/ plant
	Total	23				
	Block	2	19.0417	13.323	141.4157	0.0777
45	Treatment	7	32.10^NS	2.5914^NS	7.2367^NS	0.1317^NS
	Wild oat density	3	49.7645^NS	3.9855^NS	11.9039^NS	0.5697^NS
	Wheat spacing	1	18.3751^NS	1.2399^NS	0.9039^NS	0.1634^NS
	Interaction	3	19.0105^NS	1.6479^NS	4.673^NS	0.6293^NS
	Error	14	20.4807	3.6277	3.6183	0.8227
	Total	23				
	Block	2	69.6557	0.3467	25.2257	2.317
60	Treatment	7	20.2410^NS	30.27^NS	316.6357^NS	1.0976
	Wild oat density	3	13.6339^NS	69.8893^NS	652.246^NS	0.3324
	Wheat spacing	1	0.35083^NS	0.7004^NS	33.3633^NS	2.3648^NS
	Interaction	3	33.4781^NS	0.5072^NS	102.4495^NS	0.9973
	Error	14	12.2744	8.8362	164.5785	0.5821

APPENDIX C

EXPERIMENT II. Analysis of variance for mean square values of various Biological characters of wheat plant grown at two densities in association with 5 wild oat densities.

Days from planting.	Source of variation.	Degrees of freedom.	Plant height	No. of tillers/ plant.	Leaf dry wt/plant.	Green/senesced leaf ratio	No. of leaves/ plant.
	Total	29				3.031	
	Block	2	117.005	1.1364	0.0436	11.6676*	18.441
	Treatment	9	27.691*	6.547**	0.563*	22.6895*	72.986*
50	Wild oat density	4	50.5859**	13.3835**	1.1577**	9.6333 NS	150.6451**
	Wheat spacing	1	43.6803*	3.0271*	0.2803 NS	1.1542 NS	47.8797 NS
	Interaction	4	0.7991 NS	0.7141 NS	0.1399 NS		1.6041 NS
	Error	18	10.0676	0.9119	0.2009	2.8599	14.9292
	Total	29					
	Block	2	149.295	1.7924	0.1014	5.2464	27.173
64	Treatment	9	1.74 NS	7.36*	2.0582*	8.735**	72.004*
	Wild oat density	4	3.7375 NS	14.8188**	4.333**	18.6229**	149.0675**
	Wheat spacing	1	0.087 NS	4.8804*	0.5118 NS	1.728 NS	27.7067 NS
	Interaction	4	0.1558 NS	0.5212 NS	0.1699 NS	0.5988 NS	6.0141 NS
	Error	18	8.1539	2.8827	0.4797	0.8604	24.3301

Appendix C.(Contd...)

			Plant height	No. of tillers/ plant	Leaf dry wt/plant	Stem dry wt/plant	Green/senesced leaf ratio	No. of leaves/plant
	Total	29						
	Block	2	79.845	0.8185	0.9666	0.1704	0.3824	5.5095
78	Treatment	9	15.642^{NS}	7.519**	2.7112*	0.0068^{NS}	1.1036*	25.7387**
	Wild oat density	4	26.8063^{NS}	14.9316**	5.3511**	0.0131^{NS}	2.3138**	56.9168**
	Wheat spacing	1	24.4873^{NS}	5.9833*	2.3367^{NS}	0.0021^{NS}	0.30^{NS}	0.6753^{NS}
	Interaction	4	9.0717^{NS}	0.49^{NS}	0.1907^{NS}	0.0017^{NS}	0.0941^{NS}	0.8266^{NS}
	Error	18	22.223	0.7746	0.559	0.1815	0.2134	2.1630
	Total	29						
	Block	2	159.665	0.3944	3.6907	0.2893	0.225	58.8465
92	Treatment	9	26.4789^{NS}	6.8337**	5.093*	0.4216*	0.3559*	8.9623*
	Wild oat density	4	43.7768^{NS}	12.9562**	11.0812**	0.9101**	0.7678*	16.093*
	Wheat spacing	1	23.767^{NS}	5.8964*	0.0711^{NS}	0.0886^{NS}	0.075^{NS}	0.1836^{NS}
	Interaction	4	9.859^{NS}	0.9455^{NS}	0.3603^{NS}	0.0162^{NS}	0.0142^{NS}	0.1836^{NS}
	Error	18	17.7839	0.9188	0.6596	0.1164	0.1539	5.1897

Appendix C.(Contd..)

		df	Plant height	No. of tillers/ plant	Leaf dry wt/plant	Stem dry wt/plant	Green/senesced leaf ratio	No. of leaves/plant
	Total	29						
	Block	2	9.89	0.8564	6.859	2.4224	0.0503	7.2334
	Treatment	9	30.241^NS	5.3052*	6.2815*	3.4989*	0.6311*	16.128*
106	Wild oat density	4	54.2958^NS	10.328**	12.703**	6.3281**	1.2409*	33.4072**
	Wheat spacing	1	53.0733^NS	4.4084*	2.1924^NS	5.5298*	0.2254^NS	5.6334^NS
	Interaction	4	0.4784^NS	0.5067^NS	0.8822^NS	0.1622^NS	0.1227^NS	1.4725^NS
	Error	18	29.6778	1.7030	1.2138	1.0083	0.1637	3.4644
	Total	29						
	Block	2	24.42	0.569	-	-	-	-
158	Treatment	9	31.6474*	6.0602**	-	-	-	-
	Wild oat density	4	67.0608**	11.6867**	-	-	-	-
	Wheat spacing	1	12.807^NS	7.0083**	-	-	-	-
	Interaction	4	0.7443^NS	0.1967^NS	-	-	-	-
	Error	18	10.7274	0.6786	-	-	-	-

APPENDIX D

EXPERIMENT II. Analysis of variance for mean square values of various Biological characters per plant of wild oats grown in association with wheat.

Days from plan-ting	Source of variation	Degrees of freedom	Plant height	No. of Tillers/ plant	Leaf dry wt/plant	Stem dry wt/plant	No. of leaves/ plant
	Total	23					
	Block	2	472.6663	1.9154	2.5929	-	314.5806
50	Treatment	7	59.4171^{NS}	3.991^{NS}	0.5271^{NS}	-	83.02^{NS}
	Wild oat density	3	5.5433^{NS}	6.8999^{NS}	0.4215^{NS}	-	141.9783^{NS}
	Wheat spacing	1	51.6267^{NS}	0.4817^{NS}	1.2604^{NS}	-	104.5842^{NS}
	Interaction	3	115.8877^{NS}	2.2639^{NS}	0.3682^{NS}	-	16.8736^{NS}
	Error	14	105.1548	2.0726	0.6567	-	65.1049
	Total	23	-	-	-	-	
	Block	2	-	-	-	0.0913	
64	Treatment	7	-	-	-	0.221^{NS}	
	Wild oat density	3	-	-	-	0.1889^{NS}	
	Wheat spacing	1	-	-	-	0.0417^{NS}	
	Interaction	3	-	-	-	0.3128^{NS}	
	Error	14	-	-	-	0.2022	

Appendix D. (Contd..)

			Plant height	No. of tillers/ plant	Leaf dry wt/plant	Stem dry wt/plant	Green/Senesced leaf ratio	No. of leaves/ plant
	Total	23						
	Block	2					22.085	-
78	Treatment	7					2.1319	-
	Wild oat density	3					1.235	-
	Wheat spacing	1					1.6017	-
	Interaction	3					3.1613	-
	Error	14					7.0517	-
	Total	29						
	Block	2	13.144	15.4317	276.4004	14.3007	6.2888	55.8767^{NS}
106	Treatment	7	63.0743^{NS}	2.3598^{NS}	47.1961^{NS}	2.9294^{NS}	8.4188	78.8967^{NS}
	Wild oat density	3	81.3944^{NS}	1.6961^{NS}	34.4660^{NS}	2.5429^{NS}	13.8628^{NS}	91.1218^{NS}
	Wheat spacing	1	61.7583^{NS}	7.7067^{NS}	63.7^{NS}	2.8021^{NS}	0.0067^{NS}	40.8212^{NS}
	Interaction	3	45.1928^{NS}	1.2411^{NS}	54.4250^{NS}	3.3582^{NS}	5.7789^{NS}	59.5225^{NS}
	Error	14	28.5416^{NS}	2.8083	31.0597	3.4785	8.5673	77.4862

APPENDIX E

EXPERIMENT II. Analysis of variance for mean square values for wheat yield and yield components .

Sources of variation	Degrees of freedom	Grain wt/ ear	Ear dry wt/plant	1000 Grain weight	Grain yield per plant	No. of seeds/ ear	No. of fertile tillers/plant
Total	29						
Block	2	0.0739	1.2844	24.6095	0.097	130.3	1.2304
Treatment	9	0.0424^{NS}	3.6684*	1.9328^{NS}	1.5309**	56.2556^{NS}	3.8537*
Wild oat density	4	0.0591^{NS}	6.7503*	1.7613^{NS}	3.0722**	120.4500*	7.5987*
Wheat spacing	1	0.0282^{NS}	5.2083^{NS}	3.2017^{NS}	0.2813^{NS}	32.0333^{NS}	0.4083^{NS}
Wild oat density x Wheat spacing	4	0.0293^{NS}	0.2017^{NS}	1.7871^{NS}	0.0218^{NS}	2.6167^{NS}	0.4699^{NS}
Error	18	0.0157	1.3618	3.3334	0.17996	39.8556	0.4292

* = Significant at 5% level

** = Significant at 1% level

NS = Non significant .