INFLUENCE OF SOIL-WATER POTENTIAL ON GERMINATION AND ROOT ELONGATION OF WHEAT (Triticum aestivum) AND MUNG (Phaseolus aureus Roxb.)

THESIS

Submitted in partial fulfilment of the Requirement for the Degree of
MASTER OF SCIENCE
IN
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By
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CERTIFICATE-I

This is to certify that the thesis entitled "Influence of Soil-Water Potential on Germination and Root Elongation of Wheat (*Triticum aestivum*) and Mung (*Phaseolus aureus* Roxb.)", submitted in partial fulfilment of the requirements for the degree of 'Master of Science in Agriculture' of the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, is a record of the bona fide research work carried out by Shri Khamman Singh under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Postgraduate Studies.

No part of the thesis has been submitted for any other degree or diploma. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

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CERTIFICATE-II

This is to certify that the thesis entitled "Influence of Soil-Water Potential on Germination and Root Elongation of Wheat (*Triticum aestivum*) and Mung (*Phaseolus aureus* Roxb.)", submitted by Shri Khuman Singh to the J.N. Krishi Vishwa Vidyalaya, Jabalpur, in partial fulfilment of the requirements for the degree of M.Sc. (Ag.) in Soil Science & Agricultural Chemistry, has been approved by the Student's Advisory Committee and External Examiner after an oral examination on the same.

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Krishi Nagar
Jabalpur
October 18, 1973

(Khazan Singh)

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CHAPTER-I

INTRODUCTION

The rapidly proliferating interest in water resources and accelerated research activity on effect of 'drought' on plants are indicative of soil moisture to be one of the important environmental factors affecting plant growth. Early research on the plant-soil-moisture relationship was based principally on moisture content effects. It was soon recognised, however, that plants performed equally well in soils with very diverse moisture contents. With the advent of the energy concept of soil moisture and suitable devices for measuring energy levels, came the recognition that static energy levels bore a dominant influence in moisture utilisation. In fact, it is not the absolute amount of potential energy 'contained' in the water which is important in itself, but rather the relative levels of that energy in different regions within the soil. The concept of soil-water potential is a criterion for this energy.

For most crops, there are specific critical periods during the growth seasons when soil water potential is required to be high in order to get substantial yields. For almost all crops, moisture is needed at the time of germination and early seedling stages. In the establishment of plants in their habitat, germination is an essential and active phase which is escaped only by those species which depend partly or completely upon vegetative production.

Establishment may be related to the ability of seeds to germinate under a given moisture stress (Dotzenko, 1959).

In the arid zones, with meagre irrigation facilities, low water potential is the most limiting factor for germination. This low water potential may be due to the actual lack of adequate moisture in the soil, i.e. low matric potential or presence of excessive quantities of salts in the soil water or both. This is particularly important for saline soils, where in selecting varieties of crops, special attention should be paid to salt tolerance of the crop for germination. This problem is complicated by the fact that some crop varieties, although, salt tolerant during latter stages of growth, may be quite sensitive to salinity during germination (Richard, 1954).

As the soil dries out, the surface forces acting on the soil moisture increase. Difference in surface force action will be reflected in the amount of water that a seed can remove from the soil and should influence germination. Thus an appreciation of soil-moisture stress is necessary for an adequate evaluation of the effects of soil moisture and soil salinity upon the germination of seeds. To obtain water from the soil, two main groups of forces must be overcome (a) the surface-force action of the soil particles which accounts for the moisture retentive properties of the soil and which is usually referred to as soil moisture tension and (b) the osmotic force action which is due to the dissolved materials in the soil solution (Ayers, 1952).

Seeds, however, require an optimal range of moisture below or above which they will either not germinate or if germination takes place, it will be poor or slow. There are two schools of thought regarding the capacity of plants to absorb soil moisture within the whole available range. One group of workers (Wadleigh, 1955; Veihmeyer, 1956) believes that plants are equally capable of absorbing water regardless of the soil moisture within the field capacity and permanent wilting percentage, although the tension, at which water is absorbed, increases from field capacity to permanent wilting percentage. According to another group of workers (Aldrich and Work, 1934; Krammer, 1944; Lucey and Tesar Milo, 1965) water is not equally available in the entire range between field capacity and permanent wilting percentage.

Seeds contain embryonic plants, but from this, it does not necessarily follow that germinating seeds have the same water requirements as grown up and growing plants. In spite of the importance of seed germination in the soil, only a few references may be found in the literature concerning the water relation of seeds and their specific requirements for germination.

Effects of moisture stress on seed germination and early seedling growth have definite implications for agriculture. In regions of irrigated agriculture, it is customary, when necessary, to pre-irrigate and then to prepare the seed bed and plant as soon as possible to ensure a good stand of the crop. In areas of dryland agriculture seeding usually follows a rainy period. When soil moisture is limiting, catch crops such as mung, safflower, urid, etc. are often used and under unfavourable soil moisture conditions, even these may fail. Even if the seeds germinate and a crop gets underway, lack of soil moisture may stunt the growth, causing reduction in yield.

In consideration of what has been stated above, it was felt that there is a great need for carrying out experiments to critically assess the influence of soil-water potential on germination and root elongation of different field crops giving special emphasis on wheat and mung, a cereal and a pulse respectively. Recently introduced varieties, Narmada-4 (wheat) and Jawahar-45 (mung) in dry land agriculture of Madhya Pradesh were selected for the present investigation to study their behaviour at germination and root initiation stages under varying degrees of soil-water potential, in order to assess their ability to give satisfactory germination and root elongation at specific moisture or osmotic stress or both, particularly in a clayey soil.

In view of the importance of such information, the present study was undertaken with the following objectives:

1. To study the effect of matric potential on germination (emergence) and root elongation of wheat and mung in a clayey soil.

2. To study the effect of osmotic potential on germination and root elongation of wheat and mung.

3. To study the effect of total soil-water potential (matric potential plus osmotic potential) on germination and root elongation of the same crops in a clayey soil.

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CHAPTER-II

REVIEW OF LITERATURE

A brief review of the work carried out in different parts of the world relating to the influence of soil-water potential on germination and root elongation has been presented in this chapter with a view to assess the available information on the different relative aspects taken up under the present investigation. The presentation has been made under the following heads:-

A. SEED GERMINATION

1. Germination and drought resistance.
2. Mechanism and essentials for xeric germination.
3. Germination in relation to osmotic potential.
4. Germination in relation to matric potential.

B. ROOT ELONGATION

Effect of soil-water potential on root elongation.

A. SEED GERMINATION

1. Germination and drought resistance

In arid and semi arid zones having meagre irrigation facilities, water shortage is the most important cause of the failure of seed germination and plant growth. This water deficit may be due to an actual lack of adequate moisture in the soil (matric potential) or due to presence of excessive quantities of solutes in the soil water (osmotic potential) or both (Manohar and Mathur, 1965). The selection of varieties and species of plants that have the capability to germinate under drought and still produce optimum is, therefore, of prime importance in arid zone farming (Lahiri and Kharbanda, 1963).

Germination of seeds in the presence of osmotic potentials produced with a suitable solute is a simple, easy and reproducible test which gives a relative measure of any differences among varieties for their character of drought resistance (Vasudevan and Balasubramanium, 1965). This is done with the assumption that a seed which can germinate by absorbing water against a lower osmotic potential, its resulting plant may also absorb moisture under similar conditions of moisture stress. A considerable amount of work has been done on this aspect, but the views of the scientists are much controversial. Some accept that the ability of germination in lower osmotic potentials is inherent character of varieties and species and is generally correlated with drought resistance and adaptability in dry tracts (Yamasaki, 1929 and Vasudevan and Balasubramanium, 1965) while the second view does not support this hypothesis (Ameodt and Johnston, 1936; Birdsall and Neatby, 1944 and McGinnies, 1960).

2. Mechanism and essentials for xeric germination

For germination of seeds, a certain level of hydration of seed must be attained before the physiological processes are triggered on (Hunter and Erickson, 1952). It has been reported that dry seeds may have as low as -10,000 Joules/kg (101.3 Joules/kg = 1 atmosphere) water potential (Manohar, 1966a), therefore the soil moisture content need not be very high for their germination (Peters, 1920). However, most rapid germination occurs when soil moisture is at or slightly below field capacity. According to Doneen and Mac Gillivary (1943), and Manohar and Heydecker (1964a), the seeds of certain species may germinate even when the soil moisture level is at permanent wilting or slightly lower. It is, therefore, logical to deduce that a seed which has a capacity to germinate with lower degree of hydration may stand better chances of germination in scanty rainfall areas. Soriano (1962) has pointed out in this connection that xeric germination depends not only on the minimum imbibition required, but also on the imbibition pressure and the time factor.

Blaim (1960) stated that very little attention has, so far, been paid to water uptake problem. Seed water uptake has been distinguished into two stages by Atkins (1909). The first stage i.e., imbibition was thought to be connected with the swelling of colloids and the second i.e., germination due to osmosis. Blaim (1960) doubted this conjecture and proposed that uptake of water by embryo should be considered as a physiological process and it is distinct from that of endosperm which is exclusively connected with imbibition of soil colloids. Although different mechanisms of water uptake may exist in endosperm and embryo, yet it appears that embryo growth is dependent, to a great extent, on the endosperm food and growth factors (Sircar and Lahiri, 1956).

Sircar and Ghosh (1962) observed that endosperm protein is hydrolysed and other amino acids appear and are translocated to the embryo at germination. Presumably the endosperm must attain certain degree of hydration to trigger on the hydrolysis processes which are essential for the availability of food factor for the growing embryo. Similarly, Manohar (1966b) reported that embryo cells must attain a definite degree of moisture level to initiate vital processes to growth. This degree of hydration will, of course, vary in different types of seeds. Soriano (1962) stressed that a high power of imbibition is considered to be characteristic of xeric germination.

3. Germination in relation to osmotic potential

The adverse effect of lower osmotic potential on absorption of water by seeds has been observed by several workers.

Shull (1916) found that seeds of Xanthium pennsylvanicum imbibed 12 per cent as much water from a saturated sodium chloride solution having an osmotic pressure of 375 atmospheres as from pure water. Intake of water from a solution with an osmotic pressure of 19 atmospheres was 75 per cent that of the control. Even though some seeds have this remarkable power of imbibition, very few of them will germinate if the soil moisture content is below the wilting percentage.

Doneen and Mac Gillivary (1943) stated that the germination of seeds of all of the crops studied took place in a shorter period of time at high soil moisture than at low. Since rate of germination is dependent upon rate of water intake, this observation implies that the imbibitional power of the seed is conditioned by the moisture content of the seed bed.

Uhvits (1946) studied the germination of alfalfa seeds on artificial substrate, supplied with sodium chloride and mannitol solutions at various osmotic pressures. The rate at which the seeds absorbed water was continuously decreased by increasing the concentration of either sodium chloride or mannitol. Rate of germination was also decreased by increasing the osmotic pressure of the substrate. Germination was almost completely inhibited by 15 atmospheres of sodium chloride but 84 per cent of the seeds germinated at 7 atmosphere osmotic pressure of salt. On the mannitol substrate 57 per cent of the seeds germinated even in the presence of 15 atmosphere osmotic pressure. The relatively adverse effect of the sodium chloride at a given osmotic pressure appears to be related to the excess intake of chloride during germination when this ion is present in the substrate in high concentration.

Stiles (1948) showed that the embryo and the seed of drought resistant No. 293 cotton absorbed about half as much water during the first 96 hours of germination as those of Roger Acala Cotton. The low proportion of water in the seed and embryo of former with rapid initial extended absorption of water and high proportion of water in the endosperm were the factors that made this variety to germinate under dryland conditions. On the other hand Roger Acala cotton seeds required almost twice as much water as the former and is, therefore, drought susceptible. Similar trend was observed with different varieties of corn.

Decreased physiological availability of water arising from increased concentration of solutes in the soil solution affects the germination of seeds of various crops quite differently. Ayers and Haywards (1948) point out that soil salinity impedes the rate at which seeds germinate and also decreases the number of seeds that do germinate.

Lawton (1949), from a series of field studies, had suggested that the crop plants of weak, medium and strong salt tolerance will not grow when the soil solution at field capacity exceeds 2, 2.3 and 2.7 per cent salt concentrations respectively.

Rogers *et al*. (1957) reported a method for evaluating winter hardiness in alfalfa based on differences in rate and total germination in sucrose and sodium chloride solutions of definite osmotic potentials. He found that lower osmotic potentials decreased the rate and total germination.

Mehta and Desai (1958) reported 100 per cent germination of Bajra at 1 per cent salt concentration of soil solution at field capacity while only 54 per cent germination was recorded at 2 per cent salt concentration.

Dotzenko *et al*. (1959) studied the germination of six alfalfa varieties at three levels of osmotic pressure using mannitol as substratum. They found that rate of emergence as well as total emergence percentage were decreased as the osmotic stress increased. They concluded that if seedlings were slow to emerge, final percentage emergence was low. Logically the longer an ungerminated seed lies in the soil, the greater the opportunity for it to succumb to seed rotting fungi or other environmental hazards.

Dotzenko and Hans (1960) further confirmed that the ability of alfalfa seeds to germinate in lower osmotic potential was heritable.

McGinniss (1960) while working on germination of different grass seeds under various osmotic potentials observed delayed germination in lower osmotic potential, the rate as well as total germination was reduced in all cases.

Lahiri and Kharbanda (1964) observed significant differences in the moisture requirement for germination of three grasses native to arid and semi-arid regions and that close parallelism existed between their pattern of water uptake and germinability under low levels of moisture. Seeds of _Cenchrus setigrus_ were found to attain the equilibrium stage with water within two hours and the amount of water absorbed was also significantly less than the other two grasses while the seeds of _Lasiurs sindicus_ reached the same stage in six hours and also with big amount of moisture absorption.

Manohar and Heydecker (1964b) reported that the lowering of the potential of the germination medium results in a decrease in the potential gradient between the seed and its germination medium.

Manohar and Mathur (1965) studied the problem in detail by germinating *Pennisetum typhoides* seeds under different osmotic potentials and showed that the rate of germination as well as the total germination were significantly reduced in lower osmotic potentials.

Abichandani and Bhutt (1965) studying the salt tolerance of germinating Bajra and Jowar varieties concluded that Bajra was more salt tolerant than Jowar. Some highly salt tolerant varieties of Bajra were found to stand fairly a salinity level of 3 per cent in soil solution while the upper limit of salt tolerance of jowar was only 1.8 per cent salt. Varietal differences with regard to germinability in lower osmotic potentials have also been reported by Hayward (1954), Wahhab (1961), Burnstein (1962) and Manohar (1966b).

4. Germination in relation to matric potential

Some of the workers have studied the effects of low matric potential on germination of various crops in texturally different soils under laboratory conditions. The general observation is that the total rate of germination as well as total germination are decreased as matric potential decreases. In other words, there exists an inverse relationship between the soil moisture tension and percentage germination.

Hunter and Erickson (1952) found that when the available soil moisture was below the moisture required for germination of soybean seeds, the seeds became covered with mycelia of fungi and were killed at the end of a week without germination taking place. They also observed that in order for seeds to germinate each crop seed studied had to attain a specific moisture content.

Hanks and Thorp (1956), while studying the seedling emergence of wheat as related to soil moisture content, Bulk Density, Oxygen Diffusion Ratio and Crust Strength, found that seeds germinated in a shorter time at high soil moisture potential than at low when the other three parameters were kept constant.

Kmoch _et al_. (1957) found that winter wheat grown on Nebraska had been found to germinate in the soil at a matric potential of -1500 joules/kg.

Mehrotra _et al_. (1967) studied the germination of certain Rabi seeds as influenced by variation in soil moisture. They took four levels of soil moisture from field capacity to wilting point and found that on an average seeds took shorter time in completing germination at higher soil moisture than at lower one. The total time taken in germination was, however, not markedly influenced by the amount of absolute water present in the soil, but its rate was materially reduced at the lowest level.

Phillips (1968) found that water uptake rates in soybeans, corn and cotton decreased with increasing soil moisture tension at 24°C.

Experiments have also been conducted by some workers to study the comparative effects of osmotic and matric potentials as well as to assess the combined influence of both of these on seed germination.

Helmerick and Pfeifer (1954) found that the germination and early growth of yogo winter wheat were significantly superior to the germination and early growth of cheyenne winter wheat when germinated under controlled initial moisture conditions. They germinated seeds of both varieties in soil in a pressure-membrane apparatus and also in petri dishes using osmotic solutions prepared from d-mannitol. Both methods gave similar results. They also found that seeds of the two varieties grown at two locations, Laramire and Sheridan, Wyoming did not give significantly different results when tested under limited moisture. They concluded that the differential germination and growth response between the two varieties were inherent rather than environmental.

Collis-George and Sands (1962) while studying seed germination using equipment that enabled them to distinguish between matric potential and osmotic potential, observed that matric potential was more effective than osmotic potential in decreasing germination rate. Osmotic potential was found to reduce germination only when values were above 1000 cm of water, when NaCl and glycerol were the solutes. Matric potential upto 100 cm of water reduced the germination rate but not total germination. Matric potential of 15000 cm of water equivalent to the permanent wilting percentage prevented germination of perennial rye grass and oats; alfalfa germinated 38 per cent. They also concluded that different solutes had different effects on germination for each seed species.

Lyles and Fanning (1964) tried different combinations of matric and osmotic potentials and found that at 5.2 atmospheres total moisture stress or total potential, equal emergence was obtained when 72 per cent of the total potential was attributed to matric potential and 28 per cent to osmotic potential or 19 per cent to matric potential and 81 per cent to osmotic potential.

B. ROOT ELONGATION

Effect of soil moisture potential on root elongation

There are many factors which affect plant growth directly or indirectly such as soil water, aeration, nutrient supply etc. Actual availability of soil water involves the ability of a plant to absorb water at the root surface, the energy with which it is held by the soil and its rate of movement through the soil to the plant root. (Gardner and Ebling, 1962; Holtz and Remson, 1971).

Larson and Johnston (1955) in an experiment, conducted to determine the effect of soil moisture level on yield, consumptive use of water, and root development of sugarbeets, found that by removing the available water from the root zone, the yield and consumptive use of water for the growing season decreased. But the moisture level had no effect on the rate of root extension.

Gingrich and Russell (1956) reported that radicle elongation and hydration of corn seedlings decreased with increasing soil moisture tension or osmotic stress over the 1/3 to 12 atmosphere range. Growth characteristics that were influenced by osmotic stress responded linearly in the 1/2 to 1 atmosphere range. However, growth as a function of soil moisture was not linear in the same range and was most sensitive to moisture changes in the 1/3 atmosphere range. These differences were attributed to the water transmitting characteristics of soil. Similar observations have been put forth by Vaadia _et al_. (1961).

Inden (1961) compared the root growth of cucumber and beans in the red clay and sandy soils and found that the osmotic pressure of soil solution generally inhibited root-growth at 10-30 atmospheres.

Gardener (1962) reported that penetrating ability of cotton roots decreased with increasing soil moisture stress for the suction range above 1/2 bar, with increasing osmotic stress in soil solution and with increasing partial pressure of Co_2.

Gardner and Danielson (1964) found that penetration percentage of cotton roots increased as the soil-moisture tension was increased from 0.05 to 0.52 bars, then decreased as tension was further increased to 10.8 bars. Penetration also decreased with increasing salt concentration in the soil solution.

Stevenson and Boersma (1964) found that root growth was dependent on the moisture content of the sandy loam soil but showed a curvilinear increase with increased moisture content in a clay loam. Similar observations have been reported by Moderski and Wilson (1960).

Grable and Danielson (1966) reported that in corn roots highly significant depression in elongation (length) were produced by increasing suction from 0.3 to 0.7 bar but not from 0.7 to 0.9 bar. As suction increased, root elongation decreased.

From this array of literature, it is apparent that germination and root elongation of a number of field crops have negative co-relation with the soil-moisture stress as well as osmotic stress. The combined effect of both of these components of soil-water potential plays an important role in germination and root elongation. Whether these two components are equal in their effect, or in other words, are interchangeable or not, still remains an inadequately answered question as there is difference of opinion.

Further, no adequate information is available in the literature on the influence of total soil-water potential on germination and root elongation. It is, therefore, imperative to conduct a detailed study of the effect of these two components separately, as well as, in combination to get a better understanding of the mechanism involved and the manner in which the two components of soil-water potential influence seed germination and root elongation.

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CHAPTER-III

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MATERIALS AND METHODS

Two crops, a cereal and a pulse were taken for the study. Amongst cereals, wheat (*Triticum aestivum*) variety Narmada-4 (NMD-4) and amongst pulses, mung (*Phaseolus aureus* Roxb.) variety Jawahar-45 were selected. Both the crops have been recently introduced to dryland agriculture in India.

Genetically pure seeds from 1971-72 crops were collected.

The experimentation was divided into two main parts. In the first part, germination studies for both the crops were conducted under:

1. Different osmotic potentials in petri dishes.
2. Different matric potentials in the soil.
3. Different osmotic potentials in the soil.
4. Different total soil-water potential (matric potential + osmotic potential) in the soil.

In the second part, radicle elongation was studied under:

1. Varying degrees of matric potentials in the soil.
2. Varying degrees of osmotic potentials in the soil (soil maintained at field capacity).
3. Varying degrees of total soil-water potential (matric potential + osmotic potential) in the soil.

Part-I: GERMINATION STUDIES

1. Germination as a function of osmotic potential

A separate experiment for each crop was conducted in the petri dishes, at room temperature (25°C ± 1). The seeds were germinated in solutions of different osmotic potentials. The solutions of various osmotic potentials were prepared by using d-mannitol, a hexahydric alcohol. The use of d-mannitol, to obtain different osmotic potentials was decided in view of the fact that solutions of a given osmotic suction can be prepared easily and, at the same time, it is non-toxic to the seeds (Uhvits, 1946). Besides, d-mannitol is the best chemical known so far to limit water uptake in a plant without effecting the metabolic activity of the plant (Thimann, 1954).

1.1. Specifications for osmotic solutions

The relation between the osmotic potential of a solution and its molar concentration is given by the following expression:

Osmotic Pressure (P) = $\frac{g}{M} \cdot \frac{RT}{V}$ (Waggans and Gardner, 1959) (1)

where g = grams of solute (d-mannitol)

R = 0.0820 atms. per degree per mole

T = absolute temperature

M = Molecular weight of d-mannitol
V = Volume of solution in litres

Since osmotic potential is equal to the water potential of the solution at atmospheric pressure (Barrs and Slatyer, 1965), from the above relation, the water potential of 1M mannitol solution is 0.0820 times the absolute temperature. A 1M mannitol stock solution was used to prepare solutions of different osmotic potentials.

The ratio of the stock solution and water for prepation of these solutions was calculated by using the expression:

$$Vs = \frac{Vt \times Xt}{Xs} \quad -- \quad (2)$$

where

V_s = Volume of the stock solution.
V_t = Volume of the solution to be prepared.
X_t = Required osmotic potential of the solution.
X_s = Osmotic potential of the stock solution.

Thus the osmotic stresses of 0, 1, 3, 7, 10 and 15 bars were prepared. The control consisted of distilled water representing 0 bar osmotic stress.

1.2. Procedure

Clean 9 cms dia. glass petri dishes with three 9 cms diameter Whatman No. 4 filter papers well set in each dish were used. The petri dishes were sterilised in an oven for 2 hours at 120°C, in order to reduce growth of bacteria and mold. Twenty ml. solution of the desired osmotic stress was sprayed on the filter-papers in each dish. Twentyfive healthy seeds almost of the same size were sown in a symmetrical manner in each petri dish. Each treatment was replicated four times. The placement of the dishes was completely randomised.

Separate experiments for each crop were carried out. The germination count was recorded daily. A seed was considered germinated when both a normal radicle and plumule were visible and distinct from the seed and radicle had reached a length of about 2 mm. The counting was continued till no more seed sprouted.

2. Germination as a function of matric potential

2.1. The surface soil samples (0-15 cm) from the experimental farm of the university were used in this study. Before conducting the experiment, the following parameters were determined:-

(a) Texture: Mechanical analysis of the soil by the universal Pipette Method (Piper, 1950) showed the percentages of different soil separates as follows:

Clay	63.50%
Silt	19.00%
Sand	17.50%

(b) pH: The soil pH was determined in soil suspension using 1:2 soil water ratio with glass electrode pH meter, and it was found to be 7.0.

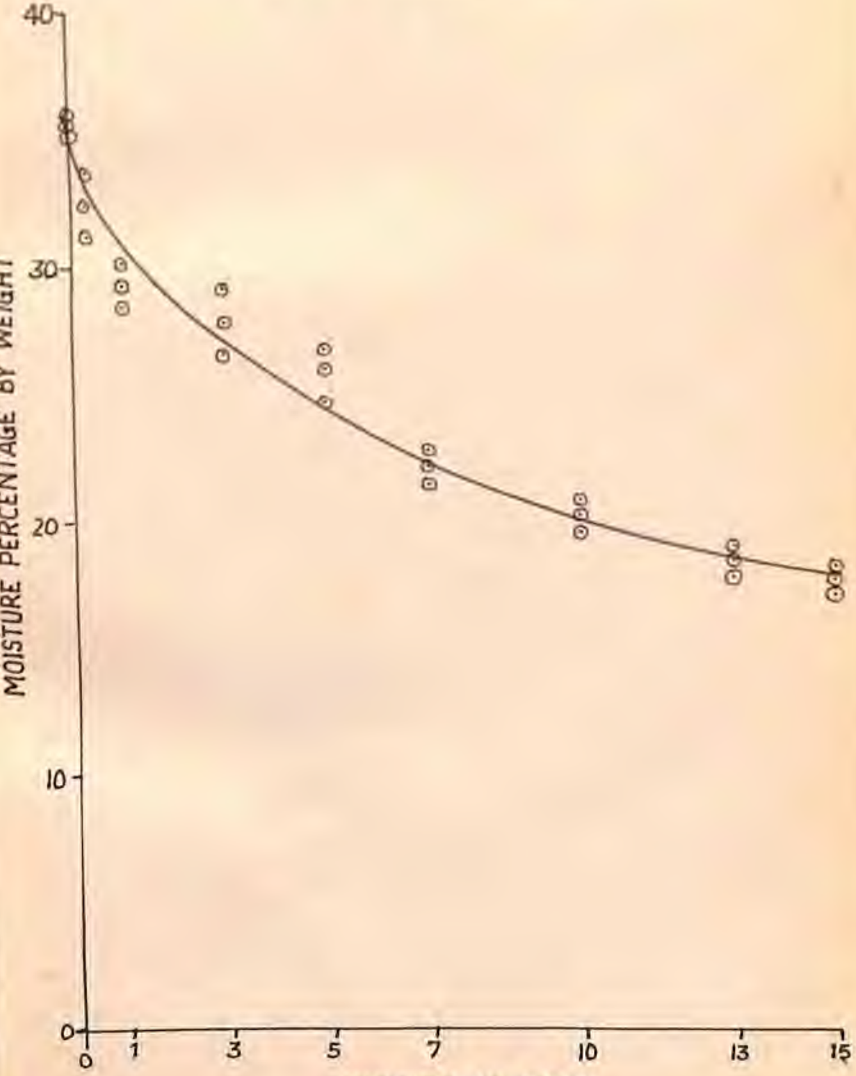
(c) E.C.$_e$: The Electrical Conductivity of the saturation extract was determined according to the technique given in U.S.D.A. Hand Book No. 60. It was found to be 0.3 milli mhos/cm at 25°C.

(d) Moisture characteristics: For the construction of soil-moisture desorption curve, the moisture content at 0.3 and 1.0 bar suction was determined with pressure plate and from 1.0 upto 15.0 bars with the pressure membrane apparatus (Richards, 1949). The results of these measurements are presented in Fig. 1.

2.2. Procedure

The air dry soil was passed through 2 mm sieve and thoroughly mixed. Moisture tensions of 0.3, 1, 3, 7, 10 and 15 bars were created by adding an amount of distilled water calculated using moisture desorption data to a known amount of air dry soil. The soil was spread on a rubberized sheet and water added with an automizer in small instalments. The

FIG.-1 MOISTURE CONTENT AT VARIOUS SUCTIONS DURING DESORPTION



mixing of water with soil was done with the help of a spatula under polyethylene covering in order to minimize evaporative losses of water.

After preparing the soil approximately of a desired suction, it was packed to a bulk density of 1.25 gm/cm^3 in small aluminium cans filled upto 3/4th of their height.

Twentyfive seeds were uniformly pressed into the soil and the remaining soil was placed over them maintaining the bulk density as 1.25 throughout. The cans were then covered with polyethylene sheets which touched the soil surface so that no appreciable vapour condensation on the inner side of the polyethylene covers could occur.

A completely randomised block design was adopted with six treatments and four replications.

Separate experiments were conducted for each crop. The room temperature was 25°C ± 1. Germination counts were made daily to determine the influence of the factor studied on the rate of germination. "Germination" as used here indicates the percentage of seeds that sprouted and from which the plant emerged above the soil surface. The counting was continued till no more seedlings emerged.

3. Germination (emergence) Vs osmotic potential in soil at a constant matric potential of 0.3 bar

Osmotic solutions of 1, 3, 7, 10 and 15 bar pressures were prepared in exactly the same manner as described in 1.1. The solutions of different pressures were used instead of pure water to bring the soil samples to a matric suction of 0.3 bar. The mixing of the different solutions with the soil was accomplished in the same manner as described in 2.2. The soil was packed to a bulk density of 1.25 gm/cm^3. The packed soil, therefore, had a constant matric suction (.3 bar) equivalent to field capacity, but differing in osmotic stresses. The rest of the procedure was the same as described in 2.2.

4. Germination (emergence) as a function of total soil water potential (matric potential + osmotic potential)

4.1. In order to create desired levels of osmotic and matric potential in the same sample, mannitol solution of desired osmotic pressure was used to wet the soil to a desired moisture level.

4.1.2. The following combinations of osmotic and matric potential were used to get six levels of total soil water potential viz., 1.3, 3, 6, 9, 12 and 15 bars.

Combination Set No.	Matric potential (in bar)		Osmotic potential (in bar)		Total soil water potential (in bar)
I	0.3	+	1	=	1.3
	1	+	2	=	3
	2	+	4	=	6
	3	+	6	=	9
	4	+	8	=	12
	5	+	10	=	15
II	1	+	0.3	=	1.3
	2	+	1	=	3
	4	+	2	=	6
	6	+	3	=	9
	8	+	4	=	12
	10	+	5	=	15

All the six treatments were replicated three times. Thus two simultaneous experiments were conducted with each set for one crop at a time. The room temperature was 27°C ± 1. The rest of the procedure was the same as described earlier.

Part-II: ROOT ELONGATION OF WHEAT AND MUNG

1. Root elongation Vs matric potential

Soil-moisture tensions used were .3, 1, 3, 7, 10 and 15 bars, and were created in the similar manner as described in 2.1 of Part-I, using the same type of soil. The packing of the soil in the aluminium growth cans was done at a bulk density of 1.25 gm/cm^3. Healthy looking seeds, almost of the same size were selected and soaked in aerated water for approximately 24 hours and then germinated in petri dishes at room temperature (25°C ± 1) until a sufficient number of radicles had reached a length of 5 mm. The radicle lengths were measured to the nearest mm and 5 of the intact seedlings were placed on soil in the growth cans which were about three-fourth filled with soil at bulk density of 1.25 gm/cm^3. The rest of the soil was spread over the seedlings in instalments tapping the cans gently at intervals so as to maintain the bulk density of 1.25 gm/cm^3 throughout and to bring a close soil-seedling contact. The boxes were, then, covered with polyethylene sheets to check evaporation. The covering sheets almost touched the surface of soil so that no appreciable vapour condensation on the sheet could occur.

A completely randomized block design was adopted. Each treatment was replicated four times.

Separate experiments were conducted for each crop.

The seedlings were allowed to remain in the growth cans for a period of 24 hours, after which they were removed and the lengths of the radicles were measured again.

2. Root elongation Vs osmotic potential in soil maintained at field capacity (0.3 bar matric suction)

Five levels of osmotic potential viz., 1, 3, 7, 10 and 15 bars were used. In all the cases, soil moisture was maintained at field capacity. Control consisted of soil at field capacity where only distilled water was used to create moisture tension of 0.3 bar. The same procedure was adopted as described under 3.1 and 2.1 of Part-I for preparation of samples and the other experimental details were similar to 1 of Part-II.

3. Root elongation in relation to total soil water potential (matric potential + osmotic potential)

Six levels of total soil-water potential in two different sets for each crop, were used. The combination of the two components was done exactly in the same manner as described in 4.2 of Part-I.

The preparation of the samples was done as mentioned in 4.1 of Part-I and the rest of the procedure was same as described in 1 of Part-II.

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CHAPTER-IV

RESULTS AND DISCUSSION

PART-I: GERMINATION

4.1. Effect of matric potential on germination of wheat and mung

The germination (emergence) percentage of wheat and mung are plotted against time at different matric potentials in Fig. 2 and 3, respectively. The figures reveal two major effects on seed germination as moisture tension increased; germination rate was reduced and greater time was required to reach final germination.

The combined result was a progressive decrease in total germination (emergence) as moisture tension increased from 0.3 to 15 bar. Fig. 2 shows that 94, 92 and 87 per cent germination at matric suction of 0.3, 1 and 3 bar respectively was obtained in case of wheat. Further, more than 80 per cent germination occurred on the 3rd day at 0.3 and 1 bar, and on 4th day at 3 bar moisture tension.

In case of mung (Fig. 3), however, 91 per cent germination took place at 3 bar moisture tension and 87 per cent germination was obtained even at a moisture tension of 7 bar. Besides, more than 80 per cent germination occurred at matric suction of 0.3, 1 and 3 bar on the 2nd day, and at 7 bar on the 3rd day.

FIG.-2 RELATION OF GERMINATION (EMERGENCE) OF WHEAT SEED TO TIME AND MATRIC POTENTIAL.

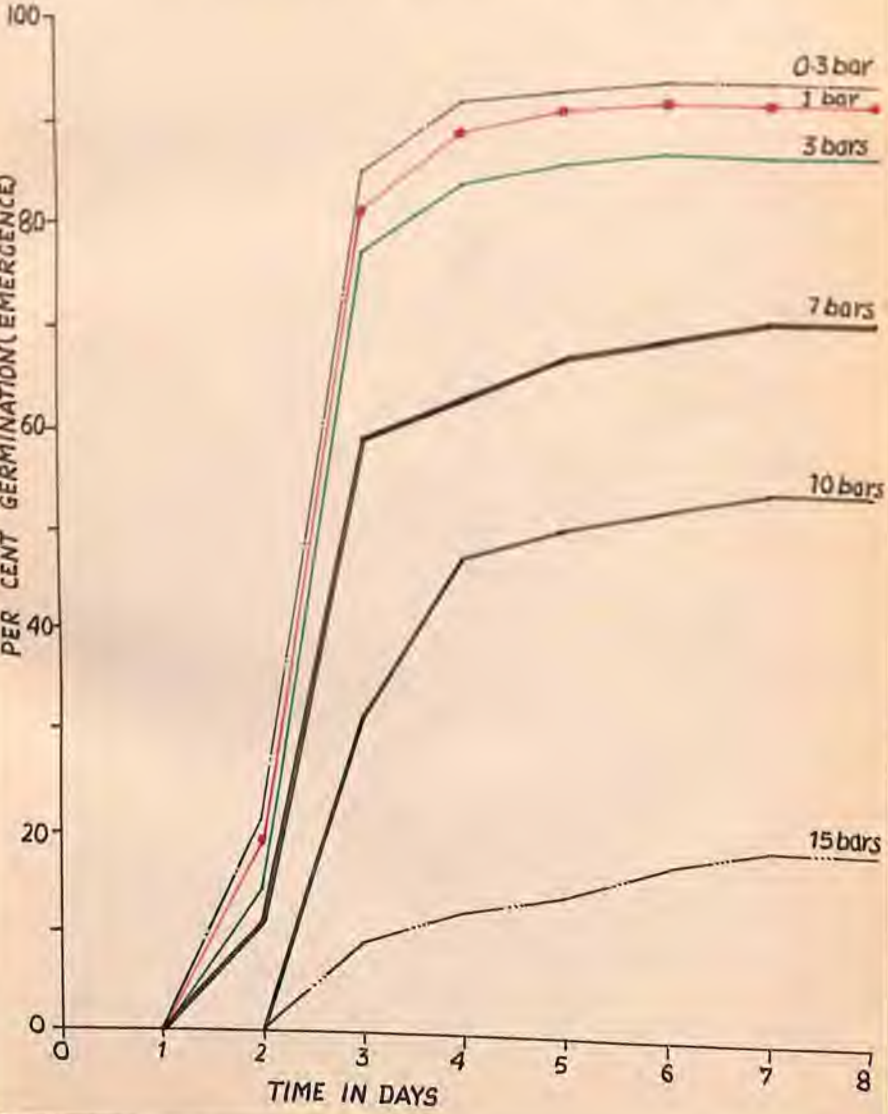
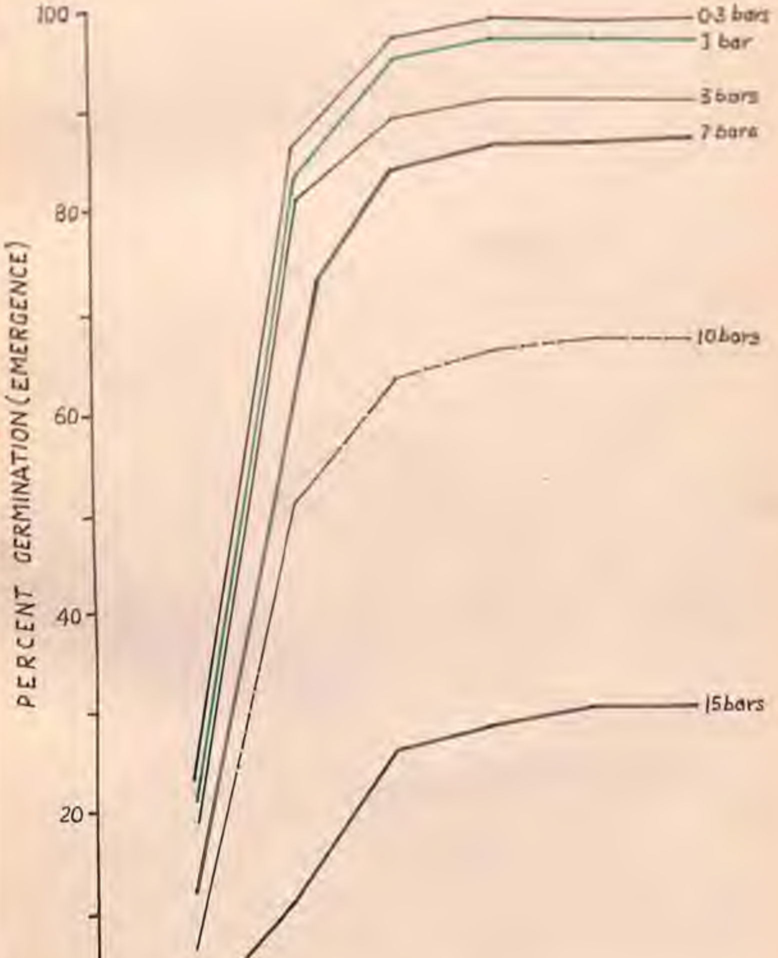


FIG.-3 RELATION OF GERMINATION (EMERGANCE) OF MUNG SEEDS TO TIME AND MATRIC POTENTIAL.



The lowest seed germination of 19 per cent in case of wheat and 31 per cent in mung was recorded at a matric suction of 15 bar.

In the end of the experiment, the seeds were examined for any sign of sprouting. It was observed that seeds of both the crops had sprouted at higher moisture tensions, but there was no emergence of the plumule above the surface, and thus were not counted in the germination.

Increased moisture tension affects seed germination in two ways. Firstly, there is a marked reduction in rate of water uptake by the seed from its immediate surrounding soil. Secondly, the replenishment of water, in the soil surrounding the seed, becomes slower. Thus it takes longer time for seeds to germinate. Of course, the rate at which seeds can imbibe water from a given soil at a particular moisture tension may vary from crop to crop and variety to variety. Ayers (1952) has reported that the ability of seeds to germinate under high moisture stress varies widely among plant species.

A further point of consideration is that when the rate of water uptake by a seed is too slow, the emergence is delayed by a relatively long period and fungal growth may take place on partially swollen and tender seeds resulting in their decay (Hunter and Ericksen, 1952). This fact was further proved by observing the condition of unsprouted seeds at the end of the experiments. The seeds were found partially or completely decayed.

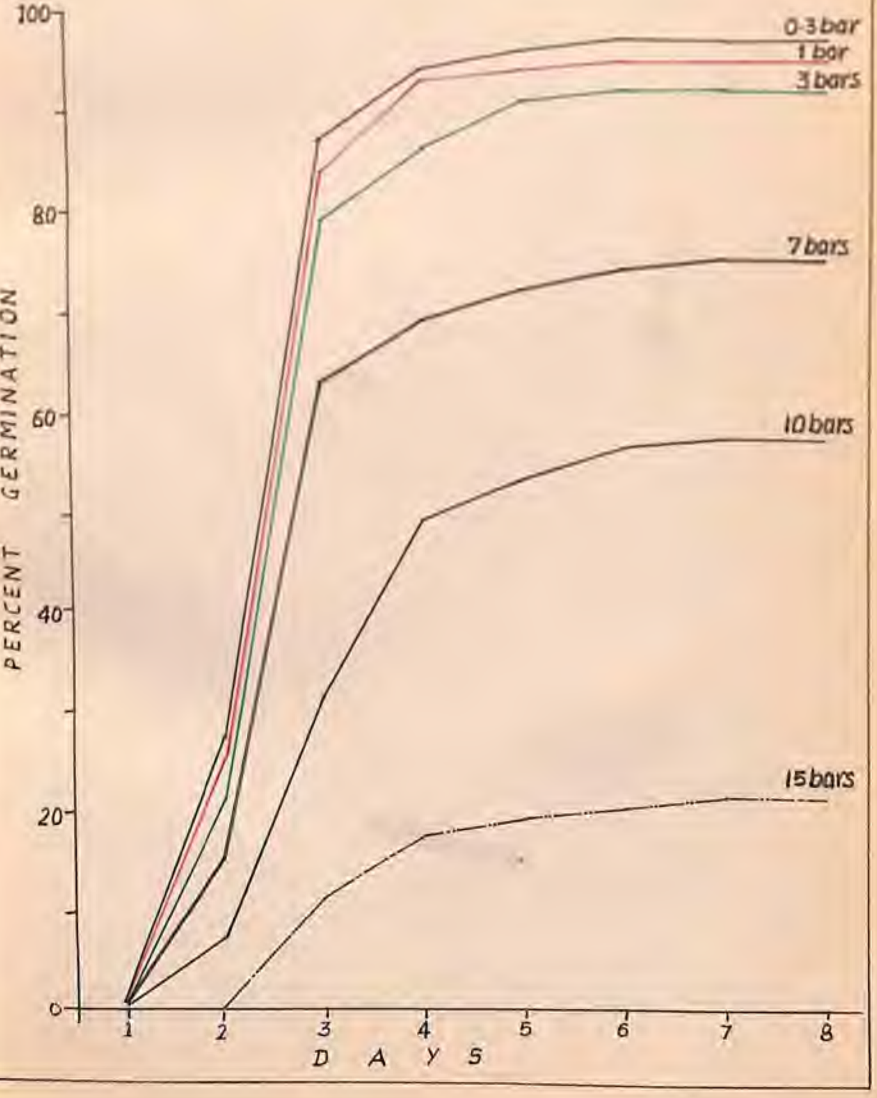
In the present study, mung variety J-45 has been found to give satisfactory germination (above 85 per cent) even upto 7 bar moisture tension, which indicates that this variety can very well withstand the drought conditions at germination stage. The same is true for wheat variety Narmada-4 which can give more than 80 per cent germination at a moisture tension of 3 bars. However, for the best seed germination in clayey soils, a moisture tension of 0.3 to 1 bar is required for both the crops.

The general trend of delay in emergence and decrease in emergence percentage with increasing soil moisture tension has been reported for a number of field crops by some other investigators also (Hunter and Erickson, 1952; Collis-George and Sands, 1962; Mehrotra et al. 1967).

4.2. Effect of osmotic potential on germination of wheat and mung

Figs. 4 and 5 show the relationship of wheat and mung seedling emergence respectively to time after planting at various osmotic potentials. From the figures, it is revealed that the rate of germination as well as total germination decreased progressively with increasing osmotic stresses. Further, greater time was required to reach final germination of both the crops as osmotic stress

FIG.-4 RELATION OF GERMINATION OF WHEAT SEED TO TIME AND OSMOTIC POTENTIAL



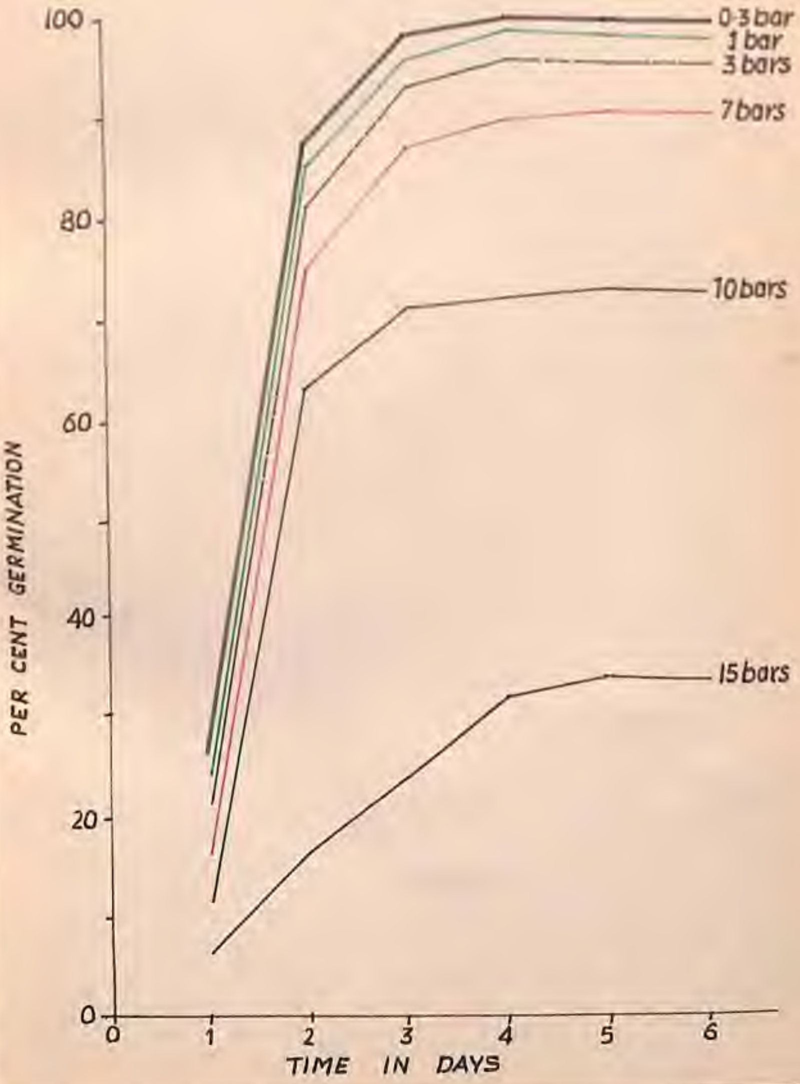


FIG.-5 RELATION OF GERMINATION OF SEEDS OF MUNG TO TIME AND OSMATIC POTENTIAL

increased indicating that longer time may be required for seed germination under saline conditions.

Although the seeds of both the crops germinated and grew to some extent even under the 15 bar osmotic stress, the dehydrated and burned appearance of the seedlings suggested that growth couldn't be sustained under such conditions. This was confirmed by transferring seedlings from 15 bar to 0 bar tension at the completion of the experiment.

Germination of seeds in various osmotic potentials produced with a suitable solute is a simple, easy and reproducible test which gives a relative measure of any differences among varieties for their character of drought resistance. This is done with the assumption that a seed which can germinate by absorbing water against a lower osmotic potential, its resulting plant may also absorb moisture under similar conditions of moisture stress (Yamasaki, 1929b and Vasudevan and Balasubramanium, 1965).

Apart from the present investigation, a side experiment was also carried out for mung variety J-45 to confirm the above statement. The experiment was conducted in pot cultures. On the basis of the observations that mung can germinate satisfactorily at an osmotic stress of 7 bars (89% germination), the crop was grown at osmotic stresses of 1, 3, 7, 10 and 15 bars in the clayey soil (soil moisture maintained at F.C.) for one month. It was, however, observed that this variety could survive under 7 bar osmotic stress with no visual symptoms of wilting for at least one month. The plants grown under 10 bar osmotic stress started showing symptoms of wilting after 15 days, whereas those grown under 15 bar osmotic stress germinated to some extent, but withered away soon.

Besides, visual observations showed marked lack of turgidity and thickness of the leaves and stem of the plants respectively at 10 bar osmotic stress. On comparing the length of roots of the plants grown under different osmotic stresses (Table 1), it was observed that there was a progressive decrease in length as well as proliferation of roots with increase in osmotic stress from 1 bar to 15 bars. As regards, plant height, there seemed to be no marked difference between 1 and 3 bars osmotic stress. But at 7 bar osmotic stress, the plants had little stunted growth with lean and thin stem. At 10 bar osmotic stress, the plants had acquired pale yellow colour and had stunted growth with very thin stem.

Since it was practically difficult to maintain a particular stress condition for more than a month in the absence of a humidity control chamber, so the study could not be continued further. However, it was confirmed that mung J-45 could tolerate osmotic stress upto 7 bars at latter stages of growth also. The results may be subject to some error due to the absence of humidity control chamber.

Table-1: Root elongation as a function of osmotic stress (soil moisture maintained at F.C.)

(Average of 5 plants)

(Root length taken after one month)

Osmotic stress (bars)	Root length (mm)	General observations
1	187	Well proliferated
3	183	-do-
7	179	Less proliferated
10	111	Very less proliferated having dehydrated and burned appearance
15	51	-do- -do-

4.3. Effect of varying osmotic potential on germination in soil (soil moisture maintained at field capacity)

Figs. 6 and 7 present the effect of varying osmotic potential on germination of wheat and mung respectively in the soil keeping matric potential constant (0.3 bar) throughout. On comparing the effects of matric potential and osmotic potential on germination (Fig. 8), it was observed that the values differ to some extent; in the soil the values were lower in comparison to those in the petri dishes. This may be because of the fact that the unsaturated soil exhibits resistance to water movement to seed depending on the degree of saturation. Also, unsaturated soil allows only a fraction of surface area of the seed to

FIG.-6 RELATION OF GERMINATION OF WHEAT SEEDS TO OSMOTIC POTENTIAL IN CLAYEY SOIL

(SOIL MOISTURE MAINTAINED AT F.C.)

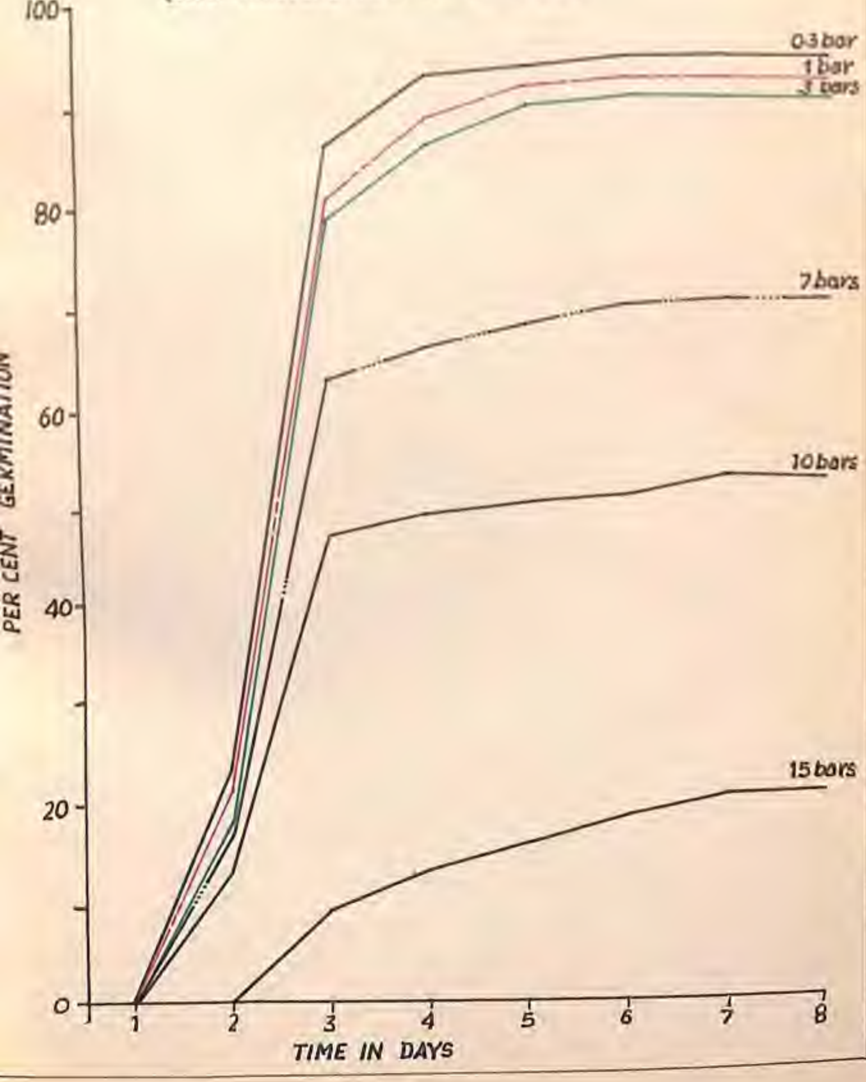


FIG-7 RELATION OF GERMINATION OF MUNG SEEDS TO OSMOTIC POTENTIAL IN CLAYEY SOILS

(SOIL MOISTURE MAINTAINED AT F.C.)

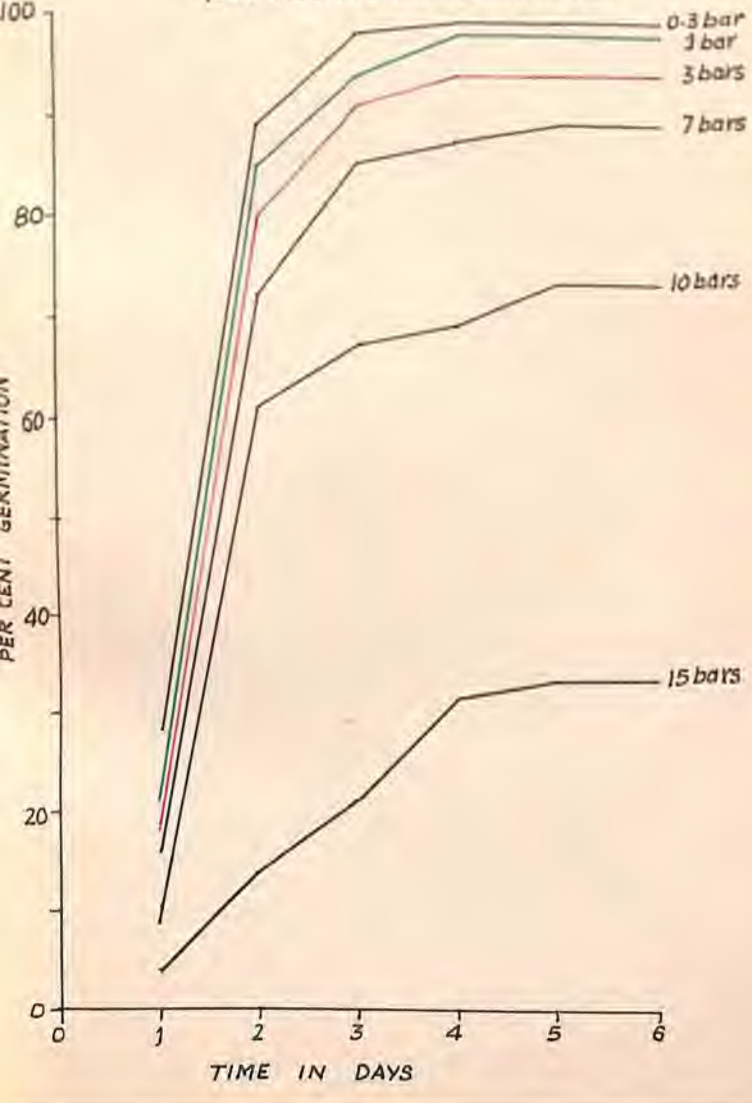


FIG.-8 GERMINATION PERCENTAGE OF WHEAT AND MUNG SEEDS IN RELATION TO OSMOTIC AND MATRIC POTENTIAL (A COMPARISION)

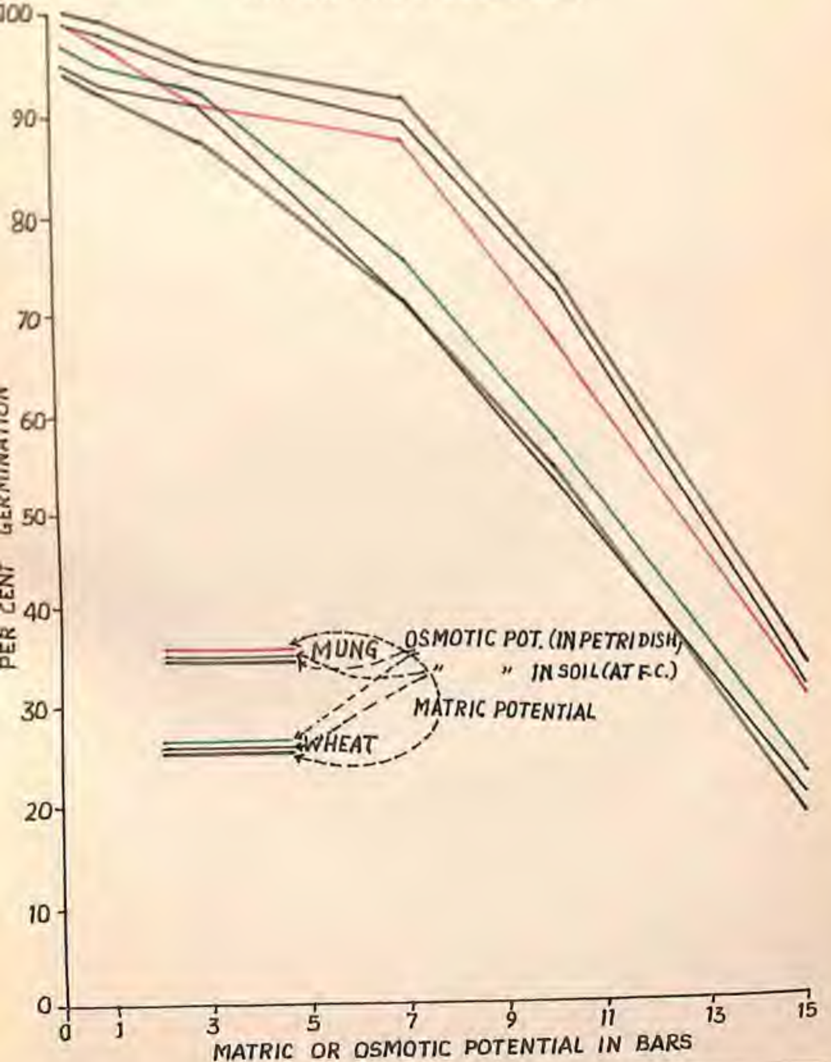
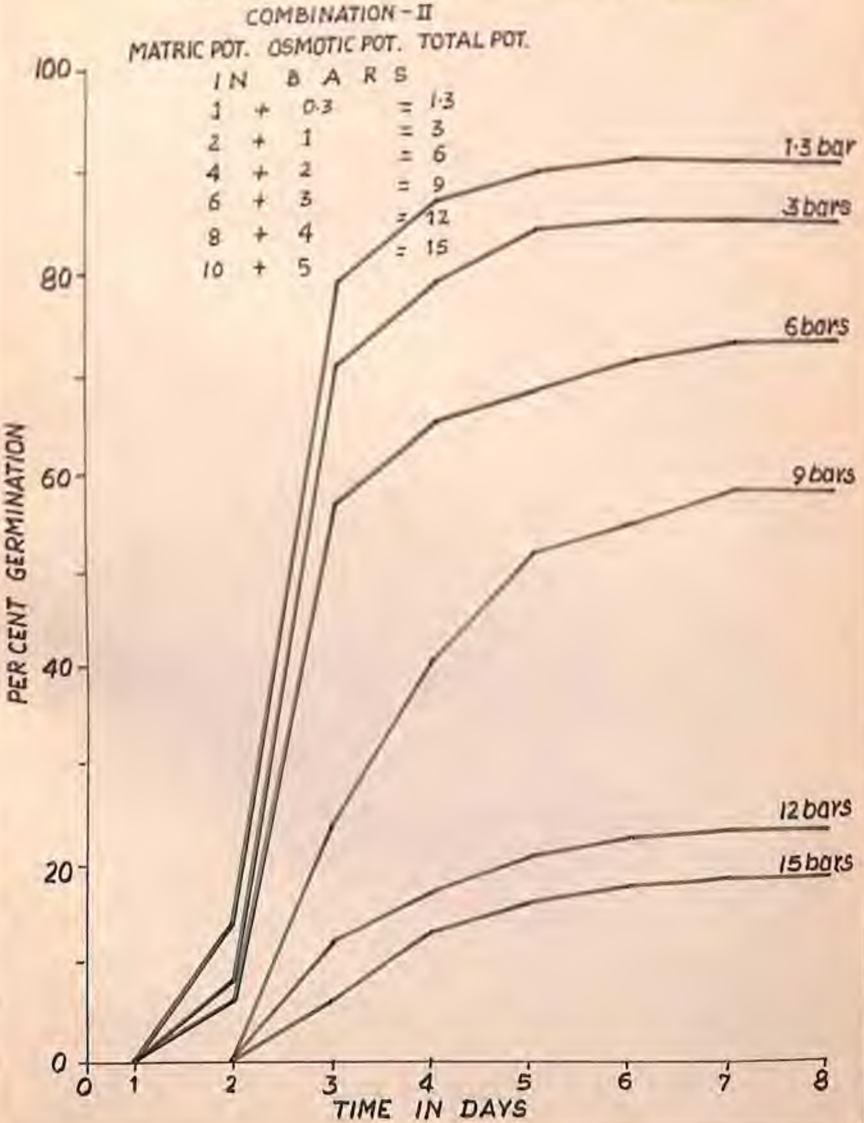


FIG.-10 RELATION OF GERMINATION OF WHEAT SEEDS TO TIME AND TOTAL SOIL-WATER POTENTIAL.



on germination of mung. The figures reveal that total soil-water potential had a marked effect on the rate as well as the total germination percentage of both the crops.

Ayers (1952) emphasized the importance of total soil-moisture stress (soil moisture tension + osmotic pressure of the soil solution) and its effect on seed germination. In the present study, the total soil-moisture stress below 3 bars had little effect on emergence of seeds of both the crops. But there was a rapid drop in seed germination of both the crops above 3 bar total soil-moisture stress. The critical value of total soil-water potential beyond which germination rate may be adversely affected should, of course, vary from soil to soil. The results obtained in this investigation hold for fine textured soils. In relatively coarse textured soils, the critical value of total potential, at which significant reduction in germination would take place, may be less than 3 bars in magnitude.

Collis-George and Sands (1962) suggested that matric potential (moisture tension) and osmotic potential are not equal in their effects on germination, particularly germination rate. However, the low matric potential they studied (0.01 to 0.1 atmosphere) would seldom exist under field conditions except for brief periods following rainfall or irrigation.

FIG.-11 RELATION OF GERMINATION OF MUNG SEEDS TO TIME AND TOTAL SOIL-WATER POTENTIAL.

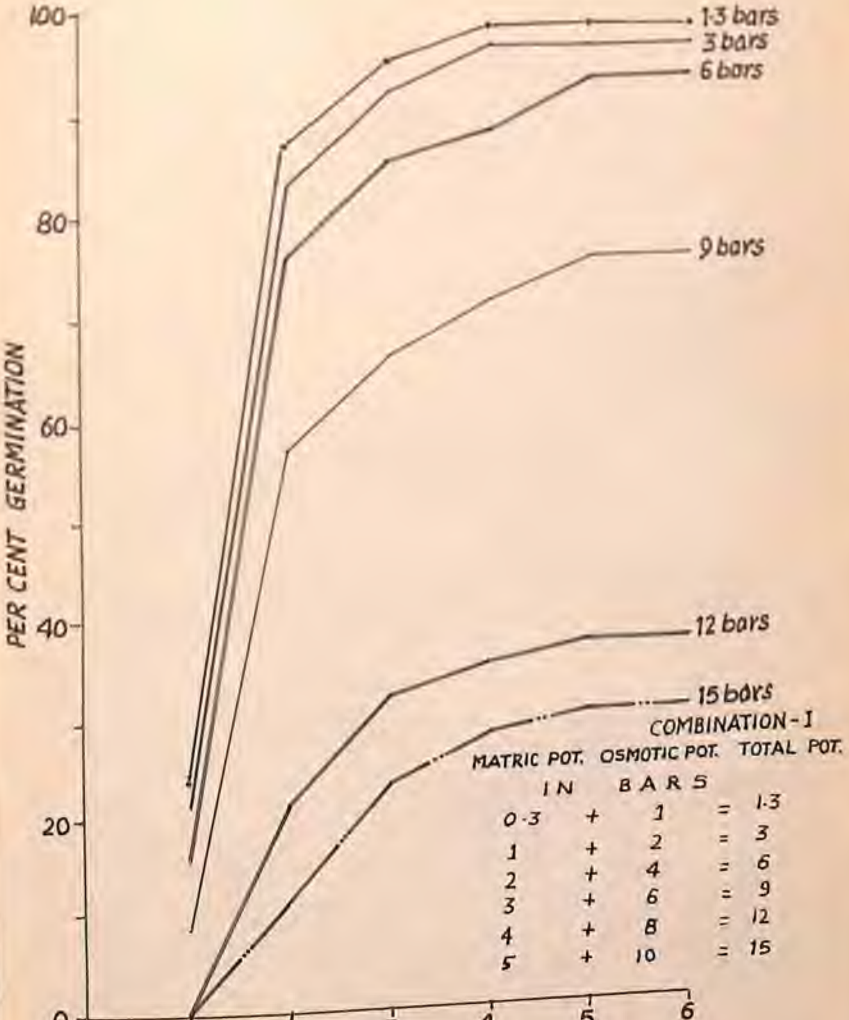
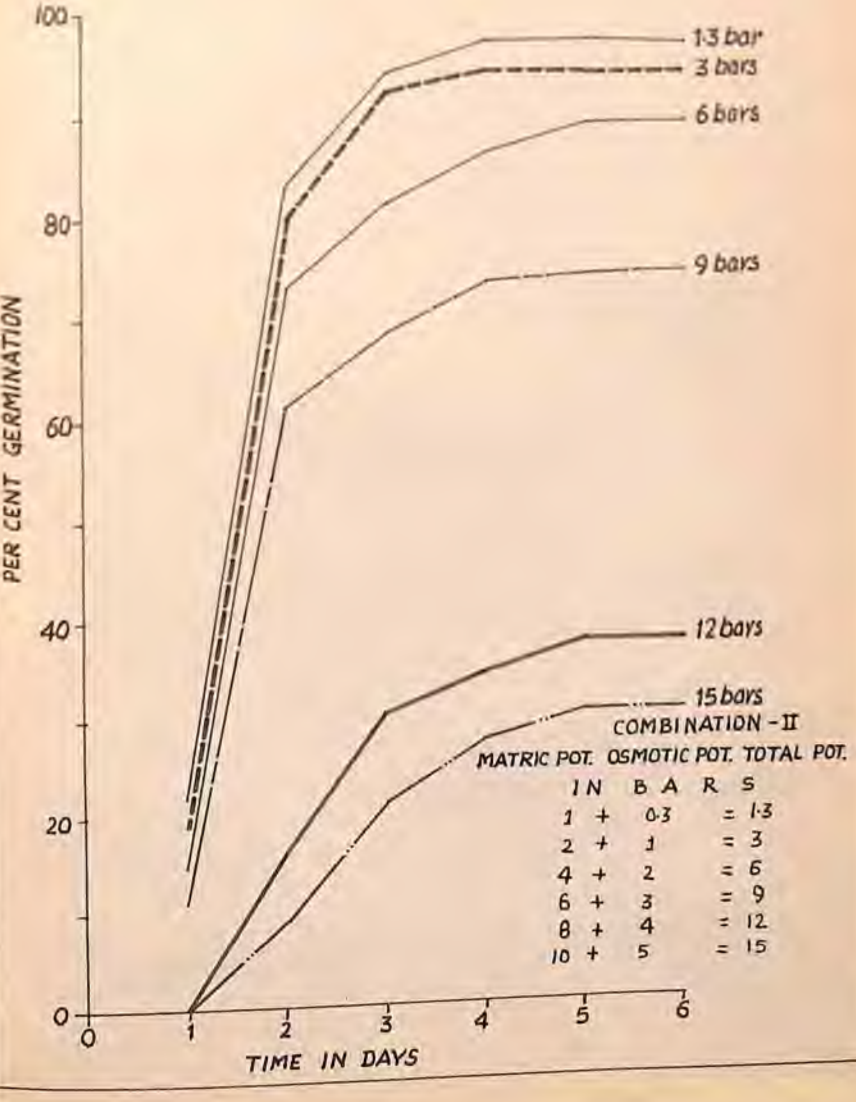


FIG.-12 RELATION OF GERMINATION OF MUNG SEEDS TO TIME AND TOTAL SOIL-WATER POTENTIAL



COMBINATION - II

MATRIC POT.		OSMOTIC POT.		TOTAL POT.
IN BARS				
1	+	0·3	=	1·3
2	+	1	=	3
4	+	2	=	6
6	+	3	=	9
8	+	4	=	12
10	+	5	=	15

In this study a significant effect of osmotic pressure on seed germination was found at higher matric tensions. This is because of the fact that as the soil dries out, there is an increase in osmotic pressure of the soil solution in addition to the normal increase in the soil-moisture tension. Thus an increased total soil-moisture stress may occur which may be critical to the seed germination under saline conditions at moisture contents well above the permanent wilting percentage reported for the non-saline soils.

Fig. 13 reveals that combination-I gives the same germination as combination-II at total moisture stress of 9, 12 and 15 bars. The differences between the two combinations at lower total potential suggest marked differences in the water transmitting properties of the soil owing to the differences in matric potential.

PART-II: ROOT ELONGATION

4.5. Effect of matric potential on radicle elongation of wheat and mung

Fig. 14 presents the relationship of radicle elongation of wheat and mung to moisture tension. From the figure, it revealed that with an increase of moisture tension from 0.3 to 15 bars, there was a progressive decrease in the length of the radicle of both wheat and mung crops.

FIG.-13 RELATION OF GERMINATION OF WHEAT AND MUNG SEEDS TO TOTAL SOIL-WATER POTENTIAL

(A COMPARISION OF TWO SETS OF COMBINATION)

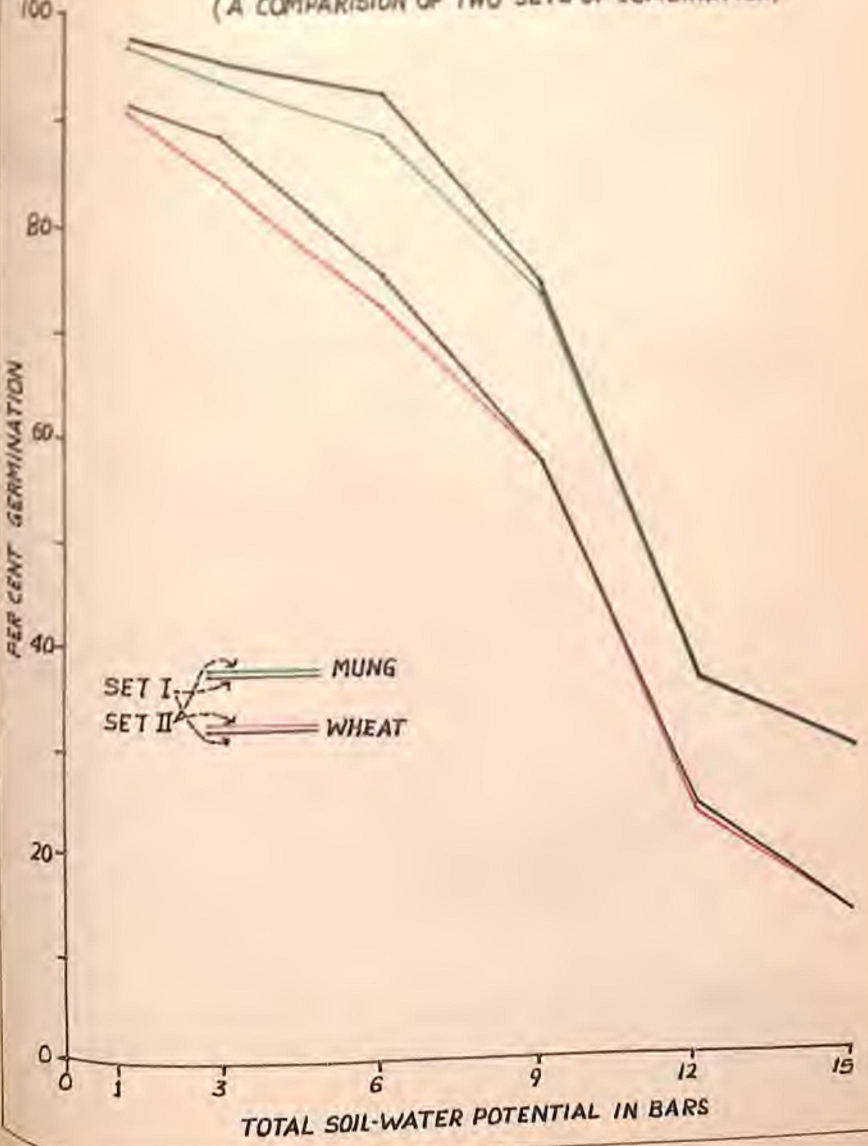


FIG.-14 RELATION OF RADICLE ELONGATION OF WHEAT AND MUNG TO MATRIC AND OSMOTIC POTENTIAL IN CLAYEY SOIL (A COMPARISION)

SOIL MOISTURE MAINTAINED AT F.C.

There was a rapid decrease in root length beyond 7 bar soil-moisture tension. Figs. 15 and 16 show the clear difference in root lengths of wheat and mung, respectively at different levels of matric potential.

4.6. Effect of osmotic potential on radicle elongation at a constant matric potential (0.3 bar)

Radicle elongation of both the crops as a function of osmotic stress is presented in Fig. ~~17~~ 14. Increased osmotic stress resulted in a gradual decrease of the radicle length. On comparing the effects of varying levels of osmotic potential (soil moisture maintained at field capacity throughout) and matric potential on root elongation, it was observed that root elongation was more in the former case in comparison to the latter one (Fig. 14). This difference may be attributed to the water transmission characteristics of the soil. Since in the former case, the soil-moisture is maintained at field capacity and only the osmotic pressure is varied, so permeability remains virtually constant. But in the latter case, unsaturated hydraulic conductivity also plays an important role.

According to Gingrich and Russel (1957) the degree of saturation and presumably the permeability remains constant in case of osmotic pressure experiment (experiment conducted by them in petri dishes, of course). However, for the soil-moisture tension experiment, a marked reduction


15

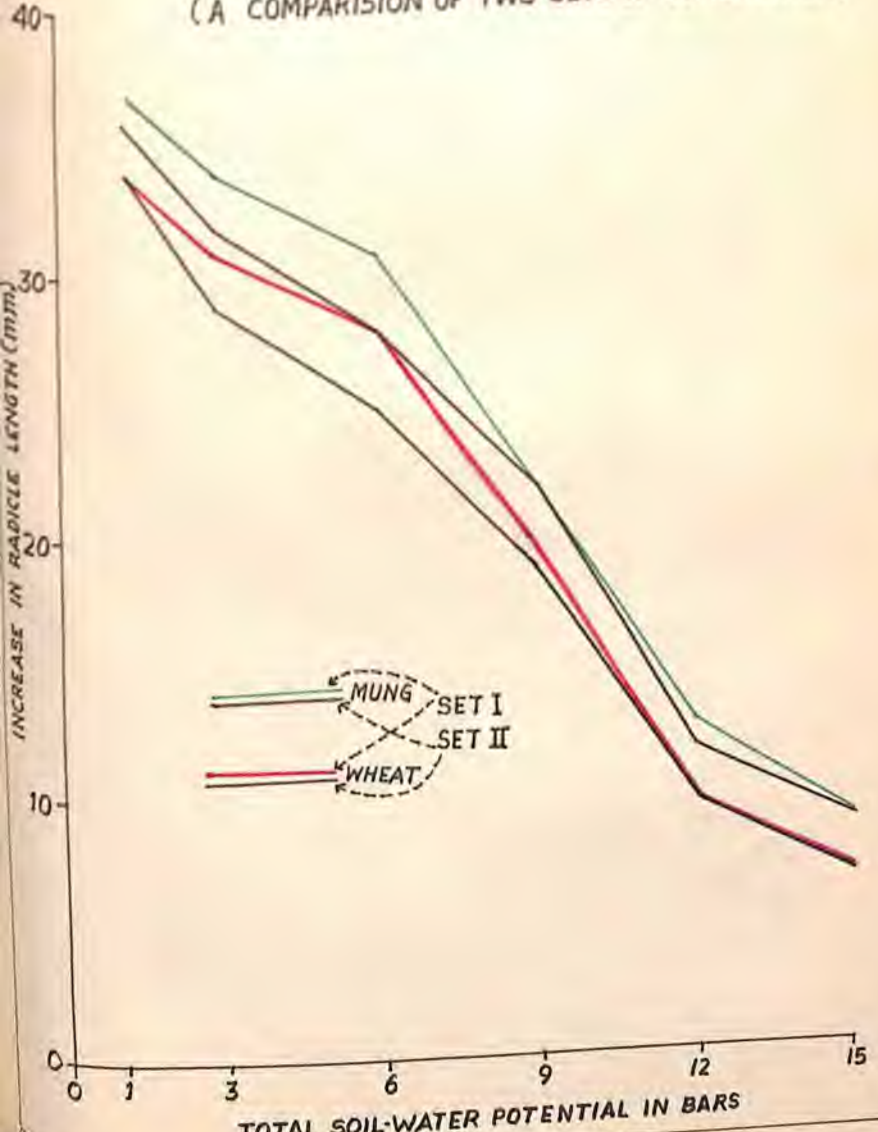

0.3 1 3 7 10 15
B A R S


3
6
9
12
—BARS—


3
3
6
9
—BARS—

FIG.- 17 ~~15~~ RELATION OF RADICLE ELONGATION OF WHEAT AND MUNG TO TOTAL SOIL-WATER POTENTIAL.

(A COMPARISION OF TWO SETS OF COMBINATION)



crops. The figure shows that there was difference in total length of the radicles upto 6 bar total moisture stress. However, the combination was immaterial at 9, 12 and 15 bars. The trend was similar in both the crops. This suggested that at lower total suctions (<9 bars) only transmission characteristics of the soil were responsible for the differences between the two cases. However, in case of total potential of 9, 12 or 15 bars the gradient in the potential between the radicle and soil became a limiting factor and transmission characteristics became less important. This is further revealed by a comparison of Fig. No. 18.

From the present investigation, it is clear that the two components are additive at relatively higher stresses and their combined effect results in a marked reduction in the root elongation.

There may be many factors, such as soil water, aeration, nutrient supply etc. which have a direct or indirect bearing on plant growth. Gardner and Ebling (1962) pointed out that the actual availability of soil water involves the ability of a plant to absorb water at the root surface, the energy with which it is held by the soil and its rate of movement through the soil to the plant root.

In the present study, all other factors remaining constant variation in the water regimes was brought about through moisture and osmotic stress. At lower levels of moisture stress, only the higher concentrations of mannitol solution had profound effects on root elongation. This suggested that in such cases, the energy status played an important role. But at relatively higher moisture tensions even the lower levels of osmotic pressures showed marked decrease in root length. This indicates that at higher moisture stress, the unsaturated conductivity and potential gradient between the radicle and soil were important.

This proved that under dryland agriculture, the lack of moisture on one hand and salinity conditions (if high salt concentration exists, at all) on the other not only affect the seed germination (as discussed in Part-I), but also the root growth at early stage. Therefore, the maintenance of the total soil-water potential at relatively higher levels in general and under saline conditions in particular is more important at the initial stages of crop growth.

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CHAPTER-V

SUMMARY AND CONCLUSION

Germination and root elongation studies of wheat, variety Narmada-4, and mung, variety Jawahar-45, were conducted at varying degrees of matric, osmotic and total soil-moisture potential (matric potential + osmotic potential) in a typical clayey soil. The rate as well as percentage germination of both the crops showed a gradual decrease with increasing osmotic and soil-moisture stress over a range of 0.3 to 15 bars. Germination percentage was found to be little higher in osmotic medium (d-mannitol) than it occurred in soil at moisture tension of equivalent stress. This was thought to be due to the moisture characteristics of the soil.

A series of combinations of moisture stress and osmotic stress resulting into the total moisture stress from 1.30 to 15 bars was tried. The total soil-moisture stress had a marked effect on the rate as well as the germination percentage of both the crops. Osmotic and matric potentials were additive in their effect at total potential of 9 bars and onwards.

Further, it was observed that more than 80 per cent germination took place at moisture stress of 3 bars in case of wheat and at 7 bars in case of mung. For root elongation, small seedlings were grown at different levels of osmotic, matric and total soil-moisture potential for 24 bars at 25°C ± 1 in the clayey soil. A marked decrease in root length of both the crops occurred when the soil moisture stress was increased from 0.3 to 15 bars. As the total soil-moisture stress (moisture stress + osmotic stress) increased, root elongation of both the crops decreased.

From the above studies, the following conclusions may be drawn:

1. The soil-moisture stress at any given moisture level increases with increased soil salinity and at any level of salinity, the stress is increased as the soil-moisture decreases.

2. Soil moisture stress adversely affects the seed germination and root elongation.

3. Moisture is not equally available to the roots from field capacity to the permanent wilting percentage.

4. Relatively higher moisture or osmotic stress cause reduction and delay in germination.

5. Mung (variety, Jawahar-45) can withstand relatively higher moisture stresses than wheat (variety Narmada-4) at germination and root initiation stages.

6. More than eighty per cent of the viable seeds of wheat and mung sown in a clayey soil (65.3% clay) can germinate at stresses as high as 3 and 7 bars, respectively.

7. Root elongation of wheat and mung is adversely affected under low soil-water potential because of less availability of water. Thus water uptake by plants may be limited by stunted root growth.

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CHAPTER-VI

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* Originals not seen

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APPENDIX-I

MOISTURE CONTENT BY WEIGHT AT VARIOUS SUCTIONS DURING DESORPTION

(AVERAGE OF 3 REPLICATIONS)

Tension in bars	Per cent moisture content
0	35.7
0.3	32.5
1	29.4
3	27.9
5	26.7
7	22.1
10	20.3
13	18.5
15	17.8

APPENDIX-II

GERMINATION PERCENTAGE OF WHEAT SEED AT DIFFERENT LEVELS OF MATRIC POTENTIAL

(AVERAGE OF 4 REPLICATES)

(CUMULATIVE RATE)

No. of days after sowing	0.3 bar	1 bar	3 bars	7 bars	10 bars	15 bars
1.	0	0	0	0	0	0
2.	21	19	14	11	0	0
3.	85	81	77	59	31	9
4.	92	89	84	63	47	12
5.	93	91	86	67	50	14
6.	94	92	87	69	52	17
7.	0	0	0	71	54	19

APPENDIX-III

GERMINATION PERCENTAGE OF WHEAT SEED AT DIFFERENT LEVELS OF OSMOTIC POTENTIAL

(AVERAGE OF 4 REPLICATIONS)

(CUMULATIVE RATE)

No. of days after sowing	0.3 bar	1 bar	3 bars	7 bars	10 bars	15 bars
1.	0	0	0	0	0	0
2.	27	25	21	15	7	0
3.	87	84	79	63	31	11
4.	94	93	86	69	49	17
5.	96	94	91	72	53	19
6.	97	95	92	74	56	20
7.	0	0	0	75	57	21

APPENDIX-IV

GERMINATION PERCENTAGE OF WHEAT SEED AT DIFFERENT LEVELS OF OSMOTIC POTENTIAL IN CLAYEY SOIL (SOIL MOISTURE MAINTAINED AT F.C.)

(AVERAGE OF 4 REPLICATIONS)

(CUMULATIVE RATE)

No. of days after sowing	0.3 bar	1 bar	3 bars	7 bars	10 bars	15 bars
1.	0	0	0	0	0	0
2.	24	21	18	13	9	0
3.	86	81	79	61	29	9
4.	92	89	86	68	50	13
5.	94	92	90	71	52	16
6.	93	93	91	73	54	19
7.	0	0	0	74	55	21

APPENDIX-V

GERMINATION PERCENTAGE OF WHEAT SEED AT DIFFERENT LEVELS OF TOTAL SOIL-WATER POTENTIAL (MATRIC POTENTIAL + OSMOTIC POTENTIAL) IN CLAYEY SOIL

(AVERAGE OF 4 REPLICATIONS)

(CUMULATIVE RATE)

Combination Set No.	No. of days after sowing	1.3 bar	3 bars	6 bars	9 bars	12 bars	15 bars
I	1.	0	0	0	0	0	0
	2.	18	11	9	0	0	0
	3.	82	75	60	29	11	6
	4.	87	86	69	48	17	13
	5.	89	88	72	53	21	16
	6.	92	89	75	57	24	18
	7.	0	0	76	58	25	19
II	1.	0	0	0	0	0	0
	2.	14	8	6	0	0	0
	3.	79	71	57	24	12	6
	4.	87	79	65	41	17	11
	5.	90	84	68	52	21	15
	6.	91	85	71	55	23	18
	7.	0	0	73	58	24	19

APPENDIX-VI

GERMINATION PERCENTAGE OF MUNG SEED AT DIFFERENT LEVELS OF MATRIC POTENTIAL IN CLAYEY SOIL

(AVERAGE OF 4 REPLICATIONS)

(CUMULATIVE RATE)

No. of days after sowing	0.3 bar	1 bar	3 bars	7 bars	10 bars	15 bars
1.	23	21	19	12	6	0
2.	86	83	81	73	51	11
3.	97	95	89	84	63	26
4.	99	97	91	86	66	29
5.	0	0	0	87	67	32

APPENDIX-VII

GERMINATION PERCENTAGE OF MUNG SEED AT DIFFERENT LEVELS OF OSMOTIC POTENTIAL

(AVERAGE OF 4 REPLICATIONS)

(CUMULATIVE RATE)

No. of days after sowing	0.3 bar	1 bar	3 bars	7 bars	10 bars	15 bars
1.	26	24	21	16	11	6
2.	87	84	81	75	63	16
3.	98	96	93	87	71	24
4.	100	99	95	90	72	32
5.	0	0	0	91	73	34

APPENDIX-VIII

GERMINATION PERCENTAGE OF MUNG SEED AT DIFFERENT LEVELS OF OSMOTIC POTENTIAL IN CLAYEY SOIL
(SOIL MOISTURE MAINTAINED AT F.C.)

(AVERAGE OF 4 REPLICATIONS)

(CUMULATIVE RATE)

No. of days after sewing	0.3 bar	1 bar	3 bars	7 bars	10 bars	15 bars
1.	28	21	19	16	9	4
2.	89	85	80	72	61	14
3.	98	94	91	85	67	21
4.	99	98	94	87	69	31
5.	0	0	0	89	73	33

APPENDIX-IX

GERMINATION PERCENTAGE OF MUNG AT DIFFERENT LEVELS OF TOTAL SOIL-WATER POTENTIAL (MATRIC POTENTIAL + OSMOTIC POTENTIAL) IN CLAYEY SOIL

(AVERAGE OF 4 REPLICATIONS)

(CUMULATIVE RATE)

Combination Set No.	No. of days after sowing	1.3 bar	3 bars	6 bars	9 bars	12 bars	15 bars
I	1.	24	21	16	9	0	0
	2.	87	83	76	57	21	11
	3.	95	92	85	66	32	23
	4.	98	96	88	71	35	26
	5.	0	0	93	75	37	30
II	1.	22	19	15	11	0	0
	2.	83	80	73	61	16	9
	3.	94	92	81	68	30	21
	4.	97	94	86	73	34	27
	5.	0	0	89	74	37	30

APPENDIX-X

ROOT ELONGATION OF WHEAT AT DIFFERENT LEVELS OF MATRIC POTENTIAL IN CLAYEY SOIL

(AVERAGE OF 3 REPLICATIONS)

Matric potential (bars)	Radicle length (average of 5 seedlings) (mm)
0.3	34
1	31
3	27
7	17
10	11
15	6

APPENDIX-XI

ROOT ELONGATION OF WHEAT AT DIFFERENT LEVELS OF OSMOTIC POTENTIAL (SOIL MOISTURE MAINTAINED AT F.C.)

(AVERAGE OF 3 REPLICATIONS)

Osmotic potential (bars)	Radicle length (average of 5 seedlings) (mm)
0.3	35
1	33
3	29
7	18
10	12
15	6

APPENDIX-XII

ROOT ELONGATION OF WHEAT AT DIFFERENT LEVELS OF TOTAL SOIL-WATER POTENTIAL

(AVERAGE OF 3 REPLICATIONS)

Combination Set No.	Total soil-water potential (bars)	Radicle length (average of 5 seedlings) (mm)
I	1.3	34
	3	32
	6	28
	9	20
	12	10
	15	6
II	1.3	34
	3	29
	6	25
	9	19
	12	10
	15	6

APPENDIX-XIII

ROOT ELONGATION OF MUNG AT DIFFERENT LEVELS OF MATRIC POTENTIAL IN CLAYEY SOIL

(AVERAGE OF 3 REPLICATIONS)

Matric potential (bars)	Radicle length (average of 5 seedlings) (mm)
0.3	39
1	35
3	32
7	24
10	15
15	10

APPENDIX-XIV

ROOT ELONGATION OF MUNG AT DIFFERENT LEVELS OF OSMOTIC POTENTIAL IN CLAYEY SOIL

(SOIL MOISTURE MAINTAINED AT F.C.)

(AVERAGE OF 3 REPLICATIONS)

Osmotic potential (bars)	Radicle length (average of 5 seedlings) (mm)
0.3	39
1	36
3	34
7	27
10	16
15	10

APPENDIX-XV

ROOT ELONGATION OF MUNG AT DIFFERENT LEVELS OF TOTAL SOIL-WATER POTENTIAL IN CLAYEY SOIL

(AVERAGE OF 3 REPLICATIONS)

Combination Set No.	Total soil-water potential (bars)	Radicle length (average of 5 seedlings) (mm)
I	1.3	37
	3	34
	6	31
	9	22
	12	13
	15	9
II	1.3	36
	3	32
	6	28
	9	22
	12	12
	15	9