TOLERANCE OF WHEAT AND BARLEY AT DIFFERENT STAGES OF GROWTH TO 2,4-D SPRAYS

By

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2,4-D ON WHEAT AND BARLEY

ULLAH

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Title: Tolerance of wheat and barley at different stages of growth to 2,4-D sprays.

Wheat and barley were sprayed with 500, 1000, 2000, 4000, and 8000 ppm (a.e.) of the butoxy ethanol ester of 2,4-D (Weedone Lv-6, 62.5% acid equivalent), at the three-leaf, five-leaf, jointing (in wheat only) booting-to-heading (in barley only), anthesis, soft dough, and the ripe grain stages of growth. Hand weeded and unweeded check plots were included in each replication. The experiments were conducted at the Agricultural Research and Education Center, in the Beqa'a plain, Lebanon, during 1966-67. Phytotoxicity notes were taken on both crops. Data on plant height, grain and straw yield, 1000-kernel weight, test weight, germination percentage, protein percentage, and protein yield were recorded.

All the concentrations used were phytotoxic at the three-leaf stage; whereas, at the five-leaf, jointing, and booting-to-heading stages, only 4000 and 8000 ppm produced phytotoxic effects, and caused lodging in the two crops. Reductions in plant height were significant at all concentrations used, in the case of barley, and at 1000 ppm and above in the case of wheat. The 8000 ppm treatment, applied at the jointing and anthesis stages, caused significant reductions in the grain yield of wheat; whereas in the case of barley, significant reductions in the grain yield were observed at concentrations ranging from 2000 to 8000 ppm, sprayed at the three-leaf, booting-to-heading, and anthesis stages. At the five-leaf stage, the 1000 ppm treatment gave a highly significant increase of 18.7% in the grain yield over the unweeded check. Significant reductions in the 1000-kernel weight and test weight of the two crops were observed only at the higher concentrations used.

The protein percentages of wheat and barley seeds were significantly increased as a result of the application of 2,4-D at 2000 to 8000 ppm, sprayed at the three-leaf, jointing, booting-to-heading, and anthesis stages of growth; However, significant reductions in the protein yield of the two crops were observed at these treatments. No significant effects were observed on the straw yield, and germination percentages of both wheat and barley as a result of 2,4-D applications at the various stages of growth.

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I. INTRODUCTION

Wheat and barley are considered as two of the major food and feed crops of the world. They are adapted to a wide range of soil and climatic conditions. In Lebanon, the climate of the Beqa'a plain is suitable for their production. According to the Agricultural Economics and Statistics Department of the Ministry of Agriculture, 764,000 dunums of wheat, and 135,000 dunums of barley were planted in Lebanon in 1965.

Weeds cause serious problems in most lands devoted to wheat and barley production. They compete with these crops for light, soil moisture, and nutrients resulting in reductions in the yield, and quality of cereals. Consequently weed infestations result in economic losses to producers. The problem of water shortage in Lebanon and the Middle East, due to the inadequate amount and distribution of rainfall, accentuates the problem of weed competition and sets the stage for the use of weed control methods.

Hand weeding was the only method employed by local growers to control weeds in small grains. Recently 2,4-dichlorophenoxy acetic acid (2,4-D) has been introduced in Lebanon, on a limited scale, as a weed killer for the selective control of broad-leafed weeds in wheat and barley.

The herbicidal effectiveness of 2,4-D varies with the formulation and concentration used, crop species sprayed, the time and the method of application, soil type and the environmental conditions such as temperature, humidity and rainfall. Therefore, due to the variations in these factors, it is necessary to investigate the effects of this herbicide under local conditions.

Several studies were made in Lebanon on the effects of 2,4-D on weeds. However, very little work was done on the tolerance limits of small grains to 2,4-D sprays. Therefore, the present study was undertaken to investigate only the tolerance of wheat and barley to 2,4-D sprayed at different stages of growth, with no emphasis on the extent of weed control. The butoxy ethanol ester of 2,4-D was applied in five concentrations at six stages of growth of wheat and barley, starting from the three-leaf stage upto the ripe grain stage just prior to harvesting. Phytotoxicity effects were studied on both crops. Data on plant height, grain and straw yield, 1000-kernel weight, test weight, germination percentage, protein percentage, and total protein yield were recorded. The experiments were conducted at the Agricultural Research and Education Center (AREC) of the American University of Beirut during 1966-67. The chemical analyses were carried out in the Agronomy Research Laboratory at the American University of Beirut (A.U.B.) during 1968.

II. REVIEW OF LITERATURE

The first note on 2,4-dichlorophenoxy acetic acid (2,4-D)[1] was reported by Pokorny (1941), who outlined a simple method for its preparation in the laboratory without making any reference on its use as a herbicide. In 1942, Zimmerman and Hitchcock, as reviewed by Klingman (1961, pp 124-125), were the first to describe the use of 2,4-D as a plant growth regulator. The selectivity of 2,4-D was first reported by Marth and Mitchell (1944). They mentioned that 2,4-D killed a dense stand of dandelions (Taraxacum officinales), Plantains (Plantago lanceolata), and other broad-leafed weeds which were growing in a Kentucky blue grass lawn, without giving any apparent injury to the grass.

Since 1944, considerable literature has accumulated on the selective control of broad-leafed weeds in cereals and other grasses. While cereals are generally considered tolerant to 2,4-D, they may be affected by the application of high concentrations of the chemical, when sprayed at a certain sensitive stage of growth. Such a susceptibility may result in serious reductions in the yield and quality of the crop. Because of these factors, the available literature on the mode of action of 2,4-D, and its effects on wheat and barley is reviewed.

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1. Structural formula of 2,4-D is cited in Appendix "A".

Mode of Action of 2,4-D

The herbicide 2,4-D is a hormone-like chemical which has been classified as a selective, translocated, and foliage applied herbicide. It differs from the natural indole auxins in that it is far more active, and persists for a longer period of time in the plant.

The complete action of a herbicide, as pointed out by Crafts (1961, pp 59) "may involve penetration, absorption by cells, migration to the vascular channels, translocation, and finally a toxic action usually involving a living protoplasm".

Absorption

Crafts (1961, pp 33-39) pointed out that there are two distinct routes for the entry of a herbicide applied to the foliage. The first is the lipoid route accross the cuticle, and the second is the acqueous route through the stomata. There is evidence that 2,4-D penetrates the leaf via the cuticle in the form of the undissociated parent acid molecule.

Translocation

Having penetrated the cuticle, the herbicide molecule must move from the lipoidal medium to enter the living mesophyll cells. Mitchell and Brown (1945, pp 405-407) noted that translocation of 2,4-D did not occur from young rapidly growing leaves, or leaves whose sugar content was relatively low. Jaworski *et al*. (1955) reported that the export of C^{14} labelled 2,4-D from leaves to stems of etiolated bean seedlings was promoted by the application of sucrose and glucose. Their observations support the work of previous investigators, who found that for adequate translocation of 2,4-D, production and translocation of photosynthates should be active.

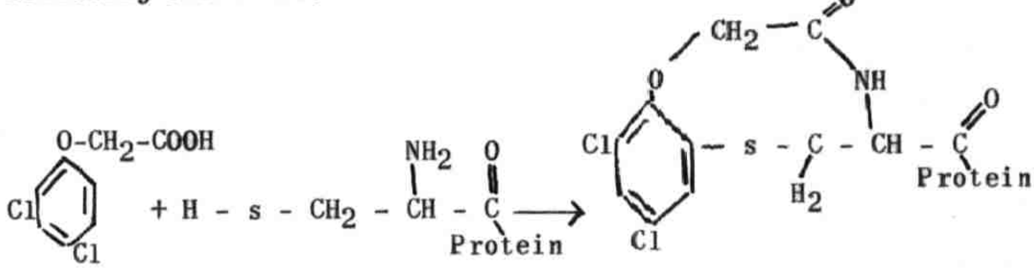
The two tissue systems, by which herbicides may be distributed into the different plant parts, are the xylem and the phloem. Crafts (1956, pp 345-347), and Crafts and Yamaguchi (1958, pp 433-438) provided much evidence that the export of 2,4-D from leaves takes place via the phloem tissue along the assimilate stream. The direction of translocation is determined by the pattern of food distribution within the plant. Such movement usually takes place from regions of food synthesis to regions of food utilization.

Gallup and Gustafson (1952) observed that radioactive 2,4-D translocated very slowly in cereals as compared to beans and sunflowers. They suggested that the reason for the lower rate of translocation in the case of monocotyledenous plants was partly due to a block in the intercalary meristems of the leaves. Similar observations of slower translocation of carboxyl C^{14} labelled 2,4-D in corn and wheat were reported by Fang and Butts (1954). They also suggested that the blockage of the intercalary meristems in the case of these plants is the cause for the differential translocation of 2,4-D. This contributes to the relative resistance of monocotyledenous plants to the hormone-like herbicide. It has been shown by Crafts and Yamaguchi (1958, pp 433-438) that 2,4-D may accumulate in the living parenchyma cells, and translocation may become limited.

<u>Toxic Action</u>

The available literature does not emphasize any single mechanism of toxic action of 2,4-D. On the other hand the wide range of physiological and biochemical responses, and the great array of plants that respond to 2,4-D, suggests that apparently more than one mechanism may be involved.

Muir et al. (1949) reported that substitution of both ortho positions on the benzene ring caused a complete loss of the growth activity of 2,4-D. Based on this observation, Muir and Hansch (1951), and Hansch et al. (1951) postulated a two-point ortho-reaction hypothesis for the mode of action of 2,4-D. According to this mechanism, 2,4-D molecule reacts with a cysteinyl unit of a protein at two points, resulting in the formation of a complex which has the following structure.



2,4-D Cysteinyl unit of a protein Complex

This complex is capable of exerting its physiological effects on sensitive crops. The blocking of the sulfhydryl group (-SH) inactivates the succinic dehydrogenase enzyme which results in the blocking of the Kreb's cycle.

Crafts (1953, pp 268-269) showed that 2,4-D may affect the equilibrium between tryptophan content and its transformation to protein or auxin, thus resulting in growth aberrations. It was pointed out by Crafts (1953, pp 265) that one characteristic effect of 2,4-D is its disturbance of the normal process of differentiation. Weintraub (1953) reported that 2,4-D activated the enzyme indole acetic acid oxidase, and as such lowered the level of endogenous auxins in bean plants. Reduction in the optimum levels of auxin results in unpolarized cell division, abnormal growth and ultimately plant death. Van overbeek, as discussed in Audus (1964, pp 387-390), pointed out that 2,4-D, being a highly persistent hormone, inhibits the normal fluctuations in the endogenous auxin levels, which are necessary for the normal growth and differentiation of plant tissues and organs.

Eames (1950) observed a complete destruction of the phloem tissue in the hypocotyl of 2,4-D treated bean seedlings, which could be a contributing factor in the ultimate killing of these plants. Bradbury and Ennis (1952) found that foliage application of 2,4-D resulted in stomatal closure. This closure was proportional to the dose applied, and seemed to result from a direct physiological action on the guard cells. The stomatal closure consequently caused reductions in the transpiration rate and CO_2 assimilation. Freeland (1949) reported that 2,4-D, at a concentration of 100 ppm, reduced the rate of photosynthesis in beans by 20%. A marked decrease in the rate of photosynthesis in bean plants was also observed by Aker and Fang (1956) as a result of 2,4-D applications.

Unrau and Larter (1952) reported that 2,4-D-treated plants caused aberrations similar to those induced by X-rays, or mutagenic substances. At the biochemical level, a doubling of RNA in both microsomal and soluble fractions of 2,4-D treated soybean hypocotyls was found 48 hours after treatment (Chrispels and Hanson, 1962). Based on this observation, they suggested that the nucleus may be a major site for 2,4-D effects. Van overbeek, as reported in Audus (1964, pp 387-390), attributed the extra growth observed in 2,4-D treated plants to the production of this extra RNA.

A rapid depletion of starch and sugars is reported by various investigators in a wide variety of plants as a result of 2,4-D applications, (Sell et al. 1949; Weller et al. 1949). Henderson et al. (1954), and Wedding et al. (1954) found increases in the rate of respiration as a result of 2,4-D treatments. Humphreys and Dugger (1957) measured the relative amount of glucose, which was catabolized via the pentose phosphate, and the glycolytic pathways, in their 2,4-D-treated root tips of peas, maize, and oat seedlings. In all plants tested, 2,4-D caused an increase in the amounts of glucose catabolized via the pentose phosphate pathway, without affecting the amounts catabolized via the glycolytic pathway. Black and Humphreys (1962) reported that the addition of 2,4-D to etiolated maize seedlings decreased the activity of several glycolytic enzymes, and increased the activity of those involved in the pentose phosphate pathway. It was shown by Switzer (1957) that 2,4-D inhibited the oxidative phosphorylation in soybean mitochondria. He suggested that 2,4-D may have acted as an uncoupling agent. Lotlikar et al. (1968) reported that 2,4-D may inhibit respiration in cabbage mitochondria by an effect on a reaction involved in coupling phosphorylation with electron transport.

Stages of Growth in Relation to 2,4-D Effects

The stage of growth of cereal crops, at the time of spraying, has been recognized by many investigators as an important factor in affecting the degree of toxicity of the herbicide applied. Derscheid (1947) treated eight varieties of barley with the butyl ester formulation of 2,4-D, at four stages of growth, and reported no abnormalities occurring when the treatments were made at the fully tillered and heading stages; however, when the plants were sprayed at the shooting stage, slight lodging occurred. In the case of the seedling stage, the sprayed plants produced abnormal heads. He concluded that the best time to spray any of these eight varieties of barley would be after tillering and before the plants reach the booting stage.

Derscheid (1948), Derscheid (1952, pp 130-134), and Olson (1952) reported that the most susceptible stages of growth to 2,4-D sprays, in barley, were the seedling and the booting stages. The fully tillered, and the post-heading stages were found to be the most resistant. Olsen recommended that 2,4-D may be applied at any time after the crop has reached a height of 13 or 15 cm until the beginning of the booting stage.

Almost similar results have been reported, by other workers, in the case of wheat sprayed with 2,4-D at different stages of growth. Klingman (1947), Elder (1948), and Phillips (1949) found that the fully tillered, and post-heading stages of growth were more resistant to 2,4-D than the three-leaf, and the booting stages.

Moore (1950, pp 405-412), and Allen (1952) reported that the seedling and flowering stages of both wheat and barley appear to be the most sensitive ones to 2,4-D injury; whereas, the period from the beginning of tillering until a reasonable time before heading was considered to be tolerant. Klingman (1953) mentioned that there were no well marked critical stages of growth in wheat sprayed with low rates of 2,4-D; However, as the rates were increased, injury resulted in the early booting and flowering stages, more than those occurring at the jointing or at the late booting stage.

Applications of radioactive labelled 2,4-D to barley, at different stages of growth, indicated that the herbicide was readily translocated to all parts of the plant when applied at the one - to three-leaf stage (Peterson, 1958). Applications to successively older plants resulted in progressively less translocations. At the five- and six-leaf stages, 2,4-D translocation was greatly restricted. Peterson concluded that the relative resistance of cereals to 2,4-D, after the five- to six-leaf stage, may be due to the lack of translocation of the herbicide, rather than due to an increase in the degree of resistance of the vegetative or floral primordia. Leaf (1959) agreed partly with Peterson's findings, in that the rate of translocation of 2,4-D may be a contributing factor to the increasing resistance of barley observed with an increase in the age of the plants; However, he emphasized the point that the age of the leaf or the spikelet primordia must still be regarded as the major cause which governs the susceptibility of the crop to 2,4-D sprays.

Van der Zweep (1961) studied the movement of labelled 2,4-D in young barley plants, and reported that after the four- or five-leaf stage there was a decrease in the translocation of 2,4-D from the leaves to the roots. He suggested that a "block" may occur which hinders the movement of 2,4-D in well-established plants. His results are in close agreement with those of Peterson's (1958), and may cast some doubt on Leaf's hypothesis (1959). Pinthus and Natowitz (1967) applied 2,4-D at five stages of growth of a spring wheat, and reported that the stage of spike initiation was found to be the most sensitive; whereas, the stage which follows the completion of spike differentiation was found to be the most resistant stage. Plants close to "earing" were also found to be very sensitive to 2,4-D.

From the literature reviewed, it can be concluded that the application of 2,4-D to wheat and barley at the three leaf, booting, and the flowering stages of growth was injurious to these crops. At the five- leaf (fully tillered), and the post-heading stages, both crops were found to be tolerant to 2,4-D sprays.

Morphological Responses of Wheat and Barley to 2,4-D Sprays

When cereals are sprayed with 2,4-D at the wrong stage of growth, or at high rates of application, they often show characteristic morphological deformities and abnormalities. Klingman (1947) reported that head abnormalities occur in both wheat and barley when sprayed with 2,4-D before the jointing stage. No apparent abnormality was observed when the treatments were made at the initiation of heading, or at the fully heading stages of growth. At the late booting stage, severe lodging occurred in barley one day after 2,4-D treatment. Moore (1950, pp 405-412) observed stunting of seedlings, lower tillering, internodal curvatures, and tubular leaves in wheat when sprayed with triethanol amine, and butyl ester formulations of 2,4-D at the seedling stage.

Olson et al. (1951) reported that conspicuous morphological changes in wheat and barley occur as a result of spraying at the early stages of growth. Onion-like leaves, spike, and spikelet abnormalities were noted as a result of 2,4-D sprays. Olson (1952) observed deformities, such as tubular leaves, club spikes, branched spikes and elongated spike internodes with clustered spikelets in barley sprayed with 2,4-D at various stages of growth. Derscheid (1952, pp 130-134) reported that the frequency of morphological malformations was increased with an increase in the rate of 2,4-D application.

Blackman (1952), and Klingman (1953) found that spraying 2,4-D prior to tillering produced the largest number of abnormalities. However, these abnormalities did not lead to any appreciable reductions in the yield of wheat and barley. Johanson and Muzik (1961) observed spike abnormalities, which included curvature and twisting of the rachis, when wheat was sprayed with 2,4-D at either the seedling or the booting stage. In addition, shortening of lateral roots, and swelling of both lateral roots and culm bases were also reported. Saghir (1966) sprayed 100, 1000, and 10,000 ppm of 2,4-D at two stages of growth of wheat and barley, and reported that at the five-leaf stage, only the concentration of 10,000 ppm caused leaf deformities and reduction in tillering of the two crops.

The cited literature indicates that the application of 2,4-D at the early stages of growth, specially at the seedling stage, caused various leaf and head deformities which increased with an increase in the rate of 2,4-D applied.

The Effect on Plant Height

Klingman (1947) reported a decrease of 18 cm in the height of barley plants, which were treated with 2,4-D at the late booting stage, when compared with untreated plants. Mc Neal (1948) applied three sprays, and three dust formulations of 2,4-D to "Federation" wheat when the plants were 15 cm high. He found that the spray treatments slightly reduced the plant height, and were more injurious to wheat than the corresponding dust formulations. Saghir (1966) found significant reductions in plant height of wheat treated with 1,000 and 10,000 ppm of 2,4-D at the three-leaf stage. At the five-leaf stage, only the 10,000 ppm concentration caused significant reductions in plant height of both wheat and barley which amounted to 20%.

The Effect on Straw Yield

The only report available on the effect of 2,4-D on straw yield was that of Filippenko and Pavlova (1964), which was abstracted in Weed Abstracts. They found that an increase in the straw yield of spring wheat resulted after the application of 2.0 and 3.4 kg of 2,4-D per hectare.

The Effect on Grain Yield

Derscheid (1947) sprayed different formulations of 2,4-D on eight varieties of barley, at various stages of growth, and reported that the butyl ester formulation increased the grain yield only when applied at the fully tillering stage. No significant differences were found in the yield, as a result of application of other formulations, at any other stage of growth. Helgeson (1947) reported that 2,4-D reduced the yield by 65% when sprayed on wheat at the booting stage. Klingman (1947) had similar results to those of Helgeson. He explained that reductions in the yield were mostly due to florets sterility observed in all the plots treated with 2,4-D at the booting stage, and particularly in those sprayed with two and three kg of 2,4-D per hectare. At the jointing stage, reductions in yield were observed only at the rate of three kg per hectare. McNeal (1948) found that the application of one kg per hectare of 2,4-D reduced the yield of "Federation" wheat as compared with the hand weeded check, indicating that some injury to wheat may have occurred.

Moore (1950, pp 405-412) found that the grain yield of wheat was reduced markedly when sprayed with different phenoxy acid formulations at the seedling (three-leaf) stage. The butyl ester formulation sprayed at 1000 ppm was mostly injurious at this stage, and reduced the yield by 655 kg per hectare. Significant reductions in yield were also observed at the flowering stage. None of the formulations tested had any injurious effect on the yield when applied at the tillering (five-leaf), and pre-shooting stages. Olson et al. (1951) showed that there were two critical periods, in barley and wheat, where reductions in yield have occurred as a result of 2,4-D treatments. The first was at the early seedling stage, where the plants were 2.5 to 12.7 cm tall, and the second was between the booting and the heading stages. Overland and Rasmussen (1951) treated two varieties of wheat, and one variety of barley with three formulations of 2,4-D, each sprayed at three different rates. He found that 2,4-D, at 0.25 and 0.45 kg per hectare, did not cause any damage to crops nor reduced the grain yield. However, at 0.9 kg per hectare, reductions in yield were observed.

Derscheid (1952, pp 128-134) reported that the application of 2,4-D butyl ester at an early stage of development, i.e. before the five-leaf stage, greatly reduced the yield in barley. This was due to reductions in the number of tillers, and the number of spikes per plant. Applications between the pre-heading, and the late heading stages resulted in low yields also; however, these reductions were due to a decrease in the number of seeds. Woofter and Lamb (1954) found serious yield reductions in wheat, when sprayed with 2,4-D at the flowering stage. Smaller, but significant, yield reductions were observed also at the booting stage. The most resistant period occurred between the fully tillered and the jointing stage. The two workers explained that retention of the spray, and the rate of application were the major factors in determining the susceptibility or resistance of the stage of growth of wheat to 2,4-D.

Yield reductions of about 408 kg per hectare were reported by Swan and Rohde (1962) when wheat was sprayed at the booting stage. A significant decrease in the grain yield was observed with an increase in the rate of 2,4-D applied. Filippenko and Pavlova (1964) found an increase in grain yield of wheat when sprayed with 2.0 and 3.4 kg of

2,4-D per hectare. Meadly (1964) showed that 0.43 kg per hectare of 2,4-D ethylester, applied in 30 liters of water at the early tillering stage, was the most satisfactory treatment. Contrary to evidence from other workers, he found that application of 2,4-D at the advanced tillering stage resulted in grain yield reductions. He attributed this reduction to the soil moisture, which was insufficiently available during the later stages of growth.

Saghir (1966) reported significant reductions in the grain yield of wheat and barley as a result of spraying with 2,4-D at the three-leaf stage. At the five-leaf stage, only the highest concentration used of 10,000 ppm, reduced the yield significantly in both crops. The other concentrations, i.e. 100 and 1,000 ppm of 2,4-D sprayed at the same stage have either increased the grain yield or gave no significant effect. Pinthus and Natowitz (1967) applied 2,4-D, at the rates of 0.5 and 1.0 kg per hectare, on four varieties of spring wheat at five stages of growth. Grain yield reductions of 19% were observed with the low dose sprayed at the time of flower differentiation; whereas, 34% reduction occurred as a result of spraying with the high dose at the time of spike initiation. The yield reductions were reported to be due to a decrease in the number of kernels per spikelet.

The Effect on 1000-Kernel Weight

Klingman (1953) reported that there was an increase in the kernel weight of winter wheat with an increase in the rate of 2,4-D applied. Contrary to this observation, Woofter and Lamb (1954) found that the kernel weight was decreased with the application of high rates of butyl ester formulation of 2,4-D, sprayed at the fully tillering, and the jointing stages; however, no reduction was observed at other stages of growth. Åberg (1960) showed that there was no effect on the 1000-kernel weight of spring wheat, sprayed with 2,4-D ethyl ester, at two- to four-leaf, four- to six-leaf, and eight-to ten-leaf stages. This observation does not agree with either of the two reports cited previously.

The Effect on Test Weight

Helgeson (1947) found no significant differences in the test weight of wheat, treated with three formulations of 2,4-D, and applied at different stages of growth. Klingman (1947) observed that the test weight was reduced significantly as a result of spraying winter wheat with 2,4-D at the boot stage. Elder (1948) reported that low test weight, and shrivelling of winter wheat kernels resulted from 2,4-D treatments. McNeal (1948) showed that the test weight of wheat was not materially affected by either dusting, or spraying with 2,4-D at the time when the plants were 15 cm high. Åberg (1960) found no effect on the test weight of spring wheat, sprayed with 2,4-D ethyl ester at two- to four-leaf, four- to six-leaf, and eight- to ten-leaf stages.

The Effect on Germination Percentage

Derscheid (1947) showed that the germination of barley seeds was not impaired by any formulation of 2,4-D sprayed at various stages of growth. Elder (1948) reported that the germination was slightly affected by 2,4-D treatments. Helgeson *et al*. (1948), as reviewed by

Dunham, found that the germination of grains (hard red spring, and durum wheats) was reduced by 2,4-D ester treatments sprayed at the boot stage. Phillips (1949), reviewing the work on the effect of some selective herbicides on fall-planted small grains, stated that none of the 2,4-D treatments gave any significant effect on the germination of winter wheat.

Derscheid (1952, pp 130-134) found that seed viability of barley was not affected by the application of butylester formulation of 2,4-D at nine stages of growth. Klingman (1953) observed no change in the germination percentage of both wheat and barley, when treated with 2,4-D at different stages of growth. Woofter and Lamb (1954) reported that high rates of 2,4-D, applied at the more susceptible stages of wheat, slightly reduced the seed viability. Aberg (1960) reported that there was a decrease in the germination of spring wheat seeds, sprayed with high rates of 2,4-D ethyl ester at the two- to four-leaf, four- to six-leaf, and eight- to ten-leaf stages. Meadly (1964) found statistically significant reducing effects on the germination of wheat seeds, when sprayed with 2,4-D ethyl ester at different stages of growth, but reported that they were not considered to be of "practical importance".

The Effect on Protein Percentage

Erickson et al. (1948) reported increases in the protein percentage of wheat grains, sprayed with varying amounts of 2,4-D. This increase corresponded with an increase in the rate of 2,4-D, and was not due to weed competition, variety, stage of growth, or moisture conditions. They observed that the increase in the protein percentage was related to the stunting effect, which resulted from the application of high rates of 2,4-D. Olson (1949) reviewed the work of various investigators, and showed that there was a highly significant increase in the protein percentage of cereals with an increase in the rates of 2,4-D ester applied at the early tillering stage. The maximum increase in protein amounted to 0.86% only. Phillips (1949) concluded in a review article that as the grain yield was reduced, as a result of 2,4-D sprays, the protein percentage was increased.

Contrary to the findings of other workers, Overland and Rasmussen (1951) found no effect on the nitrogen content of two wheat varieties treated with different concentrations, and formulations of 2,4-D. Klingman (1953) reported that the protein percentage was inversely related to yield, and that when the yield was not affected by 2,4-D treatment, no effect was observed on the protein percentage; however, Hill (1964) showed that there was a direct effect of 2,4-D on the protein percentage. He found that the protein percentage of wheat grains, taken from unweeded plots, was significantly lower than those treated with 2,4-D. In addition, Hill reported that there was no significant difference between the protein percentage of unweeded, and hand weeded plots. This observation proves clearly that the increase in protein percentage is due to 2,4-D effects.

The Effect on Protein Yield

The only report available on the effect of 2,4-D on protein yield was that of Klingman (1953), who found a significant reduction in the protein yield of wheat treated with 2 kg per hectare of 2,4-D, as compared to the check.

III. MATERIALS AND METHODS

The experiments were conducted at the Agricultural Research and Education Center (A.R.E.C.) of the American University of Beirut during 1966-67. The A.R.E.C. is located in the northern central Beqa'a plain, Lebanon. The soil is calcareous clay, low in organic matter and phosphorous, and high in potassium content with a pH of about 8.0. The average monthly temperature, relative humidity and precipitation during 1966-67 are given in Appendix B.

Field Methods

The plots were under soybean and forage crops before planting them to wheat and barley, respectively. Nitrogen and phosphorous fertilizers were added each at the rate of 12 kg of nitrogen and 20 kg of P_2O_5 per dunum. The P_2O_5 was broadcast and disked into the soil a few days before planting of both wheat and barley. Nitrogen, in the form of ammonium sulphate, was top dressed on the soil surface on February 28th, 1967, in the case of barley and March 23rd of the same year in the case of wheat.

Barley and wheat of the "Beecher" and "Najah" varieties were used, respectively. Planting was done with a grain drill in the middle of November, 1966. The plots consisted of five rows, each five meters long and 20 centimeters apart. These were laid out as a split plot in a randomized complete block design with each treatment replicated four times.

The main plots included the different stages of growth of wheat and barley. These stages were the three-leaf, five-leaf, jointing (for wheat only), booting-to-heading (for barley only), anthesis, soft dough, and ripe grain stage. The sub-plots consisted of the different concentrations of butoxy ethanol ester of 2,4-D (Weedone LV-6, 62.5% acid equivalent) sprayed at 500, 1000, 2000, 4000, and 8000 ppm (a.e.). The spray solution was applied at the rate of 2000 liters per hectare (see Appendix C). Unweeded and hand-weeded plots, sprayed with water, were included in each replication. The five-leaf stage and the unweeded plots were considered as controls. Spraying of the herbicide was done at a constant pressure, using a knap sack sprayer equipped with a one-nozzle boom. Sprays were usually applied in the morning where there was little air movement.

Data Recording

Phytotoxity notes were taken on the two crops one week after each treatment. The weed species found in the experimental plots were all annuals[1]. The most common weeds were *Capsella bursa-pastoris* and *Brassica kaber*. The plant heights of wheat and barley were measured at maturity, in centimeters, from the soil surface to the upper most spikelet. Three measurements for plant height were made in each plot.

One square meter from each plot was harvested with a hand sickle. The harvested samples were air-dried for three weeks and

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1. A complete list of the weed species found in the experimental plots is given in Appendix "D".

then were threshed. A mechanical thresher was used, and the seeds were cleaned and weighed. The grain yield, 1000-kernel weight, and test weight were obtained. The straw yield was determined by subtracting the weight of the grains from the weight of the air dried bundles before threshing.

Laboratory Methods

Germination tests were made, on representative seed samples taken from each subplot, according to the method described in the Proceedings of the International Seed Testing Association (1966, pp 49-91).

For protein analysis, a representative seed sample from each subplot was oven dried at 70°C for approximately 48 hours. The nitrogen percentage determinations were made according to the modified Kjeldahl method as specified in the A.O.A.C. (1960, pp 12-13). To calculate the protein percentage, the nitrogen values obtained were multiplied by the factor 5.7 for wheat, and 5.83 for barley. The total protein yields were obtained for each subplot by multiplying the protein percentages by the grain yields.

Statistical Analysis

The statistical analysis was made according to the methods described by LeClerg et al. (1962, pp 184-189). The least significant differences were calculated at the five percent, and one percent levels for making comparisons between the different treatments and the check.

IV. RESULTS AND DISCUSSION

Data on the effects of different concentrations of 2,4-D on the various stages of growth of wheat and barley are presented in Tables 1 to 13. Analysis of variance Tables 16 to 22 are given in Appendix E.

Phytotoxic Effects on Wheat and Barley

Table 1 shows that all the concentrations sprayed at the three-leaf stage were injurious to both wheat and barley, since tillering was active at this stage. The phytotoxicity increased with an increase in the 2,4-D concentration used. The 8000 ppm treatment was highly injurious to both crops. In general, however, the phytotoxic effects were more pronounced in the case of barley than that of wheat.

The various deformities observed as a result of high applications of 2,4-D, at the three-leaf stage, included the formation of tubular leaves, internodal curvatures, curvature and twisting of the rachis, aborted spikelets, and "bunched" ears (ears with multiple spikelets). These observations agree with the ones reported by Derscheid (1947), Klingman (1947), Moore (1950), Olson (1952), and Johanson and Muzik (1961) who found similar deformities, in both wheat and barley, as a result of 2,4-D treatments at the three-leaf (seedling) stage.

Table 1. Phytotoxic effects of different concentrations of 2,4-D on wheat and barley sprayed at six stages of growth in 1966-67*.

Concentration in ppm (a.e.)	Toxicity Index											
	3-leaf		5-leaf		Jointing	Booting to heading	Anthesis		Soft dough		Ripe grain	
	W	B	W	B	W	B	W	B	W	B	W	B
500	+	++	-	-	-	-	-	-	-	-	-	-
1000	+	++	-	-	-	x	-	-	-	-	-	-
2000	++	+++	-	-	x	x	-	-	-	-	-	-
4000	++	+++	+	+	+x	+x	x	x	x	x	-	-
8000	+++	+++	++	++	++x	++x	x	x	x	x	-	-

*W = Wheat
B = Barley
- No toxicity
+ Little chlorosis, or stunting
++ Chlorosis, leaf, or head deformities
+++ Extreme injury, deformity, or kill
x Lodging.

At the five-leaf stage, only the 4000 and 8000 ppm treatments were phytotoxic to both crops. Leaf chlorosis, head and leaf deformities, which were similar to those found at the three-leaf stage, were observed.

Severe lodging occurred one day after 2,4-D application on wheat and barley, sprayed at the jointing, and the booting-to-heading stages of growth. In the case of wheat, lodging occurred in plots treated with 2000, 4000, and 8000 ppm; while in the case of barley, it occurred even in plots treated with 1000 ppm, in addition to those treated with the three higher doses. Leaf chlorosis, head and leaf deformities were also noted in both crops as a result of treatments with 4000, and 8000 ppm. Similar data were obtained by Klingman (1947), who reported severe lodging in barley as a result of 2,4-D application at the late-booting stage.

With the exception of lodging occurring at the 4000 and 8000 ppm treatments, no apparent abnormalities were observed on wheat and barley, sprayed at anthesis, and the soft dough stages. Similarly, applications of 2,4-D at the ripe-grain stage did not produce any abnormal effects at all the concentrations used. This may be due to the absence of meristematic activity, and the slow rate of 2,4-D translocation at this stage of growth. These results are in agreement with the findings of Klingman (1947), Elder (1948), Derscheid (1948), Phillips (1949), Derscheid (1952), and Olson (1952), who reported that the fully tillered and the post-heading stages in wheat and barley are not affected by 2,4-D applications.

The Effects of Different Concentrations of 2,4-D on Agronomic Characteristics of Wheat and Barley

Plant Height

Tables 2 and 3 indicate highly significant reductions in the mean plant height of wheat and barley, treated with the different concentrations of 2,4-D used. The reduction in plant height was greater as the concentrations were increased from 500 ppm upto 8000 ppm in both crops. In the case of wheat, the reductions ranged from 3.6 to 20.6%, and in the case of barley from 4.2 to 9.8% as compared with the unweeded checks.

Straw Yield

Significant reductions in the mean straw yields of wheat were found at all 2,4-D concentrations used, as compared with the unweeded check (Table 2); However, in the case of barley, the mean straw yields were not significantly different from the unweeded check (Table 3).

Grain Yield

The mean grain yields of wheat (Table 2), in the 2000, 4000, and 8000 ppm treated plots were found to be significantly lower than the unweeded check. However, a significant increase in the mean grain yield of the hand weeded plots was noted. In the case of barley (Table 3), all the concentrations used, caused significant reductions in the mean grain yields. The hand weeded plots gave an increase in yield over the unweeded check; however, this was not statistically significant.

Table 2. The effects of different concentrations of 2,4-D on the means of plant height, straw yield, grain yield, 1000-kernel weight, test weight, germination percentage, protein percentage and protein yield of wheat sprayed in 1966-67+.

Concentration in ppm (a.e.)	Plant height (cm)	Straw yield (kg/du)	Grain yield (kg/du)	1000-kernel weight (g)	Test weight (lbs/bush)	Germination percentage	Protein percentage	Protein yield (kg/du)
500	125.6x	633x	328	51.4	58.62	98.9	12.57	41.3
1000	122.1xx	634x	312	50.7	58.56	98.2	12.74x	39.7
2000	119.8xx	633x	272xx	50.1	58.35	98.4	12.84xx	34.8xx
4000	108.7xx	618x	260xx	48.3xx	57.87xx	98.5	13.08xx	34.0xx
8000	103.5xx	628x	237xx	48.1xx	57.89xx	97.2	13.22xx	37.1xx
Handweeded	132.6	707	364x	51.7	59.06	97.2	12.62	45.9xx
Unweeded check	130.3	703	325	51.4	58.93	98.5	12.55	40.8
L.S.D. 5%	4.0	68	39	1.9	0.59	N.S.	0.16	2.7
" 1%	5.3	91	51	2.5	0.79	-	0.21	3.6

\+ These concentrations were applied to six stages of growth: 3-leaf, 5-leaf, jointing, anthesis, soft dough, and ripe-grain stage.

x Significant at 5% level.

xx Significant at 1% level.

Table 3. The effects of different concentrations of 2,4-D on the means of plant height, straw yield, grain yield, 1000-kernel weight, test weight, germination percentage, protein percentage and protein yield of barley sprayed in 1966-67+.

Concentration in ppm (a.e.)	Plant height (cm)	Straw yield (kg/du)	Grain yield (kg/du)	1000-kernel weight (g)	Test weight (lbs/bush)	Germination percentage	Protein percentage	Protein yield (kg/du)
500	102.0^{xx}	662	562^{x}	51.6	46.74^{x}	98.0	10.89	61.2
1000	99.8^{xx}	724	549^{xx}	51.5	46.72^{x}	98.3	10.89	59.5^{xx}
2000	100.4^{xx}	661	519^{xx}	50.9	46.26^{xx}	98.3	11.12^{xx}	57.3^{xx}
4000	96.5^{xx}	658	484^{xx}	50.1^{xx}	46.17^{xx}	98.1	11.36^{xx}	54.6^{xx}
8000	96.1^{xx}	659	450^{xx}	49.8^{xx}	46.00^{xx}	97.8	11.48^{xx}	51.1^{xx}
Handweeded	105.9	754	599	51.7	47.35	98.9	10.81	64.8
Unweeded check	106.5	735	587	51.4	47.25	98.5	10.78	63.2
L.S.D. 5%	2.7	N.S.	19	0.5	0.46	N.S.	0.16	2.7
" 1%	3.6	-	25	0.7	0.60	-	0.21	3.0

\+ These concentrations were applied at six stages of growth: 3-leaf, 5-leaf, booting-to-heading, anthesis, soft dough, and ripe grain stage.

x Significant at 5% level.

xx Significant at 1% level.

1000-Kernel Weight

Reductions in the mean 1000-kernel weights of both wheat and barley were highly significant in the 4000 and 8000 ppm-treated plots (Tables 2 and 3). This may be due to the adverse effects of the high concentrations of 2,4-D on kernel development, which resulted in shrivelled grains, and reduced the 1000-kernel weight. The mean 1000-kernel weights of wheat and barley sprayed at the other concentrations, were not significantly different from the unweeded check.

Test Weight

Table 2 indicates that the mean test weight of wheat was significantly reduced in the 4000, and 8000 ppm-treated plots. The test weight of grains from other treatments were not significantly different from the unweeded check; however, in the case of barley, significantly lower mean test weights were observed at all the concentrations tested. Shrivelling of seeds of the two crops occurred as a result of spraying at the two higher concentrations only.

Germination Percentage

In both crops, the mean germination percentages, at all 2,4-D concentrations tested, were not significantly different from the unweeded checks. The percentages ranged from 97.2 to 98.5% in the case of wheat, and 97.8 to 98.9% in the case of barley (Tables 2 and 3).

Protein Percentage

The mean protein percentages of wheat and barley seeds in the 2000, 4000, and 8000 ppm-treated plots were found to be significantly

1000-Kernel Weight

Reductions in the mean 1000-kernel weights of both wheat and barley were highly significant in the 4000 and 8000 ppm-treated plots (Tables 2 and 3). This may be due to the adverse effects of the high concentrations of 2,4-D on kernel development, which resulted in shrivelled grains, and reduced the 1000-kernel weight. The mean 1000-kernel weights of wheat and barley sprayed at the other concentrations, were not significantly different from the unweeded check.

Test Weight

Table 2 indicates that the mean test weight of wheat was significantly reduced in the 4000, and 8000 ppm-treated plots. The test weight of grains from other treatments were not significantly different from the unweeded check; however, in the case of barley, significantly lower mean test weights were observed at all the concentrations tested. Shrivelling of seeds of the two crops occurred as a result of spraying at the two higher concentrations only.

Germination Percentage

In both crops, the mean germination percentages, at all 2,4-D concentrations tested, were not significantly different from the unweeded checks. The percentages ranged from 97.2 to 98.5% in the case of wheat, and 97.8 to 98.9% in the case of barley (Tables 2 and 3).

Protein Percentage

The mean protein percentages of wheat and barley seeds in the 2000, 4000, and 8000 ppm-treated plots were found to be significantly higher than the unweeded checks (Tables 2 and 3). In addition, the protein percentage of the 1000 ppm treatment in wheat was also significantly greater than the check. These increases ranged from 0.19 to 0.67% in the 1000 and 8000 ppm-treated plots, respectively; whereas, in the case of barley, the percent increase ranged from 0.34 to 0.70% over the check in the 2000, and 8000 ppm-treated plots.

In general, increases in the protein percentages of wheat and barley seeds were obtained at concentrations where serious reductions in grain yields were observed (Tables 2 and 3). No significant difference was observed between the protein percentages of unweeded and hand weeded check plots. This may indicate that the increase in the protein percentage of 2,4-D treated plots was the result of a direct effect of the chemical on seed composition, rather than an effect resulting from the elimination of weed competition.

Protein Yield

The mean protein yields of both wheat and barley were significantly lower than the check, when sprayed at 2000, 4000, and 8000 ppm (Tables 2 and 3). At 1000 ppm, significant reduction in the mean protein yield was observed only in the case of barley. These reductions correlated with the significant reductions observed in the mean grain yields of the two crops at the above concentrations. Hand weeded plots gave increased protein yields in both crops; however, the increase was statistically significant in the case of wheat only, since the mean grain yield of wheat was significantly higher than the unweeded check.

It may be concluded from the results obtained on the effects of different concentrations of 2,4-D on wheat and barley, that the means of plant height, grain yield, 1000-kernel weight, test weight, and protein yields were significantly reduced in both crops, as a result of spraying with the higher concentrations of 2,4-D; however, these concentrations caused highly significant increases in the protein percentages of the two crops. Moreover, none of the concentrations used had any significant effect on the germination percentages of wheat and barley seeds.

Tolerance of Various Stages of Growth of Wheat and Barley to 2,4-D Sprays

Plant Height

Tables 4 and 5 show significant reductions in the mean plant height of wheat sprayed at the jointing stage, and of barley sprayed at the three-leaf, and booting-to-heading stages of growth when compared with the control, i.e., the five-leaf stage. These effects may be due to the rapid rate of vegetative growth, and high meristematic activity which occurred at the time of spraying. The mean plant height, at the soft dough stage, was significantly greater than the control in both wheat and barley; however, at the ripe grain stage, a significant increase in height was observed in wheat only (Table 4).

Straw Yield

With the exception of the significant increase in the mean straw yield of wheat, observed at the soft dough, and the ripe grain stages of growth, no significant differences were found between the mean straw yield of the control, and those of the other stages of growth.

Table 4. The effects of 2,4-D on the means of plant height, straw yield, grain yield, 1000-kernel weight, test weight, germination percentage, protein percentage, and protein yield of wheat when sprayed at six stages of growth in 1966-67[+].

Stage of growth	Plant height (cm)	Straw yield (kg/du)	Grain yield (kg/du)	1000-kernel weight (g)	Test weight (lbs/bush)	Germination percentage	Protein percentage	Protein yield (kg/du).
Three-leaf	115.5	570	278^{x}	49.0^{xx}	57.85	97.4^{xx}	12.72	35.3^{x}
Five-leaf	114.2	578	343	50.9	58.35	98.6	12.73	43.7
Jointing	106.8^{x}	639	269^{xx}	49.9^{x}	57.46	97.5^{x}	13.12^{xx}	35.0^{xx}
Anthesis	120.0	679	270^{xx}	50.9	58.70	98.4	13.05^{x}	34.9^{xx}
Soft dough	130.7^{xx}	702^{x}	319	48.6^{xx}	59.11	98.4	12.64	40.3
Ripe grain	135.0^{xx}	736^{xx}	319	52.2^{x}	59.35^{x}	98.6	12.56	40.0
L.S.D. 5%	6.7	102	48	1.0	0.94	0.8	0.28	6.1
" 1%	9.3	141	67	1.3	1.30	1.1	0.38	8.5

+ Concentrations applied were: 500, 1000, 2000, 4000, 8000 ppm of 2,4-D; hand weeded, and unweeded check plots were included.

x Significant at 5% level.

xx Significant at 1% level.

Table 5. The effects of 2,4-D on the means of plant height, straw yield, grain yield, 1000-kernel weight, test weight, germination percentage, protein percentage, and protein yield of barley when sprayed at six stages of growth in 1966-67^{+}.

Stage of growth	Plant height (cm)	Straw yield (kg/du)	Grain yield (kg/du)	1000-kernel weight (g)	Test weight (lbs/bush)	Germination percentage	Protein percentage	Protein yield (kg/du).
Three-leaf	95.2^{xx}	606	515^{xx}	50.6	45.90	98.4	11.30^{xx}	57.8^{xx}
Five-leaf	102.0	683	594	51.5	46.19	99.3	10.78	63.9
Booting-to-heading	97.5^{x}	739	499^{xx}	51.4	46.21	98.1^{x}	11.38^{xx}	56.3^{xx}
Anthesis	98.9	692	467^{xx}	50.5^{x}	46.85	97.5^{xx}	11.26^{xx}	52.2^{xx}
Soft dough	107.5^{x}	707	567^{xx}	50.2^{x}	47.33^{xx}	97.8^{x}	10.75	61.0^{xx}
Ripe grain	105.0	731	572^{xx}	51.7	47.35^{xx}	98.7	10.81	61.8^{x}
L.S.D. 5%	4.4	N.S.	15	1.0	0.71	1.1	0.26	1.8
" 1%	6.1	-	21	1.4	0.79	1.6	0.35	2.4

\+ Concentrations applied were: 500, 1000, 2000, 4000, 8000 ppm of 2,4-D; hand weeded, and unweeded check plots were included.

x Significant at 5% level.

xx Significant at 1% level.

Grain Yield

In both wheat and barley, highly significant reductions in the mean grain yields were observed at the three-leaf, jointing (in wheat only), booting-to-heading (in barley only), and anthesis stages of growth, when compared with yields of plants sprayed at the five-leaf stage. This may be due to the rapid vegetative (three-leaf, and jointing stages), and reproductive (booting-to-heading, and anthesis stages) activities of the plants at the time of spraying. In addition, reductions in the mean grain yields of barley were observed at the soft dough, and ripe grain stages of growth.

1000-Kernel Weight

Table 4 shows that the mean 1000-kernel weights of wheat sprayed at the three-leaf, jointing, and soft dough stages were significantly lower than that of the control; however, a significant increase in the mean 1000-kernel weight was observed at the ripe grain stage.

In barley (Table 5), the mean 1000-kernel weight was found to be significantly lower than the control, when sprayed at anthesis and the soft dough stages. The kernel weight at the other stages of growth were not significantly different from the control.

Test Weight

The mean test weights of wheat sprayed at the ripe grain stage, and of barley sprayed at the soft dough, and ripe grain stages were found to be significantly higher than their corresponding controls (Tables 4 and 5). No significant differences were found between the mean test weight of the control, and those of the other stages of growth in both crops.

Germination Percentage

Statistically significant, but very small, reductions in the mean germination percentages were found in wheat sprayed at the three-leaf, and jointing stages, and in barley sprayed at the booting-to-heading, anthesis, and soft dough stages of growth (Tables 4 and 5). The maximum reduction observed in the germination percentage of wheat seeds amounted to 1.2%, when plants were sprayed at the three-leaf stage; whereas a reduction of 1.8% was found in the case of barley sprayed at anthesis. Meadly (1964) reported similar statistically significant reducing effects on germination percentages of wheat sprayed with 2,4-D ethylester, and reported that they were not considered to be of "practical importance".

Protein Percentage

Significant increases in the mean protein percentages of wheat sprayed at the jointing, and anthesis stages of growth were observed when compared with the control (Table 4); however, in the case of barley (Table 5), the increases in the mean protein percentages were found to be highly significant at the three-leaf, booting-to-heading, and anthesis stages of growth. It may be noted that serious reductions in the mean grain yields of both crops were found at the above mentioned stages, which coincided with the increases observed in the protein percentages of seeds. This suggests that an inverse relationship may exist between the protein percentage of wheat and barley, and the grain yield. The mean protein percentages at other stages of growth studied were not significantly different from the check in both crops.

Protein Yield

The mean protein yields were found to be significantly reduced when 2,4-D was sprayed at the three-leaf, and anthesis stages of the two crops, and at the jointing stage of wheat alone, and the booting-to-heading, soft dough and the ripe grain stages of barley (Tables 4 and 5). These reductions in the mean protein yields correlated with the ones observed in the mean grain yield of both crops sprayed at the above mentioned stages of growth.

The Effects of the Interaction Between 2,4-D Concentrations and Stages of Growth of Wheat and Barley on the Various Agronomic Characteristics Studied

Plant Height

Table 6 shows significant reductions in the plant height of wheat when sprayed with concentrations ranging from 1000 to 8000 ppm of 2,4-D at the three-leaf, five-leaf, and jointing stages of growth. At anthesis,only 4000 and 8000 ppm caused highly significant reductions in plant height. The concentration of 500 ppm had no significant effect at all stages studied. All other concentrations, sprayed at the soft dough, and ripe grain stages had no significant effect on plant height. This may be correlated with the phytotoxicity observations made at these stages of growth, where no injurious effects were observed. Moreover, by the time the plants were sprayed, they had already attained their full height, and 2,4-D had no affect on them since the rate of

Table 6. The effects of different concentrations of 2,4-D sprayed at six stages of growth of wheat and barley, on plant height (cm) in 1966-67.

Wheat

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe Grain
500	121.8	123.3	119.0	125.5	130.0	134.0
1000	113.0^{x}	115.8^{x}	111.8^{x}	126.0	134.0	132.0
2000	109.0^{xx}	115.0^{x}	99.8^{xx}	120.0	138.0	137.5
4000	107.8^{xx}	96.0^{xx}	84.0^{xx}	103.8^{xx}	122.5	138.5
8000	95.8^{xx}	87.3^{xx}	75.8^{xx}	99.0^{xx}	131.3	132.3
Hand weeded	132.8	132.0	132.8	134.0	129.8	134.5
Unweeded check	128.8	130.0	124.5	133.0	129.3	136.3

Barley

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe Grain
500	95.2^{xx}	106.5	97.2^{x}	98.9^{x}	110.5	103.5
1000	94.8^{xx}	104.0	97.0^{x}	97.2^{x}	105.0	100.8
2000	91.5^{xx}	99.8^{x}	98.0^{x}	97.0^{x}	107.0	109.0
4000	89.5^{xx}	96.5^{xx}	90.0^{xx}	94.2^{xx}	104.2	104.5
8000	89.2^{xx}	95.0^{xx}	88.8^{xx}	93.5^{xx}	105.5	104.8
Hand weeded	103.2	103.2	106.2	106.2	111.2	105.2
Unweeded check	102.8	109.2	105.2	105.5	109.2	107.0

L.S.D. 5%; Wheat = 13.8 - Barley = 9.4

L.S.D. 1%; Wheat = 18.4 - Barley = 12.5

x Significant at 5% level.

xx Significant at 1% level.

translocation of the herbicide is very slow at these stages.

In the case of barley (Table 6), all the concentrations used caused significant reductions in the plant height when sprayed at the three-leaf, booting-to-heading, and anthesis stages. At the five-leaf stage, only the higher concentrations of 2000, 4000, and 8000 ppm caused significant reductions in plant height; however, none of the concentrations tested, had any significant effect on plant height when sprayed at the soft dough, and the ripe grain stages.

The results obtained agree partly with Saghir (1966), who reported significant reductions in plant height of wheat treated with 1000 ppm of 2,4-D at the three-leaf stage; however, he found no significant effect at this concentration when sprayed at the five-leaf stage, in the case of wheat, and at the three-leaf, and five-leaf stages of barley. This disagreement in the results may be due to the different varieties of wheat and barley, used in the two experiments.

Straw Yield

The data presented in Table 7 indicate that all the concentrations of 2,4-D sprayed at the various stages of growth of wheat and barley had no significant effect on the straw yield of the two crops.

Grain Yield

Very serious reductions in the grain yield of wheat were observed with 8000 ppm of 2,4-D sprayed at the jointing, and anthesis stages of growth (Table 8). These reductions amounted to 41.9 and 49.2%, respectively. This may be due to the development of shrivelled

Table 7. The effects of different concentrations of 2,4-D, sprayed at six stages of growth of wheat and barley, on straw yield (kg/du) in 1966-67.

Wheat+

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe grain
500	511	574	630	628	702	754
1000	554	553	632	606	724	733
2000	536	546	692	600	649	777
4000	449	420	596	776	723	744
8000	488	545	634	710	656	737
Hand weeded	700	748	660	739	747	647
Unweeded check	756	662	634	698	706	763

Barley+

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe grain
500	584	704	628	631	735	688
1000	729	756	757	722	634	747
2000	473	659	808	615	652	758
4000	562	587	650	674	707	768
8000	316	596	782	782	813	663
Hand weeded	819	717	802	719	719	746
Unweeded check	761	760	747	706	688	749

+ No significant difference.

Table 8. The effects of different concentrations of 2,4-D, sprayed at six stages of growth of wheat and barley, on grain yield (kg/du) in 1966-67.

Wheat

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe grain
500	315	390	311	313	323	315
1000	278	385	286	273	324	324
2000	250	328	215	213	305	322
4000	204	305	203	206	323	323
8000	205	269	154[x]	166[x]	316	310
Hand weeded	370	396	389	392	320	316
Unweeded check	328	327	325	327	322	321

Barley

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe grain
500	567	649	535	486[xx]	567	569
1000	543	669[xx]	491[xx]	460[xx]	559	573
2000	494[xx]	596	473[xx]	438[xx]	560	557
4000	406[xx]	544	441[xx]	384[xx]	561	569
8000	379[xx]	461[xx]	391[xx]	328[xx]	569	574
Hand weeded	625	645	596	587	574	571
Unweeded check	592	598	568	589	581	595

L.S.D. 5%; Wheat = 135 - Barley = 66
L.S.D. 1%; Wheat = 179 - Barley = 87

x Significant at 5% level.

xx Significant at 1% level.

grains obtained from these treatments, which might have reduced the grain yields. The concentrations of 500 and 1000 ppm, sprayed at the five-leaf stage, as well as the hand-weeded plots at the three-leaf, five-leaf, jointing, and anthesis stages gave higher grain yields than the unweeded check; however, these increases were not statistically significant.

Highly significant reductions in the grain yield of barley were observed at concentrations ranging from 2000 to 8000 ppm, sprayed at the three-leaf, booting-to-heading, and anthesis stages. In addition to these high concentrations, 500 and 1000 ppm at anthesis, and 1000 ppm at the booting-to-heading stages gave highly significant reductions in the grain yield.

At the five-leaf stage, a highly significant increase of 18.7% in the grain yield of barley was obtained from the 1000 ppm-treated plots as compared to the unweeded check. Among the various concentrations sprayed at this stage, only the 8000 ppm treatment caused a significant reduction in the grain yield. Other concentrations tested at this stage gave no significant effect.

2,4-D, sprayed at the soft dough and ripe grain stages of growth, in both wheat and barley, gave no significant effect on the grain yield. This was expected since kernel development has already been completed at the time of herbicidal application.

The results are in close agreement with those of Derscheid (1947), Klingman (1947), Moore (1950), Olson <u>et al</u>. (1951), Overland and Rasmussen (1951), Woofter and Lamb (1954), Swan and Rhode (1962), and Saghir (1966), who reported reductions in the grain yields of wheat and barley as a result of spraying with medium rates of 2,4-D at the three-leaf, jointing, and anthesis stages of growth; whereas, higher yields were obtained when the herbicide was applied at the five-leaf (fully tillered) stage.

1000-Kernel Weight

Table 9 indicates that the concentrations of 4000 and 8000 ppm of 2,4-D, sprayed at the three-leaf, jointing, and soft dough stages of wheat significantly reduced the 1000-kernel weight as compared with the unweeded check; however, no significant effect was observed at all the concentrations sprayed at the five-leaf, anthesis and the ripe grain stages.

In the case of barley, 8000 ppm sprayed at the three-leaf, anthesis, and soft dough stages produced significant reductions in the 1000-kernel weight. In addition, the 2000 and 4000 ppm treatments, at the soft dough stage, were also significant in reducing the 1000-kernel weight of barley; however, no significant effects were observed with all the concentrations sprayed at the five-leaf, booting-to-heading, and the ripe grain stages of growth.

The results obtained suggest that the higher concentrations of 2,4-D, ranging from 2000 to 8000 ppm, sprayed at the three-leaf, jointing (in wheat only), anthesis (in barley only), and soft dough stages, gave an adverse effect on the kernel development in the two crops. This can partly explain the significant reductions observed in the grain yields of the two crops, when sprayed at these stages of growth with high concentrations of 2,4-D.

The results obtained agree with the data of Woofter and Lamb

Table 9. The effects of different concentrations of 2,4-D, sprayed at six stages of growth of wheat and barley, on 1000-kernel weight (g) in 1966-67.

Wheat

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe grain
500	50.9	51.3	50.8	51.8	51.4	52.7
1000	50.3	51.1	50.1	51.7	49.7	51.7
2000	49.1	51.1	49.3	51.0	47.5[xx]	50.3
4000	45.7[xx]	50.2	48.8[x]	49.2	44.4[xx]	51.9
8000	44.9[xx]	49.5	48.2[xx]	49.6	44.3[xx]	52.0
Hand weeded	51.7	52.2	51.0	51.7	51.4	52.6
Unweeded check	50.6	51.1	51.5	51.9	51.7	51.7

Barley

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe grain
500	51.4	52.5	52.2	51.2	51.5	51.0
1000	52.2	52.2	51.6	50.5	50.9	52.0
2000	50.6	52.5	51.4	49.8	49.3[x]	52.3
4000	49.8	50.8	50.5	50.2	48.6[xx]	50.9
8000	48.7[xx]	49.9	51.3	49.1[x]	47.8[xx]	52.3
Hand weeded	51.1	51.8	52.0	51.8	52.0	51.5
Unweeded check	51.1	51.2	51.0	51.5	51.6	52.1

L.S.D. 5%; Wheat = 2.0 - Barley = 1.9

L.S.D. 1%; Wheat = 2.7 - Barley = 2.5

x Significant at 5% level.

xx Significant at 1% level.

(1954), who reported that the 1000 kernel weight was decreased at the higher rates of 2,4-D applied at the jointing stage; however, his findings at the five-leaf stage were different. In addition, the results do not agree with those of Klingman (1953), who reported an increase in the kernel weight of winter wheat with an increase in the rate of 2,4-D applied, and with Aberg (1960), who found no effect on the 1000-kernel weight of spring wheat, sprayed with 2,4-D ethyl ester at various stages of growth.

Test Weight

With the exception of concentrations ranging from 2000 to 8000 ppm, sprayed at the jointing stage, which caused significant reductions in the test weight of wheat, no effect was observed as a result of the interaction between the different concentrations of 2,4-D used, and the various stages of growth studied. However, the above concentrations produced significant reductions in the test weight of barley, when sprayed at the three-leaf, five-leaf, and booting-to-heading stages of growth. All 2,4-D concentrations applied at anthesis, soft dough, and the ripe grain stages gave no significant effect on the test weight of barley.

These results do not agree with those of Helgeson (1947), and Aberg (1960), who found no significant effects on the test weight of wheat as a result of 2,4-D applications; however, Elder (1948), reported low test weight values in the case of wheat treated with 2,4-D.

Germination Percentage

No significant effects were observed on the germination

Table 10. The effects of different concentrations of 2,4-D, sprayed at six stages of growth of wheat and barley, on test weight (lbs/bush) in 1966-67.

Wheat

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe grain
500	56.75	58.25	59.00	58.75	59.25	59.75
1000	57.87	58.37	58.37	58.62	59.37	58.75
2000	57.87	58.50	55.62[x]	58.90	59.50	59.75
4000	57.25	58.00	55.87[x]	58.12	58.62	59.37
8000	57.00	57.87	55.50[x]	58.25	59.25	59.50
Hand weeded	59.45	59.37	58.87	58.87	59.07	58.75
Unweeded check	58.75	58.12	59.00	59.37	58.75	59.62

Barley

Concentration in ppm (a.e.)	Stages of Growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe grain
500	45.70	46.37	46.75	46.75	47.62	47.25
1000	45.75	45.87	46.87	46.75	47.37	47.75
2000	45.37[x]	45.62[x]	45.50[x]	46.87	46.87	47.37
4000	45.52[x]	45.50[x]	45.37[x]	46.50	47.00	47.12
8000	44.62[xx]	45.62[x]	44.62[xx]	46.75	47.25	47.12
Hand weeded	47.25	47.12	47.37	47.25	47.62	47.50
Unweeded check	47.12	47.25	47.00	47.12	47.62	47.37

L.S.D. 5%; Wheat = 2.08 - Barley = 1.56
L.S.D. 1%; Wheat = 2.76 - Barley = 2.07

x Significant at 5% level.

xx Significant at 1% level.

Table 11. The effects of different concentrations of 2,4-D, sprayed at six stages of growth of wheat and barley, on germination percentage in 1966-67.

Wheat+

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe grain
500	97.3	98.5	97.8	99.5	98.0	98.3
1000	97.5	99.5	97.3	98.0	98.5	99.8
2000	97.8	99.5	97.5	98.8	98.3	99.5
4000	96.3	97.0	96.8	97.5	97.8	97.8
8000	96.5	97.3	97.3	96.8	97.8	97.8
Hand weeded	99.0	99.5	97.8	98.5	99.0	97.5
Unweeded check	97.5	99.3	98.5	99.5	99.3	99.5

Barley+

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe grain
500	98.0	99.3	99.5	96.5	98.8	98.8
1000	98.0	96.8	98.8	97.5	97.5	98.5
2000	99.5	99.0	97.8	97.8	97.5	98.0
4000	98.0	98.8	97.8	97.8	97.5	98.8
8000	98.3	99.8	95.0	98.0	97.8	98.5
Hand weeded	98.5	99.3	99.5	97.8	99.0	99.3
Unweeded check	98.8	99.0	98.3	97.0	99.0	99.0

+ No significant difference.

percentages of wheat and barley, as a result of 2,4-D treatments at the various stages of growth (Table 11). This may suggest that 2,4-D has no injurious carry-over effects on the germplasm of these two crops.

Protein Percentage

Highly significant increases in the protein percentages of wheat grains were observed, when 2,4-D was sprayed at concentrations ranging from 2000 to 8000 ppm, at the jointing, and anthesis stages of growth (Table 12). At the three-leaf stage, only the 8000 ppm treatment increased the protein percentage significantly over the unweeded check.

Almost similar results were obtained in the case of barley, at the booting-to-heading, and anthesis stages, where highly significant increases occurred in the protein percentages of barley grains, at concentrations ranging from 2000 to 8000 ppm. At the three-leaf stage, in addition to the 8000 ppm treatment, a significant increase in the protein percentage was observed also at 4000 ppm.

It may be noted that the significant increases in the protein percentages were obtained as a result of spraying high concentrations of 2,4-D at the susceptible stages of growth, i.e. the three-leaf, jointing (in wheat only), booting-to-heading (in barley only), and anthesis stages, which caused serious reductions in the grain yields, (Tables 2, 3, 4, 5, and 8). This may suggest an inverse relationship between the protein percentage of wheat and barley, and the grain yield. This relationship seems to be influenced by the herbicide application, since the protein percentage of the hand weeded plots was

Table 12. The effects of different concentrations of 2,4-D sprayed at six stages of growth of wheat and barley, on protein percentage in 1966-67.

Wheat

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe grain
500	12.32	12.71	12.46	12.78	12.58	12.54
1000	12.63	12.66	12.94	12.86	12.64	12.72
2000	12.67	12.77	13.38xx	13.17x	12.58	12.42
4000	13.08	12.72	13.92xx	13.47xx	12.61	12.63
8000	13.30x	12.94	13.92xx	13.82xx	12.82	12.46
Hand weeded	12.69	12.64	12.59	12.64	12.62	12.53
Unweeded check	12.31	12.62	12.59	12.58	12.60	12.59

Barley

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe grain
500	11.09	10.81	11.12	10.84	10.71	10.78
1000	11.10	10.73	11.08	10.80	10.74	10.88
2000	11.33	10.73	11.52x	11.76xx	10.74	10.62
4000	11.89xx	10.75	12.09xx	11.91xx	10.76	10.75
8000	12.09xx	10.78	12.32xx	11.95xx	10.92	10.79
Hand weeded	10.80	10.85	10.79	10.78	10.75	10.90
Unweeded check	10.81	10.79	10.75	10.74	10.65	10.93

L.S.D. 5%; Wheat = 0.55 - Barley = 0.59

L.S.D. 1%; Wheat = 0.74 - Barley = 0.79

x Significant at 5% level.

xx Significant at 1% level.

not significantly different from that of the unweeded check (Table 12).

Various investigators have reported that a rapid depletion of starch and sugars occur as a result of 2,4-D applications. This may account for the reduced grain yields observed. Therefore, it can be argued that the higher protein percentages obtained at the susceptible stages of growth, where reductions in the grain yields were observed, may be due to a high protein/carbohydrate ratio, rather than an increase in the de novo synthesis of protein.

These results closely agree with the findings of various investigators. Erickson et al. (1948), and Phillips (1949), reported significant increases in the protein percentages of wheat and barley as a result of 2,4-D treatments. Klingman (1953) mentioned that the protein percentage was inversely related to the grain yield, and that when the yields were not affected by 2,4-D treatment, no effect was observed on the protein percentage.

Protein Yield.

As indicated in Table 13, the protein yields were significantly reduced at the three-leaf, jointing (in wheat only), booting-to-heading (in barley only), and anthesis stages of growth, in both crops, when sprayed with concentrations ranging from 2000 to 8000 ppm; however, in the case of barley, the 1000 ppm treatment at the booting-to-heading and anthesis stages, and the 500 ppm treatment at anthesis only, were also significantly lower in protein yield than the control. No significant effect was observed at all the concentrations sprayed at the five-leaf, soft dough, and ripe grain stages of both crops.

In general, the data obtained on the protein yields correspond

Table 13. The effects of different concentrations of 2,4-D, sprayed at six stages of growth of wheat and barley, on protein yield (kg/du) in 1966-67.

Wheat

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Jointing	Anthesis	Soft dough	Ripe grain
500	38.8	49.6	39.0	40.1	40.6	39.5
1000	35.1	48.8	37.1	35.0	41.0	41.2
2000	31.7^{x}	42.0	29.0^{x}	28.1^{xx}	38.3	40.0
4000	26.7^{xx}	39.6	28.9^{xx}	27.6^{xx}	40.7	40.7
8000	27.3^{xx}	34.8	21.4^{xx}	22.7^{xx}	40.4	38.7
Hand weeded	47.0	50.0	49.0	49.5	40.4	39.6
Unweeded check	40.4	41.3	40.9	41.2	40.6	40.5

Barley

Concentration in ppm (a.e.)	Stages of growth					
	3-leaf	5-leaf	Booting-to-heading	Anthesis	Soft dough	Ripe grain
500	62.8	70.1	59.5	52.7^{xx}	60.8	61.2
1000	60.2	70.7	54.5^{x}	49.7^{xx}	60.0	62.3
2000	55.9^{x}	63.9	53.3^{xx}	51.5^{xx}	60.1	59.1
4000	48.5^{xx}	58.5	53.4^{xx}	46.0^{xx}	60.4	61.2
8000	45.8^{xx}	49.7	48.2^{xx}	39.2^{xx}	62.2	61.9
Hand weeded	67.5	70.0	64.4	63.3	61.7	62.3
Unweeded check	63.9	64.5	61.0	63.3	61.9	65.0

L.S.D. 5%; Wheat = 9.4 - Barley = 7.8

L.S.D. 1%; Wheat =12.4 - Barley = 10.4

x Significant at 5% level.

xx Significant at 1% level.

closely with the ones recorded on the grain yields of the two crops (Tables 2, 3, 4, 5, and 8). Whenever there were reductions recorded in the grain yields, there were corresponding reductions noted in the protein yields. This was observed inspite of the significant increases obtained in the protein percentages of these two crops.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The experiments were conducted at the Agricultural Research and Education Center of the American University of Beirut during 1966-67. The objective of this study was to investigate the tolerance of wheat and barley to 2,4-D, sprayed at different stages of growth. The experiments were laid out as split plots in a randomized complete block design with four replications. The stages of growth were considered as the main plots, and the concentrations as the subplots.

Six stages of growth of wheat and barley were sprayed. These included the three-leaf, five-leaf, jointing (in wheat only), booting-to-heading (in barley only), anthesis, soft dough, and the ripe grain stages. The concentrations used were 500, 1000, 2000, 4000, and 8000 ppm (a.e.) of butoxy ethanol ester of 2,4-D (Weedone Lv-6, 62.5% acid equivalent). Handweeded and unweeded plots were included in each replication. The five-leaf stage and the unweeded plots were considered as controls. Phytotoxicity notes were taken on both crops. Data on plant height, grain and straw yield, 1000-kernel weight, test weight, germination percentage, protein percentage, and protein yield were recorded.

All the concentrations sprayed at the three-leaf stage were phytotoxic to both wheat and barley, and resulted in various malformations, and deformities of spikes and leaves. The phytotoxicity increased with an increase in the 2,4-D concentration, and was more pronounced in barley than in wheat. At the five-leaf, jointing, and booting-to-heading stages, only 4000 and 8000 ppm were phytotoxic. At these concentrations, lodging also occurred one day after the application of 2,4-D at the jointing (in wheat only), booting-to-heading (in barley only), anthesis, and soft dough stages of the two crops.

Significant reductions in the plant height of wheat were observed at concentrations ranging from 1000 to 8000 ppm, sprayed at the three-leaf, five-leaf, and jointing stages of growth. At anthesis, only the 4000 and 8000 ppm treatments reduced the plant height significantly. In the case of barley, all the concentrations tested caused significant reductions in height, when sprayed at the three-leaf, booting-to-heading, and anthesis stages. At the five-leaf stage, only the higher concentrations ranging from 2000 to 8000 ppm reduced the plant height significantly.

No significant effect was observed on the straw yields of wheat and barley as a result of spraying different concentrations of 2,4-D at the various stages of growth studied.

The grain yield of wheat was significantly reduced only at 8000 ppm, sprayed at the jointing, and anthesis stages. Other concentrations gave reducing, but not significant effects on the yield. In the case of barley, significant reductions in the grain yield were observed at concentrations ranging from 2000 to 8000 ppm, sprayed at the three-leaf, booting-to-heading, and anthesis stages. In addition to the three higher concentrations, 500 and 1000 ppm at anthesis, and 1000 ppm at the booting-to-heading stages also produced significant reductions in the yield. At the five-leaf stage, 1000 ppm gave a highly significant increase of 18.7% in the grain yield over the unweeded check.

The 4000 and 8000 ppm treatments, sprayed on wheat at the three-leaf, jointing, and soft dough stages of growth reduced the 1000-kernel weight significantly as compared with the unweeded check. In the case of barley, 8000 ppm sprayed at the three-leaf, anthesis, and soft dough stages produced significant reductions in the 1000-kernel weight. In addition, the 2000 and 4000 ppm treatments, applied at the soft dough stage, were also significant in reducing the 1000-kernel weight of barley.

Reductions in the test weight of wheat were significant at concentrations ranging from 2000 to 8000 ppm, sprayed at the jointing stage only; whereas, the above concentrations caused significant reductions in the test weights of barley, when sprayed at the three-leaf, five-leaf, and booting-to-heading stages of growth.

No significant effects were observed on the germination percentages of wheat and barley seeds as a result of 2,4-D treatments at the various stages of growth.

Significant increases in the protein percentages of wheat and barley seeds were observed at concentrations ranging from 2000 to 8000 ppm, sprayed at the jointing, booting-to-heading, and anthesis stages. When sprayed at the three-leaf stage, the 8000 ppm treatment, in the case of wheat, and the 4000 and 8000 ppm treatments, in the case of barley, also caused significant increases in the protein percentages of the two crops.

Protein yields were significantly reduced at concentrations ranging from 2000 to 8000 ppm sprayed at the three-leaf, jointing (in wheat only), booting-to-heading (in barley only), and anthesis stages of growth in both crops. In addition, the 1000 ppm treatment applied at the booting-to-heading stage, and the 500 and 1000 ppm treatments applied at anthesis, reduced the protein yield of barley significantly.

On the basis of the present study, it may be concluded that the application of butoxy ethanol ester of 2,4-D (Weedone Lv-6, 62.5% acid equivalent) at 1000 ppm (a.e.) i.e. two kg per hectare, sprayed at the five-leaf stage of barley was the most effective treatment, which resulted in increased yield, with no adverse effects on the quality, and other agronomic characteristics of the crop.

Therefore, 2,4-D may be recommended for the control of broad-leafed weeds in barley at 1000 ppm, to be sprayed at the five-leaf stage. More work may be done to find out if this rate will significantly increase the yield of wheat, sprayed at the five leaf stage. Also more studies on the effects of 2,4-D on various stages of growth not reported in this work may be done. Since increases in the protein percentages of seeds were observed, as a result of spraying high concentrations of 2,4-D at certain stages of growth, further studies may be made on the effects of the herbicide on the protein quality of the two crops. This work will shed some light on the nutritional values of herbicide-treated cereals, particularly in connection with the limiting amino acids of wheat and barley.

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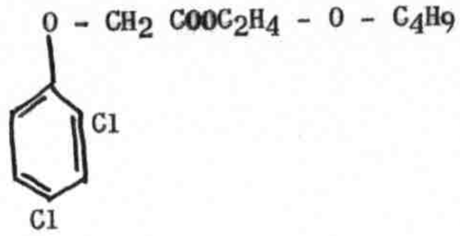
A P P E N D I C E S

Appendix A

Structural formula of 2,4-D



Butoxy ethanol ester of 2,4-Dichlorophenoxy acetic acid.

Appendix B

Table 14. Average monthly temperature, relative humidity, and precipitation during 1966-67 at the A.R.E.C. (A.U.B.) in the Beqa'a plain, Lebanon[x].

Months	Temperature (oC)	Relative humidity (%)	Rainfall (mm)
September	20.2	62.2	0.9
October	16.1	64.1	28.0
November	14.1	63.2	11.0
December	7.3	75.5	187.8
January	4.1	72.8	139.3
February	4.1	78.3	85.1
March	5.9	71.5	167.1
April	10.5	58.6	20.5
May	15.1	56.6	34.5
June	17.9	48.3	0.0
July	20.7	45.5	0.0
August	20.5	48.7	0.0
Total			674.2

x. Meteorological data collected by Reza Soroush and F.M. Malouf, A.R.E.C., Beqa'a, Lebanon.

Appendix C

Table 15. Concentrations and amounts of 2,4-D sprayed at different stages of growth of wheat and barley in 1966-67.

Concentrations of 2,4-D in ppm (a.e.)	Amounts of 2,4-D per plot in g (a.e.)/liter	Amounts of 2,4-D in kg (a.e.)/hectare	Amounts of woodone-Lv-6 in kg/hectare
500	0.5	1	1.6
1000	1	2	3.2
2000	2	4	6.4
4000	4	8	12.8
8000	8	16	25.6

Appendix D

List of weed[x] species found in the experimental plots.

Scientific name	Common name
Anthemis hyalina	Hyaline chamomile
Brassica kaber	Wild mustard
Bupleurum subovatum	Round-leafed Hare's ear
Capsella bursa-pastoris	Shepherd's purse
Chenopodium opulifolium	Maple-leafed goose foot
Cirsium acarna	Yellow plumed thistle
Lamium amplexicaule	Henbit-Bee Nettle
Lolium temulentum	Darnel, Tares
Papaver rhoeas	Field poppy
Saponaria vaccaria	Cow herb
Scandix pecten-veneris	Shepherd's Needle
Silene conoidea	Conoid catchfly
Veronica didyma	Twin speed well
Veronica triphyllos	Trifid-leafed speed well.

x. The identification of weeds was done with the help of Mrs. Winnie Edgecombe, Associate Professor of Taxonomy, Faculty of Agricultural Sciences, A.U.B.

Appendix E

Table 16. Analysis of variance for plant height, straw yield, and grain yield of wheat as affected by different concentrations of 2,4-D, sprayed at six stages of growth in 1966-67.

Source of variation	D.F.	M.S.S. Plant height	Straw yield	Grain yield
Replications	3	374.0	107233	49614^{xx}
Stages	5	3172.8^{xx}	138302^{x}	27279^{x}
Error (a)	15	139.6	32233	7218
Concentrations	6	2788.8^{xx}	32536^{x}	47865^{xx}
Stages X Conc.	30	338.6^{xx}	19190	6000
Error (b)	108	48.8	14246	4624

Table 17. Analysis of variance for plant height, straw yield, and grain yield of barley as affected by different concentrations of 2,4-D, sprayed at six stages of growth in 1966-67.

Source of variation	D.F.	M.S.S. Plant height	Straw yield	Grain yield
Replications	3	102.7	18360	1937
Stages	5	624.3^{xx}	63846	67440^{xx}
Error (a)	15	60.3	28915	698
Concentrations	6	407.5^{xx}	43300	71054^{xx}
Stages X Conc.	30	36.1^{x}	10466	8635^{xx}
Error (b)	108	22.5	77413185	1107

x Significant at 5% level.

xx Significant at 1% level.

Table 18. Analysis of variance for 1000-kernel weight and test weight of wheat as affected by different concentrations of 2,4-D, sprayed at six stages of growth in 1966-67.

Source of variation	D.F.	M.S.S. 1000-kernel weight	M.S.S. Test weight
Replications	3	0.7	28.26^{xx}
Stages	5	51.34^{xx}	14.94^{xx}
Error (a)	15	2.89	2.78
Concentrations	6	54.05^{xx}	5.22^{xx}
Stages X Conc.	30	6.28^{xx}	2.59^{xx}
Error (b)	108	1.06	1.11

Table 19. Analysis of variance for 1000-kernel weight and test weight of barley as affected by different concentrations of 2,4-D, sprayed at six stages of growth in 1966-67.

Source of variation	D.F.	M.S.S. 1000-kernel weight	M.S.S. Test weight
Replications	3	2.33	6.1^{xx}
Stages	5	10.66^{x}	12.9^{xx}
Error (a)	15	3.29	1.07
Concentrations	6	13.46^{xx}	6.9^{xx}
Stages X Conc.	30	2.58^{xx}	1.2^{xx}
Error (b)	108	0.95	0.63

x Significant at 5% level.

xx Significant at 1% level.

Table 20. **Analysis of variance for germination percentage of wheat and barley as affected by different concentrations of 2,4-D, sprayed at six stages of growth in 1966-67.**

Source of variation	D.F.	M.S.S. Wheat	M.S.S. Barley
Replications	3	1.73	1.67
Stages	5	6.16^{x}	11.82^{x}
Error (a)	15	2.07	3.99
Concentrations	6	11.28	2.75
Stages X Conc.	30	1.80	2.91
Error (b)	108	92.46	2.87

Table 21. Analysis of variance for protein percentage and protein yield of wheat as affected by different concentrations of 2,4-D, sprayed at six stages of growth in 1966-67.

Source of variation	D.F.	M.S.S. Protein percentage	M.S.S. Protein yield
Replications	3	1.52^{xx}	977.6^{xx}
Stages	5	1.45^{xx}	379.6^{x}
Error (a)	15	0.22	116.7
Concentrations	6	1.59^{xx}	642.0^{xx}
Stages X Conc.	30	0.29^{xx}	273.8^{xx}
Error (b)	108	0.08	22.4

x Significant at 5% level.

xx Significant at 1% level.

Table 22. Analysis of variance for protein percentage and protein yield of barley as affected by different concentrations of 2,4-D, sprayed at six stages of growth in 1966-67.

Source of variation	D.F.	M.S.S. Protein percentage	M.S.S. Protein yield
Replications	3	0.24	45.1^{x}
Stages	5	2.45^{xx}	508.3^{xx}
Error (a)	15	0.19	9.4
Concentrations	6	1.86^{xx}	562.7^{xx}
Stages X Conc.	30	0.43^{xx}	76.7^{xx}
Error (b)	108	0.09	15.6

x Significant at 5% level.

xx Significant at 1% level.