EXCESS WATER EFFECTS ON
DIFFERENT CROPS

by

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B. Sc. (Ag)., Allahabad University (India). 1953

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1961

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INTRODUCTION

Crop production can be harmed just as much by excessive as by deficient soil moisture. Under farming conditions much has been done to keep soil moisture in or near optimum by irrigation and drainage. While irrigation programs have been supplemented by much research on the performance of plants at low moisture levels, little has been done to gain a better understanding of plant responses in the range of excess soil moisture.

However extensive drainage operations might be, much crop damage will be done from time to time by the flooding of agricultural land, by high water tables, or by water-logged conditions following excessive rain or irrigation. This problem thus warrants further attention.

It would appear from existing information that very little work has been done to determine behavior of different crop plants under conditions of excessive soil moisture. Most of the studies were attempted to see the cause of effect rather than the effect itself.

The present investigation was undertaken to determine the effect of excess water on different crop plants. It was attempted to ascertain the effect of excess water at different stages of growth and development and also the extent of damage due to different durations of flooding.

Although this investigation does not include many species, it will give a general idea of overall effect of excess water on a few crops selected for this purpose; furthermore, this investigation should serve as a basis for future work.

REVIEW OF LITERATURE

The literature reviewed will be presented and the principles concerning previous work will be discussed in the following catagories:

1) Physical and chemical processes in water-logged soils.
2) Physiological behavior of plants grown on water-logged soils.
3) Damage to crops by flooding.
4) Crop yields on drained and undrained land.

The problem of excessive moisture as it affects crop production centres around deficient aeration. Although the work of numerous investigators has established this principle, much of the information collected under laboratory or greenhouse conditions tends to be of limited value in elucidating the problem of excessive moisture and crop production since it occurs under field conditions.

Physical and Chemical Processes in Water-logged Soils.

Soil Aeration. It is generally agreed that a high soil moisture level, as such, need not necessarily harm plant growth, were it not for the fact that such conditions interfere with soil aeration. Much information on the effect of high soil moisture levels on plant growth has been collected in studies on soil aeration. The oxygen content in wet soils is limited not only because of the small amount of oxygen dissolved in water, but also because of the extremely slow rate of gaseous diffusion through such soils (Shiori and Tanada, 1954). The concentration of oxygen in water standing above the soil surface is much higher than that in soil water, and in rice fields in northern California it was found to be subject to diurnal variations (Gerhardt and Darby, 1956). The concentration is lowest just before sunrise and from then on increases gradually to a peak reached in the late afternoon, from where it slowly falls again during the following night. The variation seemingly followed the daily march in photosynthesis.

The rapid disappearance of oxygen from recently flooded soil is generally accompanied by an increase in carbon dioxide concentration. The latter may ultimately constitute more than 50% of all gases dissolved in the soil water (Russell and Appleyard, 1915). It has generally been suggested that the disappearance of oxygen and the increase in carbon dioxide concentration in water-logged soil is due to microbiological activity. In agreement with this, Peech and Boynton (1937) were able to show that changes in the oxidation-reduction potential of a test soil were prevented by adding a few drops of toluene immediately after waterlogging. Yet, Subrahmanyan (1927) was unable to detect an increase in carbon dioxide concentration following the disappearance of oxygen from a flooded soil, and he therefore suggested a non-biological mechanism for the absorption of oxygen. After prolonged submersion only small quantities of carbon dioxide were produced in paddy soils in India. The principal gas produced was methane, with small quantities of hydrogen and nitrogen. The difference in behavior of oxygen in water and in soil points up the difficulty which exists in trying to extrapolate results from aeration studies in culture solution and applying them to field conditions.

Low oxygen levels are not necessarily confined to typically water-logged soils; they may arise temporarily in soils with slow drainage immediately following rain or irrigation, as reported by Furr and Aldrich (1943), Renther and Crawford (1947), Kramer and Jackson (1954). A decrease in oxygen and an increase in carbon dioxide may be accentuated under such conditions, if readily decomposable organic matter is present.

Reducing and Solubilizing Conditions. After dissolved oxygen in a water-logged soil has been used, anaerobic decomposition of organic matter takes place, resulting in the production of incompletely oxidized and reduced organic compounds such as methane or marsh gas, methyl compounds and complex aldehydes. Mineral substances tend to be altered from an oxidized to a reduced state. Pearsall (1950) gives the following transformation from oxidized to reduced state:

1. Nitrate ions to ammonia, nitrite, nitrous oxide and nitrogen gas.
2. Sulfate ions to sulfide ions or hydrogen sulfide.

3. Ferric ions to ferrous ions.

4. Manganic ions to manganous ions.

5. Phosphate ions to phosphine (sometimes).

According to Robinson (1930), toxic concentration of ferrous and sulfide ions may develop within a few days after submergence of a soil; those of manganous ions take somewhat longer to develop.

Waterlogging, and hence reducing conditions, leads generally to a deceleration in the rate of organic matter decomposition. Because of the slowing down in the rate of decomposition, nitrogen tends to remain bound in organic residues and nitrogen is usually a limiting factor to plant growth on poorly-drained soils. Lack of nitrogen fixation (mostly non-symbiotic) under such conditions may accentuate the deficiency. In water-logged soils the rate of nitrogen mineralization decreases rapidly following an initial period of rapid release.

In paddy soils, the decomposition process differs from that in other water-logged soils because the environment in the immediate vicinity of young rice roots is kept in an oxidized state as a result of the excretion of oxygen by roots. The roots are typically coated with ferric hydroxide, the ferric condition of the iron being maintained by the oxygen excreted by the plant roots. The presence of ferric oxide seems to act as a buffer against the formation of hydrogen sulfide near the roots. Because of the oxidizing conditions thus maintained in part of flooded rice soils, the overall rate of decomposition of organic matter in paddy soils was found to be greater where the soil had been planted in rice than where they had remained unplanted (Mitusi, 1954).

Degraded paddy soils are typically leached of iron and exhibit the evolution of considerable quantities of hydrogen sulfide. In that case crops suffer badly from the formation of the sulfide ions. Older rice plants seem to lose some of their capacity to excrete oxygen and at an advanced stage of growth traces of hydrogen sulfide can be seen lodged in the intercellular space of the rice roots. The damage caused by sulfide ions in old paddy soils has probably been accentuated by the repeated application of sulfate containing fertilizers and means are now being studied of applying nitrogen and phosphorus in non-sulfate containing forms (Mitusi, 1954).

The increase in pH which occurs when well-drained soils are submerged and the decrease in pH, which takes place when these soils are drained again, has been related to the presence of sulfate ions in a well-drained soil and of sulfide ions in a water-logged soil (Russell, 1950). The presence of either reduced or oxidized iron and manganese hydroxides has also been held responsible for this behavior (Ponnaderuma, 1955).

Probably most cations and phosphorus become more soluble when soils are waterlogged. Recent knowledge affords an explanation for losses of phosphorus from the upper layers of soil which is in a water-logged condition. Under reducing conditions, part of the total phosphorus in the soil is converted into a soluble form which is subject to being leached out as reported by Glentworth (1947) and McGregor (1953).

Applications of ammonium sulfate to flooded rice fields are generally found more efficient than those of nitrate nitrogen. Nitrogen applied as nitrate tends to be lost by leaching and denitrification where the nitrate lands in a reducing zone. Ammonium nitrogen is less subject to leaching or denitrification, as ammonium ions tend to be adsorbed on the base-exchange complex.

The presence of carbon dioxide in the soil water may lead to the formation of carbonates of iron, calcium, magnesium and manganese, which are then prevented from being leached out as observed by Robinson (1930). Also, for the same reason, a harmful effect on rice of a high concentration of soluble iron and manganese may be overcome by the addition of readily decomposible organic matter (Sturgis, 1936). On the other hand, a harmful effect on yield by the addition of green manure to flooded rice fields in Japan seemed to be related to the formation of butyric acid (Mitusi, 1954).

Physiological Behavior of Plants Grown on Water-logged Soils

Plant Adaptation to Water-logged Conditions. Plants growing naturally on water-logged sites adapt themselves by a superficial root system or by the development of specialized roots which are functional in submerged soil or in water in the absence of external oxygen. The superficial roots have been described as being slender and much branched; they are massed just below the surface of the soil or below that of water where they are supposed to derive sufficient oxygen from their environment by virtue of their large absorbing surface, as observed by Weaver and Himmel (1930), Cannon (1940), Caughey (1945). Conway (1937) reported that as much as 60 percent of the root volume of Cladium mariscus may be taken up by air space. These roots are assumed to be independent of external oxygen by being able to derive oxygen internally from the shoot, perhaps using oxygen released by photosynthesis as suggested by Cannon (1932) and Conway (1940). Conway (1937) found as much as 18 percent oxygen in the intercellulor spaces of Cladium mariscus, even though the root environment was virtually devoid of oxygen.

The significance of the conditions under which roots are formed is also illustrated by the following observations. It has often been noted that as roots die after submergence, or after the oxygen supply to culture solution is cut off, new adventitious roots develop from the base of the stem and these are better adapted to conditions of poor aeration than were the original roots. In some cases these roots may enable plants to survive prolonged periods of flooding. It was observed, for instance, by Bergman (1920) that beans, Impatiens and Pelargonium species, grown in pots developed adventitious roots at the water level one week or ten days after submersion and that from then on the plants were able to survive without artificial aeration. Also, Kramer (1951) observed in tomatoes, that as the original roots died, a well developed adventitious root system formed twelve to fourteen days after submergence. At that time the plants continued growing and formed flowers.

Herbaceous plants are probably better able to form adventitious roots than are woody ones. In flooded young apple trees Heinicke (1932) observed slight tendency for new roots to form from the base of the trunk and at the water level, while in dying yellow poplar seedlings, Kramer (1951) noted that the submerged portion of the stem showed merely protuberances, as adventitious root formation had been initiated.

Little information is available on the role of adventitious root formation on survival of flooded plants under field conditions. The only observations at hand refer to sugar cane plants in Florida, which remained flooded for several months (Satorius and Belcher, 1949). The capacity of the plants to survive the flooding seemed to depend on whether or not adequate adventitious root formation took place. Furthermore, it appeared that new, probably "normal" roots developed again as drained conditions were restored, but this was not clearly indicated.

Adaptation to conditions of submergence, and thus to poor aeration, is not confined to adventitious roots. A number of observations have been made on roots developed at the base of the root system which penetrate into saturated soil just above a water table or even some distance below the water table. It seems quite certain that these roots are adapted in such a way that they are functional in the saturated soil in which they grow. Penetration of roots below the water table has been reported by Osvald (1918), Goedewaagen (1941) and Baumann &

Klauss (1955) for alfalfa; and by Goedewaagen (1952) for wheat. The manner in which these roots operate may be explained from the observations made on roots developed in poorly aerated media, and Kramer (1951) has pointed out that these roots contain much larger intercellular spaces than do roots developed in a well aerated environment. Andrews and Beal (1919) and Bryant (1934), reported that roots of barley, corn, oats, and tomatoes, which had developed in unaerated nutrient solutions contained numerous large intercellular spaces and had thin walls. McPherson (1939) observed more extensive development of air spaces in corn roots in wet soil than in dry soil and in unaerated than in aerated nutrient solutions. McPherson concluded that aerenchyma increases as soil moisture surpasses a certain high level, in other words, as the aeration in the root environment reaches a critical low level.

The differences exhibited by plants in their tendency to develop adventitious roots, and perhaps also to develop intercellular spaces in existing roots, may be a partial explanation for the variation in tolerance to submergence which has been observed. This tolerance is undoubtedly further related to inherent characteristics of the plant. For the moment, there is no detailed explanation for the fact that roots of tobacco plants, beans and *Zinnia*, grown in culture solutions, dried and rotted away within a few days after aeration ceased as observed by Kramer and Jackson (1954), while the roots of actively growing young apple trees survived submergence for two weeks to one month according to Childers and White (1942), and the roots of sunflower remained weakly functional in nonaerated culture solutions as observed by Kramer and Jackson (1954).

Water and Nutrient Uptake. A number of studies have been made in containers on the effect of flooding on the rate of transpiration of plants. The general findings have been that immediately after submergence of the soil, a small increase in the rate of transpiration tends to take place which may last for about one day. This is followed by a sharp decline in transpiration rate. In some cases, as in tomatoes, (Kramer, 1951) and certain forest tree seedlings (Parker 1950), some recovery in the rate of transpiration took place from a few days to several weeks after the flooding started, even though the flooding still continued. This was probably related to the development of adventitious roots. The decline in the rate of transpiration which takes place when plants are flooded reflects the difficulty plants experience in taking up moisture from water-logged soil. This is related to the inhibiting effect on uptake of deficient oxygen and increased concentration of carbon dioxide under such conditions and, as these conditions persist, to the decay of roots and lack of formation of new roots (Kramer, 1933, 1940 and 1951). Kramer and Jackson (1954) discussed the variable rate of water intake with time after flooding and suggested that for plants with a root system which is rapidly killed when submerged, the general pattern is as follows: Following submersion, there is an immediate decrease in water uptake due to lack of aeration.

The rate of uptake then temporarily increases somewhat, probably following the death of some cells in the roots. A second decline in water uptake probably follows the death of the roots, which causes xylem cells to be blocked by decomposition products. Ultimately the rate of uptake of water increases again, presumably by the flow of water through decayed tissue.

From the literature on the effect of aeration on nutrient absorption, specially as stated by Russell (1952), it may be expected that the nutrient uptake by plants is upset by presence of excess water in the soil. This is suggested by certain symptoms which develop under such circumstances, such as a yellowing or reddening of the leaves, or a scorched or stippled appearance - symptoms which, under other conditions, may indicate an unbalance in nutrient supply. This suggestion is supported by a number of examples. Loustalot (1945) found that the percentage of organic nitrogen and of ash was considerably lower in pecan seedlings flooded for 35 days than in those which remained unflooded. A substantial recovery in composition towards that of the unflooded plants, however, was observed 28 days after the flooding ceased, although the flooded plants had not caught up with the unflooded plants. From India it has been reported that the juice of sugarcane plants which had been flooded from July to September (by up to 4 feet of water) had 90% of their nitrogen present as non-protein nitrogen, which accounted for poor quality of juice and for losses in sugar recovery as reported by Khanna and Chackravarti (1949).

Photosynthesis and Respiration. The rate of photosynthesis followed the same trend as that of transpiration, but was reported by Loustalot (1945) to be slightly more depressed and to decline sooner after flooding than the transpiration rate. Measurements made by Hunter and Rich (1925), Kempner (1936), and Steward et.al. (1936) on the effect of deficient aeration on the rate of respiration suggest that the march of respiration in flooded plants may be in line with that of transpiration and photosynthesis, but Childers and White (1942), reported that the rate of respiration markedly increased after flooding.

Causes of Damage to Plants. Kramer and Jackson (1954) determined, in a pot experiment with tobacco, the extent damage caused by flooding the soil could be explained from deficient aeration. Results obtained show that although artificial aeration considerably reduced injury, damage was not eliminated by the aeration treatments. The data did not support the conclusion that an increase in carbon dioxide level in water-logged soils may be even more harmful than a low level of oxygen, as has been observed on other occasions by Kramer and Jackson (1954).

As was pointed out by Kramer (1951), lack of aeration, and consequent interference with water and nutrient uptake, does not seem to provide a complete and satisfactory explanation for the injury which is generally observed. It has already been noted that toxic concentration of ferrous and sulfide ions may build up quite soon after waterlogging, while organic compounds may be produced by anaerobic decomposition which are also harmful to plant growth. One of these compounds is methane, which, as Vlamis and Davis (1944) found, inhibits the growth of tomato plants completely and affects barley more adversely than does aeration by nitrogen gas. It is reported (Mitusi, 1954) that hydrogen sulfide inhibits seriously the uptake of both minerals and water in rice plants under field conditions in Japan, with the uptake of phosphorus and potassium being most affected.

Kramer (1951) quoted that anaerobic conditions interfere with the translocation of auxins and carbohydrates through the plant and suggested that these substances are conveyed down the shoot as far as the plant is aerated (that is, to the water level) where an accumulation of these substances results in abnormally luxuriant cell growth (hypertrophy) and the formation of adventitious roots. He further pointed out that certain symptoms in flooded plants, such as twisting of the lower leaves and the development of a wider leaf angle, do not suggest reduced turgor in the cells concerned. To the contrary, a sustained turgidity and an accumulation of auxins prevented from moving downward into the roots could well account for these symptoms. On the other symptoms of wilting, often associated with flooded plants, indicated that a turgid condition is by no means maintained in all parts of the plant.

According to some investigators (Woodford and Gregory, 1948), injury due to lack of aeration is more severe at low than at high levels of nutrition. Barley could be grown for 12 days in a nitrogen atmosphere and in the absence of oxygen without being much affected, as long as the nutrient concentration was four times that of an aerated solution. Also, the observations that plants are more readily injured in unaerated water than in unaerated nutrient solutions suggest that nutrient availability has an effect on the degree of injury. This thesis is further strengthened by the observations made by Saukko (1946), working with grain and forage crop experiments in Finland where less injury by flooding in heavily fertilized plots than in less fertilized ones was obtained.

With respect to a possible recovery from waterlogging, relevent information has been quoted under plant adaptation. It was pointed out that adventitious root formation may insure survival of the plant. Heinicke (1932) reported that injured leaves became normal again after flooding ceased; and in overcupoak Parker (1950) observed that, after leaves damaged as a consequence of flooding had been shed, the plant sent out a new crop of leaves which were able to withstand further conditions of flooding. In other cases, however, plant organs are irreparably damaged (Richards, 1929). It would be of interest to establish under which conditions recovery of damaged organs is possible.

Damage to Crops by Flooding

Although the flooding of crops for anything but a short period tends to be harmful, there are instances where flooding is used to advantage, the production of lowland rice being the out-standing example. The practice of flood-fallowing sugarcane land in British Guiana seems to have beneficial effect on the next sugarcane crop. This is probably due to iron being solubilized under the submerged conditions and reprecipitated upon drainage, and to a beneficial effect on the soil structure (Follett-Smith and Robinson, 1936).

Other isolated reports show that flooding can sometimes be used to control weeds in rice fields, by keeping the flood water at a certain level (Davis, 1950), to control parasites and nematodes or to generally disinfect the soil (Moore, 1949).

Overall Flood Damage. In general, crop plants can withstand flooding fairly well when they are in a dormant state, but flooding during the off-growing season may affect subsequent crop yields because of a deterioration in soil structure or by the effect of silt deposits left behind by the flood waters. While the plants are actively growing, the injury depends on their stage of growth at the time of flooding. In general, the organ most affected is the one undergoing most rapid development at the time the flooding occurs (Luthin, 1957). The prevalent temperatures at the time of flooding markedly affect the degree of injury, and the severe damage which occurs on hot days as a result of flooding is referred to as "scalding". Some plants, for example pear trees, certain forest trees and some grasses, can withstand flooding during the growing season for a considerable length of time without suffering apparent ill-effects.

This general situation is illustrated by specific examples for individual crops in the following sections.

Grassland and Forage Crops. Little is known about the effect of flooding on permanent grassland during the off-growing season. Where the sward is truely dormant, little damage may be done (Davis and Martin, 1949), although a reduction in yield in the following growing season has been reported (Westra and Visser, 1952), apparently as a result of the deterioration in soil structure. Where grassland is not fully dormant during the winter, and where livestock is left in the field, damage may be somewhat accentuated by the trampling of the surface of water-logged soils, but a vigorous sward in the following growing season can do much to restore soil structure.

During the spring, flooding affects the viability of seed and retards plant development. The resistance to spring flooding of certain forage crops was determined by Bolton and McKenzie (1946) under field conditions in western Canada. In their experiment 100 percent damage was reported in alfalfa stands after 21 days of flooding. In the same paper they reported the range of days which forage crops can be spring flooded without incurring excessive damage in western Canada. It was found that different species could withstand flooding for various duration without incurring excessive damage; sweet clover, 9 to 12 days; alfalfa, 10-14 days; crested wheatgrass, 10-17 days; bromegrass, 24-28 days; slender wheatgrass, 31-35 days; meadow fescue, 24-35 days; timothy and reed canarygrass, 49 days. Reed canarygrass was particularly resistant to flooding. The work of McKenzie et. al. (1949) in a glasshouse experiment determined the manner in which the viability of the seed of other forage crops is affected by flooding the field after sowing. Sweet clover, strawberry clover and red clover showed negligible germination at the end of 3 weeks of flooding, but alsike clover and alfalfa emerged fairly well at that time. The seed of various grasses tested withstood submersion well, and after the longest period tested (12 weeks), only the seed of intermediate wheatgrass germinated poorly after submersion.

From Finland (Kaitera, 1941) it is reported that during late April or early May, before thawing, clover could withstand inundation for two weeks, while timothy could tolerate even longer periods of flooding. Later in the growing season, however, clover was rapidly damaged. Near the end of the summer the susceptibility of clover to flooding tended to be even greater, perhaps related to the relatively high temperatures at that time. Timothy was killed by a three-week flood in August (Saukko, 1950-51).

Experience in California has shown that narrow leaf trefoil (*Lotus tenuis* Crand.) is quite tolerant to flooding and is, in fact, the most tolerant legume forage crop known under California conditions. Similarily, tall fescue and Dallis grass (*Phalaris tuberosa*) are quite resistant to submersion, more so than rye grass or orchard grass (*Dactylis glomerata*).

<u>Cereal Crops</u>. Cereals pass through three growth stages: vegetative development, grain formation, and grain maturation. Cereals seem to differ from forage crops in that they are particularly sensitive to flooding during the flowering stage, and flooding then may affect the yield more than at any other time. During the last stage, however, that of grain maturation, flooding has generally been found to affect the yield relatively little. It is reported (Saukko, 1946) that winter cereals in Finland were rather tolerant to flooding during the winter months when they are growing slowly. During the spring, the main effect of flooding was to eliminate the weaker plants; those that survived tended to recover after drainage. In that case, the weight of the individual grains at the time of harvesting was little affected, but a loss in yield was suffered because of the smaller plant population. This point was illustrated (Kaitera, 1935) in a pot experiment in which barley, oats and rye were flooded for varying periods soon after germination. The effect was evaluated at the time of maturation. The results indicated a 50% reduction in grain yield in case of barley when seedlings were inaundated for two days, 15 days after germination and the grain yield was reduced by 66% when inaundation was done five days after germination for two to five days. It was further observed that with an increase in the duration of inaundation, there was delay in the time of ear formation.

Flooding during flowering and initial grain formation can result in total loss of the crop. It was found (Saukko, 1950-51) that under Finnish conditions, rye was not as severely affected as barley and oats. During the period of grain maturation cereal crops were found to be relatively tolerant to flooding. The same investigator further reported that rye and oats at grain maturation could tolerate thin coverings of water lasting for a month, provided that the crop did not suffer from wave action. Spring wheat was reported to exhibit about the same tolerance as oats to water-logged soil; but under California conditions, wheat is considered to be more tolerant than either barley or oats. It is, therefore, prefered as a rotational crop on wet rice land (Luthin, 1957).

Upland rice is severely damaged by accidental flooding during the flowering stage, and also 15 to 20 days after transplanting, but is relatively resistant to flooding a few days after transplanting or during grain maturation, (Kondo and Okamura, 1932).

Fruit Trees. Fruit trees are regarded as being generally susceptible to injury by waterlogging, more so than any other crop. The cases which have been recorded show that injury by flooding varies considerably according to the variety of fruit and according to the time of the year the water-logged conditions prevail.

Pear trees are particularly resistant to flooding. Kienholz (1946) reported on an orchard in Oregon which was flooded from April till August in 1943 and then again for varying periods during 1944 and 1945. In spite of this drastic treatment, only a few trees at the lowest level of the orchard died in 1943, although many trees appeared to be girdled.

In contrast to the high resistance to flooding in pears, a single row of apricot trees at the highest level in the orchard died within two weeks after the flooding started in 1943. A similar response was reported from the Nile Valley, where apricot, plum and peach trees died a few days after a 12-day flood of the Nile river commenced, even where the soil was covered by only five to 18 in. of water (Luthin, 1957).

Other Crops. Irrigated cotton and grain sorghum grown on fine textured alluvial soils in the San Joaquin Valley in California can be flooded for several days during the hot summer months without suffering damage; but under the same circumstances alfalfa, beans, tomatoes and clover suffered severe injury. Albert and Armstrong (1931) found, however, that water-logged conditions may lead to an increased shedding of young fruit buds in cotton at an unduly early stage; though Selman and Rouse (1955) pointed out that early fruiting and maturity is induced under such conditions if sodium and potassium levels are high.

Spooner (1960) working with soybeans observed that one variety (Lee) apparently was capable of handling the 21 days of water saturation whereas another variety (Dorman) responded differently. The yield of the latter was reduced considerably (almost to half) after the seven-day treatment.

Quality of crops may also be affected by excessive moisture. Although pears are able to survive periods of prolonged floodings, even during the growing season, the quality of the fruit tends to be adversely affected. Heinicke et. al. (1939) and Kienholz (1946) reported that cork formation in and on the fruit may result. Bartlett pears grown under conditions of high soil moisture were lower in dry matter content and less firm and they suffered more from core breakdown than did pears which were grown under drier conditions. Anjou pears grown under conditions of high soil moisture were unduly soft and were subject to soft scald. Over-irrigated Jonathan apples became bigger than normal, but they were easily bruised on handling, and on storage fruit decayed more rapidly than fruit from drier treatments. Also, the flavor of fruit grown at high soil moisture level tends to be impaired (Gourley and Howlett, 1941).

In vegetables, as in fruit, conditions of excessive soil moisture may have a deleterious effect on the quality, by inducing long internodes and "leggy" growth. The large turgid cells produced under such conditions are subject to bursting, and cracks in the foilage may develop (Edmond et. al. 1951).

There are many reports of losses suffered as a result of quality deterioration under conditions of excessive moisture during maturation and harvesting, but in most cases this is an indirect effect of high soil moisture in that the losses are caused by parasitic attacks (Heald, 1943; Wilson, 1932).

Crop Yields on Drained and Undrained Land

A generalization on the benefits which can be obtained from removing excess water from the land is difficult, as recent work has shown that it is not yet clear what is meant by excess water. Uncontrolled deep drainage is warranted only where excess water is supplied to the soil surface during the growing season by rainfall or irrigation. From the examples quoted by Russell (1934), it appears that an excessive lowering of the water table may actually lead to a decrease in crop yield; thus the determination of a possible optimum depth of drainage has become a new field of research in which much has yet to be learned. It is reported from Finland (Kaitera, 1941) that drainage generally leads to better crop production and increased land values. Individual reports of increases in crop yields following drainage have little general value, because of the over-riding influence of local conditions. Examples of such increases were reported by McCall, 1928; for rotational crops in Maryland; by Zon and Averell, 1929; for swamp forest in Wisconsin; and Saveson, 1950; for sugarcane in Louisiana. In some cases, it has been pointed out that the benefits may not reach a maximum till some time after drainage, as it may take some time for the soil structure to improve.

Jongedyk _et. al._ (1954) concluded that soil structure is adversely affected by an undue high water table during winter. Westra and Visser (1952) noted that flooding of pastures during the winter reduced the yield in the subsequent season. General indications are that relatively deep drainage in winter is beneficial, as this has a favorable effect on soil structure (Bloemen, 1951).

MATERIALS AND METHODS

A greenhouse study was conducted to determine the effect of excess water on wheat, barley, soybeans, corn, grain sorghum and three forage legumes. For the convenience of presentation, this section is divided as follows:

1. Wheat-Barley study.
2. Oats study.
3. Soybeans study.
4. Comparative responses of corn, soybean and grain sorghum.
5. Forage legume comparison.

Wheat-Barley Study

Two commonly grown cereals, Pawnee wheat and Dicktoo barley were selected for this study. Seeds were sown in clay pots filled with a silt loam soil on October 17th, 1960, and subsequently thinned to two seedlings per pot after emergence. These plants were grown and vernalized outside the greenhouse and were taken to the greenhouse on December 17, 1960, i.e. after two months.

A randomized complete Block design was used with six replications. The pots were flooded for 0, 7, 14 and 21 days at vegetative, elongation and bloom stages. Corks were used to plug the pots and during the required duration of flooding the soil was kept saturated with water and ¼ to ½ inch of free water was left at the surface. The pots were, however, drained immediately after each duration of waterlogging. All pots were adequately fertilized with Ammonium Phosphate (16-48-0) applied in two installments.

During the experiment, notes were taken on time of heading and bloom. The crops were harvested on April 29, 1961, and the yield of straw and grains recorded separately, as grams per pot.

Oats Study

Seeds of Andrew variety were sown on December 21, 1960, in clay pots and subsequently thinned to two seedlings in each pot.

The treatments employed were: flooded in the vegetative stage for 21 days, flooded in the elongation stage (21 days), at bloom stage (21 days), at elongation and bloom stages of 21 days each, at vegetative and elongation (21 days each), and at vegetative and bloom stages (21 days each). Some pots, however, received no flooding and served as check.

As in the previous study, corks were used to plug the pots during the waterlogging. The pots receiving two floodings were similarly treated. All pots were adequately fertilized with Ammonium phosphate. The time of heading and bloom was recorded. The crop was harvested on April 22, 1961. The yield was recorded as total dry matter in grams per pot.

Soybeans Study

In this experiment the Shelby variety was sown in glazed pots March 9, 1961, and the stand was thinned to two seedlings in each pot after germination.

A randomized complete block design with six replications was used in this experiment. The study was originally designed to determine the effect of excess water at different stages of growth and development. However, the experiment was curtailed and the data presented are confined to 21 days of flooding at pre-bloom stage and five days at bloom stage, plus a check treatment (no flooding). The water was applied at the pre-bloom stage when each plant was in the first trifoliate stage. The crop was harvested on April 15, 1961, and total dry matter (oven dry) was recorded in grams per pot.

Comparative Responses of Corn, Soybean and Grain Sorghum

This experiment was initiated to determine the comparative ability of corn, soybean and grain sorghum to withstand excess moisture. K 4003 corn, Shelby soybeans and RS 610 grain sorghum were used. The seeds were sown on March 9, 1961 in eight-inch glazed pots and thinned to two seedlings in each pot after emergence. Each pot received equal quantity of Ammonium Phosphate, applied once.

A split plot design was used with six replications. Species were whole plots and the durations (0, 7, 14, and 21 days) used were sub-plots. Rubber stoppers were used to plug the pots during flooding.

All pots were simultaneously flooded when soybeans were in the first trifoliate stage, corn in five leaf and grain sorghum in four leaf stages.

The crop was harvested on April 22nd and the yields were recorded as total dry matter (oven dry) in grams per pot.

Forage Legume Comparison

Alfalfa (Medicago sativa), birdsfoot trefoil (Lotus corniculatus) and crown vetch (Coronella varia) were selected for this study. Four strains were included for each of the above species under study, and each was subjected to both excess and ideal moisture conditions, immediately after first trifoliate condition, till the first harvest. No. 10 tin cans containing a silt-loam soil were used.

On March 9, 1961, Cody, Rhizoma, Rambler and Narraganset varieties of alfalfa, Empire, Viking, French and Fargo varieties of birdsfoot trefoil; and Beltsville, Penn., Iowa (SCS) and Mo. (SCS) strains of crown vetch were sown. The experimental design was a split-split plot. Species were whole plots, strains within species were sub-plots; and moisture level (excess vs. ideal) constituted the sub-sub plot. The seeds were scarified before sowing. Seedlings were thinned to ten in each can and flooded at first trifoliate stage.

The first harvest was made 21 days after flooding and the yield was recorded of total dry matter in mgm. per plant. The number of plants surviving at the time of harvest was also recorded.

After the first harvest, the cans were drained and all plants were kept under ideal growth conditions until May 20, 1961 when they were again harvested to measure recovery. Again, the number of plants harvested per can was recorded to determine the survival and the yield was recorded as total dry matter in mgm. per plant.

After seven days of regrowth after the previous harvest, the pots that received excess water treatment previously were again flooded for 14 days. The number of plants harvested was counted and the yield was recorded as total dry matter in mgm. per plant.

EXPERIMENTAL RESULTS AND DISCUSSION

This section is subdivided into the following for the convenience of discussion.

1. Wheat and Barley.
2. Oats.
3. Soybeans.
4. Corn, soybean and grain sorghum.
5. Forage legumes.

Wheat and Barley

Results of this experiment are presented in Tables 1 and 2. Insofar as straw yield was concerned, it appeared that both wheat and barley were not greatly affected by durations of flooding ranging from 0 to 21 days. Also, application of excess water at any particular stage seemed to have little effect. Although non-significant decreases in straw yield were found, in general it appeared that barley was affected to a greater degree than wheat, as expected from the review of literature. The porous pots also might have influenced the intensity of the decrease and hence, also, the results.

With grain yield, a significant decrease was observed in both wheat and barley when excess water was applied, particularly at the bloom stage. Barley was more affected than wheat. The differential response was shown by the significant interaction between species and treatment (Table 1). It would thus appear that winter wheat might be expected to tolerate the water-logged conditions better than winter barley. The data further revealed that with increasing duration of flooding there is a tendency for further decrease in yield, though significant only at the 10% level.

For total dry matter yield (Table 1), it appeared that the stage of growth at which flooding was applied seemed to have more effect than other variables. Total dry matter yield of both wheat and barley combined was significantly decreased when flooded in the flowering stage. But when the data were analyzed separately, this difference was significant only in the case of barley (Table 2).

A significant interaction was observed between species and treatment for time of heading (Table 1). In general, a

Table 1. The influence of stage of flooding and duration of flooding on yield and maturity in winter wheat and winter barley.

Crops	Stage of flooding	Duration in days	Yield of dry matters gm/per pot: Straw	Grain	Total	Days from planting to heading	Days from planting to bloom
Wheat	Check	0	13.8	8.1	21.9	128	132
	Vegetative	7	11.8	5.7	17.5	133	135
	Do	14	16.9	10.5	27.4	133	136
	Do	21	11.1	4.4	15.5	139	141
	Elongation	7	12.4	6.6	19.0	131	134
	Do	14	11.2	6.3	17.5	135	138
	Do	21	12.5	4.2	16.7	138	141
	Flowering	7	11.8	4.2	16.0	136	139
	Do	14	12.9	4.3	17.2	135	137
	Do	21	13.7	3.6	17.3	133	136
Barley	Check	0	17.2	10.3	27.5	115	126
	Vegetative	7	17.5	10.9	28.4	114	127
	Do	14	16.8	10.1	26.9	116	125
	Do	21	15.6	8.6	24.2	116	127
	Elongation	7	18.6	12.7	31.3	120	128
	Do	14	16.6	13.5	30.1	119	128
	Do	21	13.9	11.6	25.5	113	124
	Flowering	7	12.0	5.5	17.5	117	128
	Do	14	12.2	6.7	18.9	116	127
	Do	21	15.5	6.1	21.6	115	126
LSD, 5% level			N.S.	3.8	8.3	5	N.S.

Analysis of variance

Source of Variation	DF	Mean Squares: Straw	Grain	Total	Heading	Bloom
Replications	5	43.52+	9.22	48.12	23.20	14.80
Species	1	233.70**	440.03**	1156.05**	9816.00**	3264.00**
Repl. x Spec.	5	9.57	10.80	45.63	28.86	15.81
Treatments	9	25.99	54.63**	134.19**	35.89+	28.61
Check vs Others	1	22.11	30.74+	90.19	170.00**	—
Stages	2	34.00	169.31**	395.32**	5.00	—
Duration	2	4.75	42.15+	48.28	0.00	—
Stages x Duration	4	35.62	9.20	57.58	35.75	—
Species x Treatment	9	19.88	21.05+	65.03	49.6 *	36.89
Error	30	19.48	10.99	51.90	20.14	21.73

+ Significant at 10% level
* Significant at 5% level
** Significant at 1% level

significant delay in heading was observed only in the case of wheat. Waterlogging was found to have little effect on the time required for heading in barley and for time to bloom in wheat and barley.

Though the porous clay pots used in the experiment might have influenced the extent of damage from excess water, Pawnee winter wheat appeared to be more tolerant than Dicktoo winter barley to the excess water condition.

Oats

Results of the oats experiment are presented in Table 3. A general decrease in total dry matter yield due to waterlogging was noticed, with the highest yield being obtained from the check pots followed by pots flooded only once. The lowest yield was obtained from pots flooded at vegetative and at bloom stages. Analysis of variance, however, revealed no significant differences among treatments. A major problem in conducting the experiment was the control of variability in the greenhouse.

Results of this experiment, and the findings of other workers, suggest that in grasses probably grain yield is severely reduced if water-logged conditions prevail during the blooming period. In the present study, the oats crop was expected to behave similarly, but little grain was formed. This was presumably due to rather late seeding and occurrance of rather high temperature during and following bloom. Furthermore, the porous clay pots might have influenced the results, particularly in the pots that were kept

Table 2. The effect of flooding at different stages of growth on the yields of straw, grain and total dry matter in wheat and barley.

Crops	Stage of flooding	Total dry matter gm/per pot		
		Straw	Grain	Total dry matter
Wheat	Vegetative	13.3	6.9	20.2
	Elongation	12.1	5.7	17.8
	Flowering	12.8	4.0	16.8
Barley	Vegetative	16.6	9.9	26.5
	Elongation	16.4	12.6	29.0
	Flowering	13.2	6.1	19.3
LSD, 5% level		N.S.	2.9	4.8

under flooded conditions continuously for 42 days (i.e. vegetative plus elongation and elongation plus bloom treatments).

The time required for heading and for bloom (Table 3) was also unaffected by the excess water treatment.

Soybeans

As shown in Table 4, excess water had little effect on dry matter yield of soybeans. Analysis of variance showed a non-significant treatment variance. Thus, excess water for 21 days in pre-bloom stage or five days at bloom stage was ineffective in reducing dry matter yield. This would suggest that soybeans have considerable tolerance to excess moisture.

Corn, Soybeans and Grain Sorghum

Results of this experiment are presented in Table 5. Analysis of variance of the data revealed a highly significant interaction between species and duration of waterlogging. Of the three crops tested, corn appeared to be most susceptible to damage. There was a considerable decrease in the dry weight of corn as the duration of waterlogging increased. A statistically signigicant decrease was found when the duration was increased from 7 to 14 days and onwards. There was no significant difference in yield between the check and 7 days of flooding. Grain sorghum was affected somewhat less by flooding than was corn. A significant decrease in dry matter yield was observed when the duration was increased from 14 to 21 days. There was,

Table 3. Effect of excess water on total dry matter yield and days from planting to heading and bloom in oats.

Stage of flooding	Total dry matter gm/pot	Days from planting to heading	Days from planting to bloom
Check (no flooding)	17.8	53	57
Vegetative	16.5	53	57
Elongation	13.1	54	57
Bloom	13.7	57	61
Veget. + Elong.	14.3	55	59
Elong. + Bloom	11.6	53	57
Veget. + Bloom	10.5	55	59
LSD, 5% level	N.S.	N.S.	N.S.

Analysis of variance

Source of Variation	D.F.	Mean squares		
		Dry matter	Days from planting to heading	Days from planting to bloom
Replications	7	24.15	17.83+	34.2190*
Treatments	6	53.15	16.91	20.9820
Error	42	28.15	9.35	12.2684

+ Significant at 10% level
* Significant at 5% level

Table 4. Dry matter yield of soybeans as influenced by stage and duration of flooding.

Stage of flooding	Duration in days	Dry matter yield gm/per pot
Check	0	2.57
Pre-bloom	21	2.01
Bloom	5	2.41
LSD, 5% level		N.S.

Analysis of variance

Source	D.F.	M.S.
Replications	11	1.88
Treatments	2	1.00
Error	33	0.83

however, no significant difference in yield between 0, 7 and 14 days of treatment.

As expected, the soybeans tolerated the water-logged condition much better than either corn or grain sorghum. Significant differences in dry matter yield were not found between treated and untreated pots. This supports the findings of the previous experiment in that waterlogging did not significantly influence yields.

It is interesting to note that an overall linear relationship was found for dry matter yield (analysis of variance, Table 5). The yield trend was downwards with increased duration of waterlogging.

The orthogonal comparison between grasses (corn and sorghum) and soybeans revealed that these behaved differently under water-logged conditions. This was obviously due to the tolerance of the legume (soybeans) and susceptibility of the grasses. Statistical analysis further revealed that the linear relationship was different for grasses than for soybeans. The comparison between corn and grain sorghum also revealed a significant difference in the linear trend. This was due to higher susceptibility of corn than grain sorghum.

These results suggest that, of these three crops, corn would be most susceptible to water-logged conditions. Grain sorghum probably could endure more waterlogging than corn, but less than soybeans. It would thus appear that soybeans and grain sorghum

Table 5. Comparative response of corn, soybean and grain sorghum to water-logged conditions.

Crop	Duration of flooding days	Total dry matter gm per pot
Corn	0	28.1
	7	26.0
	14	18.7
	21	16.0
Soybeans	0	3.4
	7	3.2
	14	2.7
	21	2.3
Grain Sorghum	0	10.6
	7	11.4
	14	10.8
	21	7.0
LSD, 5% level		3.2

Analysis of variance

Source of variation	D.F.	M.S.
Main plot:		
Species	2	2299.85**
Replications	5	2.99
Error	10	9.92
Sub-plot:		
Duration	3	121.93**
Duration x species	6	50.03**
Error	45	7.43
(orthogonal comparisons)		
Grasses _vs_ legume	1	2785.64**
Corn _vs_ sorghum	1	1813.88**
Linear	1	344.04**
Quadratic	1	13.83
Cubic	1	7.89
Grasses _vs_ legume x linear	1	109.54**
Grasses _vs_ legume x quadr.	1	5.35
Grasses _vs_ legume x cubic	1	2.76
Corn _vs_ sorghum x linear	1	154.03**
Corn _vs_ sorghum x quadr.	1	13.14
Corn _vs_ sorghum x cubic	1	38.81*

* Significant at 5% level
** Significant at 1% level

would be preferred over corn as crops for sites subject to waterlogged conditions.

Forage Legumes

The results obtained after first harvest are presented in the Tables 6, 7, 8 and 9. Analysis of variance revealed highly significant differences among species for dry matter yield. Water level also significantly affected yield; species and water level, however, interacted. Alfalfa yields at the ideal water level were significantly greater than with the excess water level. Alfalfa outyielded birdsfoot trefoil and crown vetch at both water levels. Of three species studied, on a relative basis, crown vetch dry matter yield was most seriously affected by excess moisture. On the average, birdsfoot trefoil showed the greatest tolerance to waterlogging. Only alfalfa actual dry matter yields, however, were decreased significantly by excess water conditions. Strains within species contributed significantly to variability, but a significant interaction between strains within species and water level was also observed (Table 6). Dry matter yields of each of the four strains of alfalfa were significantly decreased under water-logged conditions. Individual strains of birdsfoot trefoil did not exhibit such a great yield reduction, particularly Empire (Table 6). Yields of each of the four strains of crown vetch were reduced by excess water to about the same relative degree. This probably indicates that all four strains of crown vetch were equally susceptible to excess water damage.

Table 6. Effect of first flooding on dry matter yield and survival percentage of forage legumes.

Crops	Strains	Water level	Total dry matter: mgm/per plant	Survival percentage
Alfalfa	Cody	excess	20.6	100
		ideal	61.2	100
	Rhizoma	excess	26.3	100
		ideal	82.9	100
	Rambler	excess	16.5	100
		ideal	71.5	100
	Narragansett	excess	26.5	96
		ideal	78.9	100
Birdsfoot Trefoil	Empire	excess	10.2	92
		ideal	10.7	100
	Viking	excess	13.3	97
		ideal	21.3	100
	French	excess	12.1	96
		ideal	18.6	100
	Fargo	excess	11.7	98
		ideal	13.2	100
Crown Vetch	Beltsville	excess	7.4	72
		ideal	35.1	98
	Penn.	excess	4.6	55
		ideal	23.7	100
	Iowa (SCS)	excess	4.3	65
		ideal	31.7	100
	Mo. (SCS)	excess	4.0	59
		ideal	22.0	100
LSD, 5% level			31.3	N.S.

Analysis of variance

Source of variation	D.F.	M.S. dry matter	M.S. survival %
Replication	4	370.27	100.00
Species	2	14410.46**	4130.00**
Reps. x spec. (error a)	8	104.42	41.88
Strains: species	9	3428.40**	963.59**
Reps. x strains (error b)	36	126.31	220.23
Water level	1	20431.08**	5875.00*
Water x species	2	5594.50*	3894.05*
Reps. x water / Reps. x water x spec. (error c)	12	1262.48	777.02
Water x strains: species	9	65943.00**	930.81
Reps. x water x str.: species (error d)	36	597.26	694.27

* Significant at 5% level
** Significant at 1% level

Table 7. Mean dry matter yield of three legumes under ideal and excess moisture.

Crops	Dry matter, mgm/per plant	
	Excess	Ideal
Alfalfa	22.5	73.6
Birdsfoot Trefoil	11.8	15.9
Corwn Vetch	5.1	28.1
LSD, 5% level	24.5	

Table 8. Survival percentages of three legumes as affected by moisture level.

Crops	Excess	Ideal
Alfalfa	99	100
Birdsfoot Trefoil	96	100
Crown Vetch	63	100
LSD, 5% level	19	

The survival percentage at the time of first harvest varied significantly among species and between water levels. Water level and species interacted (Table 9). Survival of crown vetch was significantly decreased with excess water. Also, survival of crown vetch was significantly lower than that of alfalfa and birdsfoot trefoil with both water levels (Table 8). Stands of alfalfa and birdsfoot trefoil were unaffected by waterlogging.

The results obtained when the recovery growth was harvested are summarized in Tables 10, 11 and 12. Analysis of variance showed significant differences among species (Table 11). Recovery of alfalfa was significantly less than that of birdsfoot trefoil and crown vetch (Table 12). This was due to complete failure of Rambler and Narraganset strains of alfalfa to recover from the effect of the previous excess water treatment (Table 10). The recovery growth of birdsfoot trefoil and crown vetch, however, showed no such effect, (Table 11). French variety showed lowest recovery among the four varieties of birdsfoot trefoil tested. The other varieties of birdsfoot trefoil, alfalfa and crown vetch did not show significant differences in recovery. The interaction between water level and species was found to be significant at 10% level.

Survival percentage after recovery showed significant differences between water levels and also among strains within species (Table 11). It appeared that there was an overall effect of water level on the survival percentage in the recovery growth. This was due to failure of Rhizoma, Rambler and Narraganset

Table 9. Survival percentage of different strain of three forage legumes after initial flooding.

Crops	Strains	Survival percentage
Alfalfa	Cody	100
	Rhizoma	100
	Rambler	100
	Narraganset	98
Birdsfoot Trefoil	Empire	96
	Viking	99
	French	98
	Fargo	99
Crown Vetch	Beltsville	85
	Penn.	77
	Iowa (SCS)	82
	Mo. (SCS)	79
LSD, 5% level		13

Table 10. Influence of previous water level on dry matter yield and survival percentage of different strains of three legumes.

Crops	Strains	Water level	Total dry matter mgm/per plant	Survival percentage
Alfalfa	Cody	excess	104.4	61.4
		ideal	168.9	86.0
	Rhizoma	excess	132.7	9.0
		ideal	91.0	78.8
	Rambler	excess	0	0
		ideal	106.8	68.0
	Narragansett	excess	0	0
		ideal	183.2	44.0
Birdsfoot Trefoil	Empire	excess	154.7	39.6
		ideal	122.9	49.4
	Viking	excess	154.8	67.6
		ideal	174.3	50.0
	French	excess	281.4	63.2
		ideal	120.1	83.6
	Fargo	excess	119.3	69.2
		ideal	116.0	44.2
Crown Vetch	Beltsville	excess	149.6	33.2
		ideal	137.2	58.6
	Penn.	excess	56.5	14.8
		ideal	157.9	78.0
	Iowa (SCS)	excess	98.8	62.0
		ideal	304.0	72.0
	Mo. (SCS)	excess	146.4	56.2
		ideal	205.8	64.5
LSD, 5% level			N.S.	N.S.

strains of alfalfa to recover from the effect of excess water. These were significantly lower in survival than cody and also lower than the varieties of birdsfoot trefoil and crown vetch (Table 11).

The results of reflooding the plants after allowing recovery growth are summarized in Tables 13 and 14. Analysis of variance of dry matter yield per plant (Table 14) revealed a significant difference between water levels (at 5%) and among species (10% level). Although an overall effect of excess water was noted in the second flooding, as was the case in the first, differential response among species was not detected. This was possibly due to shorter duration (14 days) of flooding the second time than the first one (21 days).

With regard to survival percentage, the species effect was significant. The water level effect was significant at the 5% level. Thus, there was an overall significant effect of excess water on the survival, which was largly due to crown vetch which showed a greater mortality in comparison after the second flooding with alfalfa and birdsfoot trefoil (Table 14). The species and water level also interacted though at 10% level. Also, strains within species variance was highly significant. Further, analysis revealed a highly significant strains within species by water levels interaction. The survival percentages of Rhizoma, Rambler, and Narraganset varieties of alfalfa under waterlogging were significantly less than their survival under ideal conditions and also from Cody under both conditions. Penn., Mo. (SCS), and

Table 11. Influence of previous water level on dry matter yield and survival percentage of different strains of three forage legumes.

Crops	Strains	Dry matter mgm/per plant	Survival percentage
Alfalfa	Cody	136.7	74
	Rhizoma	85.4	44
	Rambler	53.4	34
	Narraganset	73.3	22
Birdsfoot Trefoil	Empire	134.8	45
	Viking	164.6	59
	French	200.7	73
	Fargo	106.1	57
Crown Vetch	Beltsville	128.4	50
	Penn.	90.3	46
	Iowa (SCS)	151.3	67
	Mo. (SCS)	146.8	60
LSD, 5% level		84.8	26

Analysis of variance

Source of variation	D.F.	M. S. dry matter	M. S. survival %
Replication	4	8971.31	1178.08
Species	2	42717.31*	2448.36
Reps. x Spec. (error a)	8	5109.56	724.64
Strains: species	9	21758.55*	3003.70**
Reps. x strains (error b)	36	8727.12	847.44
Water level	1	70108.20	18825.08*
Water x species	2	74985.99+	7499.43
Reps. x water			
Reps. x water x species (error c)	12	23170.05	2600.20
Water x strain: species	9	17536.31	2988.20
Reps. x water x str: species (error d)	36	25174.66	2552.23

+Significant at 10% level
*Significant at 5% level
**Significant at 1% level

Table 12. Influence of previous water level on the dry matter yield of forage legumes.

Species	Dry matter yield (mgm/plant)
Alfalfa	87.2
Birdsfoot trefoil	126.5
Crown vetch	129.2
LSD, 5% level	36.9

Table 13. The influence of a second flooding on dry weight per plant and survival percentage in three forage legumes.

Crops	Strains	Water level	Total dry matter mgm/per plant	Survival percentage
Alfalfa	Cody	excess	31.75	90
		ideal	168.39	96
	Rhizoma	excess	1.00	7
		ideal	210.14	100
	Rambler	excess	0	0
		ideal	165.75	100
	Narraganset	excess	0	0
		ideal	265.58	70
Birdsfoot Trefoil	Empire	excess	3.70	32
		ideal	72.80	37
	Viking	excess	21.89	63
		ideal	73.70	47
	French	excess	25.65	89
		ideal	95.80	62
	Fargo	excess	14.37	56
		ideal	13.20	41
Crown Vetch	Beltsville	excess	1.00	40
		ideal	107.03	49
	Penn.	excess	1.00	10
		ideal	128.00	91
	Iowa (SCS)	excess	0	0
		ideal	162.83	48
	Mo. (SCS)	excess	0	0
		ideal	73.06	57
LSD, 5% level			N.S.	49

Table 14. The effect of excess water on different species of forage legumes, when flooding was done after the recovery growth.

Species	Survival percentage
Alfalfa	58
Birdsfoot Trefoil	54
Corwn Vetch	36
LSD, 5% level	11

Analysis of variance

Source of variation	D.F.	M. S. dry matter	M. S. survival %
Replication	4	21881.00	2243.00*
Species	2	44996.01+	4179.50**
Reps. x species (error a)	8	13593.79	468.50
Strain:species	9	13919.92	4382.00**
Reps. x strains (error b)	36	10360.23	850.2
Water level	1	429623.15**	29265.00*
Water x species	2	53892.83	16577.00+
Reps. x water			
Reps. x water x species (error c)	12	42912.99	5481.40
Water x strains:species	9	15604.56	6705.4 **
Reps. x water x strain: species (error d)	36	27805.47	1931.8

\+ Significant at 10% level
* Significant at 5% level
** Significant at 1% level

Iowa (SCS) strains of crown vetch showed a significant decrease in survival due to flooding. With Beltsville strain, however, no significant difference was found in survival due to waterlogging (Table 13).

On a relative basis, excess water caused the greatest yield reduction in crown vetch. Stands of crown vetch were also decreased significantly by flooding. In terms of actual dry matter yield per plant, however, excess water caused significant yield reductions only in alfalfa. Yields of each of the four alfalfa strains were reduced by the treatment. Birdsfoot trefoil was least affected by flooding. This suggests that birdsfoot trefoil is more adapted to excess water conditions than alfalfa and crown vetch. Though, in general, no strain showed greatly different responses from others within the same species, it is interesting to note that the Narraganset strain of alfalfa, which was expected to be more resistant than the other three strains, did not excel in tolerance to waterlogging. On the contrary, Cody was the most tolerant of waterlogging.

SUMMARY AND CONCLUSIONS

A greenhouse study was conducted to determine the effects of excess water on winter wheat, winter barley, oats, soybeans, corn, grain sorghum, alfalfa, birdsfoot trefoil and crown vetch.

In the wheat and barley, and oats experiment, porous clay pots were used, the treated pots being plugged with cork and kept under saturated condition a free water depth of ½ to ¼ inches over the soil surface for the desired duration. In the soybeans, corn and grain sorghum study, glazed pots were used and rubber stoppers were used to keep the treated pots under saturated condition as above. The forage legume comparison was conducted in No. 10 tin cans. Holes were punched in the untreated pots for proper drainage. All pots were drained immediately following the treatments.

In the wheat-barley study it appeared barley was more susceptible to water-logged conditions than wheat. A significant decrease in total dry matter yield was obtained in barley with flooding at flowering stage. A significant decrease in the yield of grain was also observed in both wheat and barley, the later being more affected, when flooding was done at flowering stage. A significant delay in heading was observed with wheat in treated pots, though the time to bloom in both cases remained unaltered by the treatment.

The Andrew variety of oats appeared to be able to tolerate water-logged conditions for a considerable period of time (42 days), without undergoing significant decrease in total dry matter yield. Grain yields were not obtained, however.

It is suggested that further experiments be conducted in glazed pots and that careful attention be paid to reducing environmental variability in the greenhouse.

The Shelby variety of soybeans appeared to be tolerant to water-logged conditions. Under the experimental conditions encountered, it endured 21 days of flooding at pre-bloom stage and five days of flooding at bloom stage without undergoing any significant decrease in dry matter yield.

The corn, soybean and grain sorghum experiment revealed that corn and sorghum were less susceptible than soybeans to water-logged conditions. Corn and sorghum responded differently to waterlogging. Corn showed a significant decrease in dry matter yield when the duration of flooding was increased from seven to 14 days and onwards. Grain sorghum showed a significant decrease in dry matter yield only when the duration was increased from 14 to 21 days. Soybeans, however, showed no significant decrease in dry matter yield even with 21 days of flooding. A linear relationship between yield and duration of waterlogging was noticed in all comparisons. This was because a regular decrease in dry matter yield was observed with the increasing duration of water-logged condition, although the three species also differed in the magnitude of decrease.

Among the forage legumes, crown vetch was the most affected by waterlogging, on a relative basis. All four strains used showed severe decreases in the dry matter yield and stand when subjected to excess water for 21 days. In terms of actual plant yield, however, excess water caused significant reduction only in the case of alfalfa. Recovery of alfalfa was found to be influenced by the previous water treatment. Stands and yields of Rhizoma, Narraganset and Rambler were most severely reduced. In crown vetch, though in general a significant decrease in stand was observed after the first treatment, a specific effect on individual strains was noted after the second treatment. The Penn., Mo. (SCS) and Beltsville strains showed very poor survival after the second treatment. Birdsfoot trefoil appeared to be most resistant among the three species evaluated. In general, the dry yield per plant and stand of this species were not significantly reduced by the excess water level, though the French strain exhibited some loss in stand during recovery after the first treatment.

ACKNOWLEDGMENT

The writer wishes to extend sincere thanks to Dr. F. C. Stickler who suggested this study, supervised and assisted throughout the experimental work and assisted during preparation of this thesis. Sincere appreciation is also extended to Dr. S. Wearden for his expert guidance in the statistical analysis of the data. To Dr. A. W. Pauli; Dr. M. B. Russell, Head of the Agronomy Department, University of Illinois, and to other faculty members of this university who have aided in various phases of this study and preparation of thesis, thanks are extended.

Gratitude is due to the Danforth Foundation, St. Louis, Missouri, for granting a fellowship to the writer.

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EXCESS WATER EFFECTS ON
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by

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B. Sc. (Ag)., Allahabad University (India). 1953

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1961

Crop production can be harmed just as much by excessive as by deficient soil moisture. Under farming conditions much is done to keep soil moisture availability in or near optimum range by irrigation and drainage. While much research has been conducted on irrigation practices, little has been done to gain a better understanding of plant responses to excess soil moisture.

The present investigation was undertaken to determine the effect of excess water on different crop plants. Greenhouse studies were conducted to determine the effect of excess water on winter wheat, winter barley, oats, corn, soybeans, grain sorghum, alfalfa (*Medicago sativa*), birdsfoot trefoil (*Lotus corniculatus*) and crown vetch (*Coronella varia*).

Treated pots were kept under saturated condition and ¼ to ½ inch of free water was left at the surface for the desired length of time.

Winter barley was more affected by waterlogging than was winter wheat. While grain yield was reduced considerably in both cases, especially when flooding was done at the flowering stage, straw and total dry matter yield was reduced more in barley than with wheat. Waterlogging also delayed the time for heading in wheat without affecting the time of blooming. This effect, however, could not be found in barley.

Under the experimental conditions encountered, Andrew variety of oats appeared to be able to tolerate waterlogging for a considerable period of time without undergoing much reduction in dry matter yield.

Of all crops evaluated, Shelby soybeans appeared to be most resistant to water-logged condition. It could endure up to 21 days of flooding without undergoing any significant decrease in dry matter yield.

From the corn, soybeans, and grain sorghum comparison it appeared that grasses responded differently from the legume (soybeans). This was due to more susceptibility of corn and perhaps grain sorghum than soybeans. Corn appeared to have suffered more when waterlogging continued beyond seven days, while grain sorghum dry matter yield was affected only beyond 14 days of waterlogging. The soybean crop was, however, not affected seriously by 21 days of flooding. The effect of duration on the decrease in the dry matter yield was found to be linear.

Among the three forage legumes studied, birdsfoot trefoil was found to be most resistant to waterlogging. On a relative basis, crown vetch, which showed decreases in dry matter yield, was also severely affected in stand survival. Alfalfa yields were significantly reduced by excess water. In general, none of the strains studied within each forage legume appeared to behave differently from others, except that cody alfalfa showed more tolerance as far as stand survival was concerned. Narragansett alfalfa did not tolerate waterlogging, as expected.