EFFECT OF MOISTURE STATUS AND BULK DENSITY ON GERMINATION AND EMERGENCE OF PEARL MILLET, SORGHUM AND GROUNDNUT ON AN ALFISOL

BY

M. NIVEDITA
B.Sc. (Ag.)

THESIS SUBMITTED TO THE
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

MASTER OF SCIENCE

IN THE FACULTY OF AGRICULTURAL SCIENCE

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE, RAJENDRANAGAR
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
RAJENDRANAGAR, HYDERABAD-500 030.

SEPTEMBER, 1992

C E R T I F I C A T E

This is to certify that the thesis entitled **"EFFECT OF MOISTURE STATUS AND BULK DENSITY ON GERMINATION AND EMERGENCE OF PEARL MILLET, SORGHUM AND GROUNDNUT ON AN ALFISOL"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** of the **ANDHRA PRADESH AGRICULTURAL UNIVERSITY**, Hyderabad is a record of the bonafide research work carried out by **Ms. M. NIVEDITA** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

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

(Dr. K.B. LARYEA)
CHAIRMAN OF THE ADVISORY COMMITTEE

Thesis approved by the Student Advisory Committee.

CHAIRMAN : **(Dr. K.B. LARYEA)**
PRINCIPAL SOIL PHYSICIST,
RMP-SOIL,
I C R I S A T,
PATANCHERU - 502 324, A.P.

CO-CHAIRMAN : **(Sri. SRIKANTH MEDAKKER)**
ASSOCIATE PROFESSOR,
DEPT. OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY,
COLLEGE OF AGRICULTURE,
RAJENDRANAGAR, HYDERABAD-30.

MEMBER : **(Dr. D. SUBBARAMI REDDY)**
PROFESSOR OF SOIL PHYSICS
DEPT. OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY,
COLLEGE OF AGRICULTURE,
RAJENDRANAGAR, HYDERABAD-30.

MEMBER : **(Dr. G. NAGESWARA RAO)**
PROFESSOR AND HEAD,
DEPT. OF STATISTICS AND MATHEMATICS,
COLLEGE OF AGRICULTURE,
RAJENDRANAGAR, HYDERABAD-30.

CERTIFICATE

Miss M. Nivedita has satisfactorily prosecuted the course of research and that the thesis entitled **"EFFECT OF MOISTURE STATUS AND BULK DENSITY ON GERMINATION AND EMERGENCE OF PEARL MILLET, SORGHUM AND GROUNDNUT ON AN ALFISOL"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part there of has not been previously submitted by her for a degree of any University.

Date: 14th Sept. 1992

(Dr. K.B. LARYEA)
MAJOR ADVISOR

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES IN APPENDIX IV

ACKNOWLEDGEMENTS

I wish to express my deep sense of gratitude and sincere thanks to **Dr. K.B. Laryea,** Principal Soil Physicist, ICRISAT, Chairman of the Advisory Committee and **Shri Srikanth Medakker**, Co-chairman, APAU for their inspiring guidance, valuable help, sound advice and constant encouragement during the entire course of my research investigations.

I sincerely express my thanks to **Mr. P. Pathak**, Senior Agricultural Engineer, ICRISAT for his kind guidance and encouragement during the period of my research.

My grateful thanks to **Dr. D. Subbarami Reddy** and **Dr. G. Nageswara Rao**, members of the Advisory Committee for their personal encouragement, affection, valuable guidance and keen interest shown during the course of my research investigation and completion of the thesis.

I take this opportunity to express my gratitude to **Dr. D.L. Oswalt** for extending all possible help and encouragement during my stay at ICRISAT. My special recognition and thanks to the Institute for providing all the facilities required for my research investigation.

I deeply appreciate the help and assistance that I received from **Mr. L. Nageswara Rao**, Senior Field Assistant, ICRISAT during the course of my research work. I also take this opportunity to thank all the **Regular Work Force** members who have helped me in my research work.

I affectionately acknowledge the help, assistance and friendly guidance I received from **Jyothi, Madhavi, Padmaja, Caddy, Arvind, Sujatha, Sudi, Srinivas, Narsimloo, Baig, Prasad** and **colleagues** during the course of my studies.

I express my deep and sincere thanks to **Mr. Y. Prabhakara Rao** for his patient, neat and excellent typing of my thesis in spite of his busy schedule.

I take this opportunity to express my sincere regards and deep love to my parents **Dr. Ved Bhushan** and **Smt. Sunita**, for their tender affection and encouragement given to me during the course of my studies. I also take this opportunity to express my love and affection to **Dhanu, Suja, Preeti** and **Deepa** for their love and encouragement. I express my love and thanks to **Gudiya** and **Deep** for their love and affection.

Finally, I am grateful to the **Government of Andhra Pradesh** for providing financial assistance during the course of my post-graduate study.

Nivedita. M.
NIVEDITA, M.

DECLARATION

I, **M. NIVEDITA**, hereby declare that thesis entitled **"EFFECT OF MOISTURE STATUS AND BULK DENSITY ON GERMINATION AND EMERGENCE OF PEARL MILLET, SORGHUM AND GROUNDNUT ON AN ALFISOL"** submitted to Andhra Pradesh Agricultural University for the degree of Master of Science in Agriculture is the result of the original research work done by me. It is further declared that the thesis or any part thereof has not been published earlier in any manner.

Date : 14th Sept 1992

Nivedita M

(M. NIVEDITA)

NAME OF THE AUTHOR	:	**M. NIVEDITA**
TITLE OF THE THESIS	:	**EFFECT OF MOISTURE STATUS AND BULK DENSITY ON GERMINATION AND EMERGENCE OF PEARL MILLET, SORGHUM & GROUNDNUT ON AN ALFISOL**
DEGREE TO WHICH IT IS SUBMITTED	:	**MASTER OF SCIENCE (Ag.)**
FACULTY	:	**AGRICULTURE**
DEPARTMENT	:	**SOIL SCIENCE & AGRICULTURAL CHEMISTRY**
CHAIRMAN OF THE ADVISORY COMMITTEE	:	**DR. K.B. LARYEA** **PRINCIPAL SOIL PHYSICIST** **RMP - SOIL** **I C R I S A T** **PATANCHERU 502 324** **ANDHRA PRADESH** **INDIA**
UNIVERSITY	:	**ANDHRA PRADESH AGRICULTURAL UNIVERSITY**
YEAR OF SUBMISSION	:	**1992**

ABSTRACT

In greenhouse experiments, the germination and emergence of pearl millet, sorghum and groundnut in an Alfisol, was found to decrease significantly with reduction in soil moisture content and increase in bulk density. The effect of increasing bulk density was considerable at low soil moisture contents. A bulk density of 1.45 g cm^{-3} and moisture contents ranging from 8% to 11% were observed to be favorable for germination and emergence of all the three crops. A bulk density of 1.65 g cm^{-3} was critical for emergence of pearl millet and sorghum. Excessive dryness and high bulk density were detrimental to germination as well as seedling emergence. Initiation of germination occurred when the gravimetric moisture content ranged from 4% to 8% for the three crops. A gravimetric moisture content greater than 19% significantly decreased germination and emergence. Emergence was delayed by one or two days when the soil was at higher bulk density in the low moisture content ranges. Rate of emergence was faster at a bulk density of 1.45 g cm^{-3} than at either 1.55 or 1.65 g cm^{-3}. In the wet moisture range, the rate of emergence was faster at all the three bulk densities than in the dry moisture ranges. Emergence increased with increase in moisture content. Increase in bulk density decreased the emergence for the three crops.

CHAPTER I
INTRODUCTION

CHAPTER I

INTRODUCTION

Alfisols which are a major order of soils found in the semi-arid tropical regions of India are poor soils, shallow in depth with low available water retention capacity, low infiltration rate often due to crusting at the soil surface and have poor nutrient status. Crusting is a major problem in these soils and it affects the germination and emergence of small seeded crops. Uncertain rainfall and low water holding capacity of these soils also play a major role in limiting the yield potential of crops grown on these soils. Bulk density of Alfisols increases with depth caused by compaction of the finer materials deposited in the lower soil depths. Due to the prevalence of aberrant weather and soil related constraints, the germination and emergence of seeds sown in these Alfisols decrease thereby resulting in low and unstable crop yields.

Crop establishment problems on Alfisols are usually caused by a combination of soil, weather and environmental factors. Failure of crop establishment is a common problem in many sorghum and pearl millet growing areas. Poor seedling emergence frequently results from lack of sufficient seedbed moisture at the time of sowing. Seedling emergence is also inhibited largely by occurrence of surface soil crusts that can form naturally on Alfisols as a result of rainfall impact. Once these crusts are formed, they mechanically hinder the emergence of seedlings and cause poor stand. Crusting is a result of a combination of processes such as soil compaction, structural breakdown and deposition of fine particles on the surface.

Germination of seeds and seedling emergence are greatly influenced by soil physical conditions especially bulk density and soil moisture status. When seedling emergence is poor, plant population would then be reduced and would in turn result in poor yields. For example, soybean yields were reduced by as much as 8 to 9% due to poor crop stand as a result of decreased emergence (Goyal et. al., 1981).

The soil or seed bed factors that influence the expression of germination and emergence potential of seed are many and they interact in various ways to permit, impede or prevent germination and emergence. The potential of seeds to germinate and emerge, under varying levels of factors is governed by a range of environmental conditions in which the seeds are planted.
The main soil factors are temperature, soil moisture content, oxygen supply, microrganisms, bulk density, hydraulic conductivity and moisture suction or potential. Seed factors such as the genetic and physiological attributes also influence germination, emergence and stand establishment of crops.

Pearl millet and sorghum are the two most important cereal crops cultivated in the semi-arid tropical regions of India. They constitute the staple food of a large section of population in India. Groundnut is also an important oil seed crop grown in this region. These crops are usually grown under erratic rainfall conditions, high temperatures and adverse soil characteristics that may inhibit crop establishment and also subsequently reduce their yield potential. India ranks first in terms of the area under sorghum and groundnut, ranks first in groundnut production and second in sorghum production in the world. Both pearl millet and sorghum are tolerant to drought conditions. Consequently, most of the farmers do not take proper care and management in cultivating these crops.

In recent years increased mechanization which relies on heavy machinery on farmlands has resulted in the deterioration of soil structure through compaction which affects infiltration of water, germination and seedling emergence. Increase in soil strength as a result of compaction is one of the critical factors affecting the emergence of seedlings. Increased soil bulk density results in reduced pore space, reduced aeration and decrease in hydraulic conductivity. If the bulk density of the soil is too high, then the emerging plumule would be unable to overcome the resistance of overlying soil and would therefore result in decreased emergence of the seedlings. The adverse effects of high bulk density on the seedling emergence of small seeded crops such as sorghum and pearl millet is great.

The soil moisture status is another important factor which influences germination and emergence of crops. Even though sorghum and pearl millet are drought tolerant, their yields decrease during droughty years mainly because of poor emergence and crop stand due to lack of availability of sufficient moisture. Poor germination due to low soil moisture content is a major obstacle in increasing the production. If it was possible to identify the minimum moisture required for germination and the appropriate soil moisture ranges required for maximum germination then sowing of crops could be done at appropriate periods when there has been sufficient rainfall to ensure good, crop establishment. Effect of moisture on germination is very complex due to various factors involved, such as the initial water content of the seed, amount of water in soil, hydraulic conductivity of the soil, seed-soil contact and potential of water in the soil. Reduction in soil moisture content below a minimum results in reduced emergence. Optimum soil moisture condition around the seed is one of the critical factor governing the germination and emergence of seedlings. Therefore a study of the effect of soil moisture on germination and emergence would provide the basic information essential for ensuring an ideal soil environment for emergence and growth of seedlings.

Because the volumetric water content of a soil comprises of the gravimetric water content and the bulk density, the gravimetric water content of the soil that ensures an optimum germination and emergence at one bulk density may not be the same for other bulk densities of the same soil. Examination of the literature reveals that there is little quantitative studies on the interactive effects of bulk density and soil moisture status on germination and emergence of pearl millet, sorghum and groundnut grown on Alfisols. Therefore the present investigations were designed to determine the effect of different levels of soil moisture status and bulk density and their interactions on germination and emergence of pearl millet, sorghum and groundnut in Alfisols.

CHAPTER II
REVIEW
OF
LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Seed germination and seedling emergence are the two critical stages governing the success or failure of a crop. Moisture is an essential requirement for seed germination. Seed germination varies with the species of the plant as well as with the soil moisture status. Bulk density is another important soil physical factor which influences germination and emergence of crops. Bulk density influences other soil physical factors especially soil temperature, volumetric moisture content, moisture potential, total porosity, soil aeration and the hydraulic conductivity of the soil.

In this chapter, the effect of temperature, moisture status and bulk density on the germination and emergence of crops would be briefly reviewed.

2.1 Effect of temperature on germination of crops

Temperature is an important environmental factor governing the germination of seeds in moist soil. The prevailing soil temperature determines the fraction of seeds which germinate and the rate at which they germinate. Indeed temperature exerts a major influence on the rate at which various crop plants develop. When a crop is sown, the time that elapses before germination and emergence of seedlings is strongly dependent on temperature as well as moisture in the seed bed.

The imbibition of water by seeds, germination rate and final germination of the crops have been found to be linearly related to temperature (Dewez, 1964). However, in actual field situations the water content of the seed zone changes with time and therefore there is an interaction between temperature and water content of the seed zone.

Kanemasu et al., (1975) indicated that soil temperature strongly influences both percentage germination and the time of emergence of sorghum. , Each crop has a minimum and a maximum temperature at which no seeds will germinate and an optimum temperature at which germination will be greatest. In their studies, Kanemasu et al., also found that sorghum required an optimum soil temperature of about 23°C. At that soil temperature, the percentage emergence of sorghum was found to be 81%. Similar results have been reported by Wilson et al., (1981). Poor and delayed emergence of sorghum seedlings was observed at high soil temperatures.

Peacock (1981) observed that the minimum temperature for germination of sorghum is between 7.2°C and 10°C. The minimum temperature for germination may vary within species from 4.6°C to 16.5°C. Peacock (1981) found that during the initial germination of sorghum seedlings, respiration and mesocotyl extension declined as temperatures were reduced from 24°C to 8°C.

In the tropics, high temperatures may cause a loss of viability of seeds. This has been reported to be responsible for poor seed germination and seedling emergence (Garcia-Huidobro et al., 1982). Also, the rate of germination has been found to increase linearly with temperature from a base temperature to a sharply defined optimum temperature beyond which the rate decreases linearly as temperature approaches zero.

Huges et al., (1984) reported from their laboratory experiments that no germination occurred within 14 days at 5/10°C night/day temperatures., The difference in germination percentage at 10/15 and 15/20°C night/day temperatures was greatest for pearl millet. Germination percentage for Echinocloa and Pennisetum spp. was depressed more by low osmotic potential at 10/15°C night/day temperatures than at high temperatures.

In laboratory experiments conducted by Khalifa and Ong (1990) on four pearl millet cultivars, there was no germination between 7 to 8°C and 41 to 49°C. A 5% germination was obtained at 11°C and the rate of germination for all four cultivars increased linearly with increase in temperature from a base temperature to an optimum temperature. Above the optimum temperature, the rate of germination decreased linearly to zero at maximum temperatures of 46 to 48°C. Short duration varieties were found to be more tolerant to high temperatures than long duration varieties.

In laboratory studies conducted by Brar et al. (1991), to test a model for sorghum seedling establishment, a combination of cool temperature (15.9°C) and moderate level of stored water at a matric potential of -0.1 MPa at planting produced an emergence count of 80%. Similarly, a combination of warm temperature (35.8°C) with stored *water at a matric potential of -0.03 MPa provided a favorable environment for 87% seedling emergence. Their study* indicated that temperatures in the range of 20.5 to 30.2°C and moisture potentials between -0.03 and -0.1 MPa had no effect on final emergence.

2.2 Effect of Moisture Status on Germination and Emergence of Crops

Even though several reports have been published on the effect of soil moisture on germination, very few report accurate measurements of available soil moisture. Consequently, there is little accurate experimental evidence on the effects of different levels of soil moisture on germination.

Vegetable seeds have been found to give satisfactory germination percentage over a wide range of available soil moisture. Doneen and MacGillivray (1943) observed that germination at low soil moisture appeared not to be correlated with size of seeds. Seeds germinated more quickly at high soil moisture (18%) than at low (8%), the interval between first and last germination of seeds increased as the gravimetric water content decreased. In all trials, soil moisture at planting was taken into consideration.

Hunter and Erickson (1952) characterized the soil moisture required for seeds to germinate by relating germination to soil moisture tension. At soil moisture potentials lower than that required for germination, the seeds were unable to obtain sufficient amount of moisture to resume active growth even though the soil air was saturated with water vapour. Once seeds imbibed water from the surrounding environment, they became moist, fleshy and tender and unless they were able to obtain sufficient moisture for germination, they usually remained in this condition and became prey to certain fungi which caused their decay.

Hanks and Thorp (1956) observed that seedling emergence was nearly the same when the moisture content was maintained between field capacity and wilting percentage if other factors were optimum for maximum seedling emergence. The rate of seedling emergence was faster at higher moisture content (three fourth of available water) than at lower moisture content (i.e., one fourth of available water). In general, the lower the moisture content the slower the seedling emergence rate.

Collis-George and Sands (1959) studied the response of Medicago species to decreased matric potential. Their results indicated that a decrease in matric potential by 0.1 bar, was sufficient to retard germination rate. When all other factors were constant, the water uptake by seeds would appear to be controlled by both the matric potential and hydraulic conductivity of the soil.

Evans and Stickler (1961) in their studies on the effect of simulated drought on four sorghum varieties, indicated that there was a progressive decrease in germination with increasing moisture tension. They observed that a lot of time was required for sorghum to reach final germination as osmotic tension increased, an indication that lengthening of the time required for germination under drought stress would be critical under field conditions. The dehydrated and burned appearance of seedlings grown by these researchers under moisture tension of 15 atmospheres suggested that growth could not be sustained under such conditions.

Hudspeth and Taylor (1961) studied the effect of moisture content on seedling emergence of Blackwell Switchgrass. They observed that 18-19% gravimetric moisture content was optimum for seedling emergence. Emergence decreased when moisture content was greater than 19%. At a soil moisture tension of 10 atmospheres no emergence occurred.

Wright et. al. (1978) working with seeds of several grass and legume species found that as temperature and moisture tension increased, the rate of emergence and total emergence declined. Water uptake of several field crops decreased with increase in soil moisture tension. Highest emergence was obtained at low soil water potential of -1/3 bars. Insufficient moisture reduced seedling emergence and resulted in seedling damage and death as a result of infection by pathogens.

In a study conducted by Fawusi and Agboola (1980), germination of sorghum and millet seeds was observed to be adversely affected by soil moisture in excess of 50% of field capacity. This observation that sorghum and millet performed well at low soil moisture retention partly explains their ability to survive in dry ecological regions. Poor germination was also obtained at a soil moisture retention of 100% and 25% of field capacity in the case of tomato. Since germination was inhibited at high moisture (100% of field capacity), it would seem that respiration of seeds was inhibited because oxygen was limited whereas at low soil moisture (25% of field capacity), soil-seed contact seemed insufficient for optimum imbibition. It is also possible that at low soil moisture regimes, the moisture potential gradient was not sufficient for water to flow to seed for imbibition to occur thus reducing germination and emergence. Sorghum and millet showed increased emergence with increasing soil moisture retention. For optimum germination and emergence a soil moisture retention of 25 to 50% of field capacity for sorghum; 25% of field capacity for millet and 50% of field capacity for tomato was found to be essential.

Stout et al., (1980) reported delayed initiation, slow rate and reduced percentage of germination at low water potentials (-15 bars). Sorghum seeds however were found to tolerate low water content and hence were able to survive in drought stress conditions (Wilson and Eastin, 1981).

In laboratory studies conducted by Mali and Varade (1981) on emergence of rice seedling in a clay soil, a significant decrease in emergence with reduction in soil moisture content and increase in bulk density was observed. Seed germination and seedling emergence suffer due to soil moisture potential and hydraulic conductivity. *Seedling emergence was reduced by 54.2% and 47.5% when gravimetric soil moisture content decreased from 33% and 28%* to 20%. The lower emergence percentage at 20% soil moisture was due to lack of water for germination. The rate of emergence of rice seedling was also found to be influenced by moisture and bulk density interactions.

Brar et. al. (1982) observed an increase in seedling emergence with increase in moisture content at a shallow depth of 2.5 cm while seedling emergence decreased with deeper seedling depth. Reduction in water content reduced water uptake by seeds and thus affected germination.

Haller (1984) reported that decrease in yield was greater when the same low moisture, i.e., 30-35% of field capacity, prevailed from sowing to second leaf stage of wheat. He concluded that soil water and air regimes at germination have far reaching effects on crop development causing differences in density of plant cover and yield of grains. Insufficient aeration caused by high soil moisture or soil water deficits at the beginning of germination reduced yields.

Painuli and Abrol (1984) found that seedling emergence was relatively fast initially at volumetric moisture content of 40%, 10% and 5% i.e. at high, medium and low moisture content respectively, but emergence slowed down with time and finally became static. Ultimate emergence decreased with increasing crust strength. Rate of emergence in general decreased with increase in crust strength. Maize emergence was poor under low (i.e., 5%) volumetric moisture content and high (i.e., 40%) volumetric moisture content whereas the emergence for pearl millet was highest at 40% volumetric moisture content.

Pearl millet is a potentially productive high-quality grain crop that appears superior to sorghum in establishment under limited soil moisture. Smith and Hoveland (1986) observed a reduction in germination of pearl millet and sorghum by 6% and 44% respectively when the osmotic potential (OP) increased from 0 to 1.0 MPa. The median germination time for pearl millet was found to be significantly less than that of sorghum at all osmotic potential levels. Total sorghum germination decreased steadily with each increase in OP. These results imply that pearl millet is more capable of germinating under drought conditions than sorghum. The fact that pearl millet has a mass approximately one-fifth that of sorghum may play a role in its ability to germinate under drought conditions (Smith et al., 1989).

Germination and emergence of most crop species are progressively delayed and reduced as soil water potential decreases. Emergence of cotton seedlings decreased slowly with decreased soil water potential from -400 to -750 kPa and a sharp decrease occurred at a potential of -800 kPa. Rao and Dao (1987) reported a decrease in total seedling emergence of Brassica sp. with decrease in soil water potential from -250 to -500 kPa. At lower soil temperatures, a significant difference was observed in seedling emergence at different soil water potentials. Differences between the time required for first seedling emergence and time required for attaining 50% seedling emergence were minimal when soil water potentials were in the range of -10 to -250 kPa. However that time interval increased with decrease in soil water potential from -250 to -500 kPa. Rapid uniform emergence can be achieved as long as soil water potential is greater (or less negative) than -250 kPa. Soil water potentials less (or more negative) than -250 kPa reduced and delayed germination and rate of seedling emergence under low soil temperatures.

In experiments conducted by Bouaziz and Bruckler (1989) decreasing (or more negative) soil water potential was observed to lead to a significant reduction of both emergence and elongation rates of roots and shoots. Time required for complete emergence increased with decreasing water potential.

Germination and early seedling growth involve the hydrolysis of stored seed constituents and the transfer of solubilized derivatives to the growing embryonic axis. This process is initiated by water uptake and eventually leads to seedling emergence. Hadas (1969) suggested that there are three stages in seed germination viz., (a) imbibition, (b) a pause in growth during which enzymatic and merismatic activities are initiated, and (c) the resumption of active growth and emergence of radicles from the seed coat. He contended that moisture stress has less effect on imbibition than on the crucial events during the "pause" stage.

Experimental evidence on the effects of soil moisture content on germination relates the reduction in the rate of germination to various factors. It has been well established that matric potential and hydraulic conductivity of the soil, the osmotic potential of the soil solution, the seed soil contact area and their interaction affects the rate and percentage of emergence (Collis- George and Sands, 1959).

On the other hand, Hadas and Russo (1974) suggested that rate of water movement in the soil across the seed-soil interface and into the seed must be analyzed to predict the rate of emergence. It therefore appears that both soil and seed factors are determinants in the rate of water uptake by seed and rate of germination.

2.2 Effect of Bulk Density on Germination and Emergence of Crops

Germination and emergence of seeds require favorable soil water, oxygen and temperature. In a soil media, the seedling root and shoot encounters a porous medium composed of voids and obstructions through which growth occurs. Soils which are compact have higher bulk density and lead to excessive impedance which has adverse effects on the growth of roots and shoots of seedlings. The smaller seed size of some crops, like sorghum and millet, is an additional factor increasing the adverse effects of high bulk density on the germination and seedling emergence. Bulk density also influences the moisture content of the soil. The volumetric moisture content of the soil increases linearly with bulk density and depending on texture, a maximum bulk density is reached above which continued compaction decreased the water content. Increasing bulk density at constant moisture content and temperature, increases the matric potential in most soils. The moisture content increases as bulk density decreases because the volume of pores increases. Air capacity normally decreases progressively as bulk density increases. In all soils, compaction beyond a critical bulk density would progressively decrease available water capacity (Archer and Smith, 1972).

The experimental data of Hanks and Thorp (1956) indicated that bulk density was related indirectly to seedling emergence in that any change in bulk density changed other factors such as oxygen diffusion rate and soil crust strength. They reported that an increase in bulk density decreased seedling emergence because of increase in soil strength. As soil compaction was increased from optimum, the oxygen diffusion rate decreased, crust strength also increased and these led to a decrease in seedling emergence. At the same bulk density, seedling emergence varied depending upon the soil moisture content. At higher soil moisture content i.e. at field capacity, the emergence was high (82%) even at a high bulk density of 1.5 g cm^{-3}, but at the same bulk density a decrease in moisture content reduced the seedling emergence. Thus an interrelationship exists between bulk density and available moisture content in relation to seedling emergence.

A high bulk density usually leads to increase in soil strength. This increase in bulk density also increases mechanical impedance which in turn limits seedling emergence. Hanks and Thorp (1957) studied the effect of soil crust strength on seedling emergence. Their results indicated that crust strength was dependant on soil moisture content. At a given crust strength, seedling emergence was lowest where soil moisture content was lowest (i.e., 25% of the available water). Both moisture and crust strength greatly affected emergence of wheat seedlings. Emergence of wheat seedling through a crust was found by these researchers to be influenced by crust strength immediately around the growing tip and not by the strength of the entire crust. This suggests that seedlings do not "press" on the crust until it breaks but rather must "worm" their way slowly through the crust. The time required for a specified number of seedlings to emerge increased with the crust strength and decreased with moisture content.

However, Hudspeth and Taylor (1961) observed that when compaction pressure was applied, emergence was not hindered. On a soil having gravimetric moisture content of 16.8%, all pressures either on the seed or on the soil surface increased the rate and total seedling emergence when compared to the soil medium where no pressure was applied. At high gravimetric moisture content of 21%, pressures of 703 to 14060 kg m^{-2} applied on surface of soil had little effect on the rate of total seedling emergence. A pressure of 703 kg m^2 on loose soil caused significantly greater emergence than no pressure, which may be attributed to greater seed soil contact as a result of the applied pressure.

Many investigators have found that excessive soil strength caused by increased bulk density reduces emergence of a large variety of crops. Parker and Taylor (1965) found that an increase in soil strength causes a progressive decrease in emergence. Sorghum emergence ceased when soil strength due to high bulk density increased to about 18 bars. Most of the seedlings emerged within a few days from soils having a low strength but the emergence rate decreased as soil strength was increased. An increase in soil moisture tension to 1 bar or greater, decreased the rate and amount of emergence and decreased total emergence at a specific soil strength. Thus an increase in soil moisture tension decreased seedling emergence, especially when the seedlings encountered considerable resistance to emergence as a result of high bulk density of 1.60 g cm^{-3}. Greater percentage of plants emerged at low strength than at high soil strength. In the field, evaporation occurs continuously and this would have the effect of reducing soil moisture around the seed if there is no rainfall and thus increase the soil strength and decrease seedling emergence.

Huges et al., (1966) observed a decrease in grass seedling emergence with increasing crust strength, when moisture content was held constant. For a given crust strength, seedling emergence was lowest (55%) at low moisture potential of -3 bars. At -3 bar soil water potential and all levels of bulk density, seedling emergence of Bermuda grass was 55% and that of weeping lovegrass was 60%. At 1.5 g cm^{3} bulk density, emergence of bermuda grass was 65% even at -1/3 bar soil water potential.

The results of experiments conducted by Mali, et. al., (1977) indicate that seedling emergence of sorghum was adversely influenced by bulk density. The seedling emergence of sorghum varieties CSH-4 and M35-1 decreased from 97 to 80% and 93 to 83% respectively as soil bulk density increased from 1.0 to 1.1 g cm^{-3} in a clay soil. Emergence of all varieties of sorghum seedlings was greatly influenced by soil bulk density of 1.2 g cm^{-3}. The decrease in seedling emergence with increase in bulk density was attributed to increased mechanical impedance, low moisture availability, lack of oxygen and low temperatures. For a seedling to emerge it must not only germinate but also penetrate through the compacted layer. Energy required for emergence of seedling increases with increase in bulk density. Therefore, it appears that seedling emergence was adversely affected by the increased mechanical impedance of the soil due to high soil strength induced by increasing bulk density.

Hegarty and Royle (1978) found a negative linear relationship between seedling emergence and soil impedance, which accounted for 80% variation in percentage emergence of carrot, onion and ginger. Pre-emergence losses of onions were found to be largely due to failure of seedlings to emerge through the soil after germination rather than failure of seeds to germinate.

Mali and Varade (1981) in laboratory studies observed that emergence of rice seedling in a clay soil decreased with increase in bulk density and reduction in soil moisture content. The effects of increased bulk density was considerable at lower soil moisture. A gravimetric soil moisture content of 33% at 1 to 1.15 g cm^{-3} bulk density was found to be most favorable. The rate of seedling emergence at all soil moisture levels was reduced with an increase in bulk density. An increase in bulk density to 1.30 g cm^{-3} decreased the emergence by 11.7%. In the studies of Mali and Varade (1981) the interaction of soil moisture and bulk density was highly significant. At 20% moisture content, there was a drastic reduction in seedling emergence from 77 to 22% with increase in bulk density from 1.0 to 1.15 g cm^{-3}. Similarly at a bulk density of 1.0 g cm^{-3}, the soil moisture did not affect the seedling emergence but at 1.15 and 1.30 g cm^{-3} bulk density, decrease in soil moisture from 28% to 20% severely reduced the emergence.

A seedling must exert considerable force to penetrate a crust during emergence from the soil. Therefore larger and heavier seeds such as corn have been shown to have greater emergence force than smaller and lighter seeds (Reusche, 1982).

Soman, et. al., (1984) reported that due to small seed size of sorghum and millet, the seedling emergence was affected by soil crusting. Seedlings emerged through soil crusts in various ways. Individual seedlings can exert sufficient pressure through a soil crust to emerge or groups of seedlings may crack the crust from below by cumulative force. In case where seedlings did not emerge, curved plumules or damaged whorls of the first leaf were observed when surface crust was removed.

Haller (1984) observed an inverse relation between barley yield and bulk density of the soil in early sowings but bulk density was proportional to yield in later sowings. This may be due to soil aeration rather than bulk density. In later sowings, soil moisture was usually lower and by increasing the bulk density the germinating seed was better supplied with water resulting in proportional relation between yield and bulk density of soil.

In a field experiment, Venkaiah (1985) observed that a higher bulk density decreased the leaf area index of groundnut and reduced water supply resulting in dimunition of top growth. A high bulk density per se apparently is not a controlling factor in root development but it is augmented by soil strength from this increase in bulk density. The increase in bulk density increased mechanical impedance which is mainly responsible for decreased peg penetration and ultimately led to reduced yields. The threshold bulk density for groundnut in sandy clay loam soils was identified to be 1.50 g cm^{-3}.

Maiti et al., (1986) reported that an increase in crust strength was accompanied by a decrease in soil moisture and an increase in soil temperature in the seed zone. The emergence percentage decreased with increase in crust strength and decrease in soil moisture content.

Ahmed et al., (1989) found that bulk density was a measure of soil compaction which hindered peg penetration and pod development in groundnut as reported by Venkaiah (1985). They found a restricted root growth both laterally and vertically at a bulk density of 1.6 g cm^{-3}. Pod yield decreased with increasing bulk density.

In field experiments conducted by Soman, et. al., (1992) seedling growth was observed to be affected by soil crusting. The crust tolerant varieties were found to have longer mesocotyls with faster growth rates which enabled them to escape the crust by emerging before the crust became too hard. Their results indicate that growth was inhibited by physical conditions of the soil where crust had not been disturbed. This indicates that mechanism involved in crust tolerant genotypes is crust avoidance resulting from faster growth of the plumule.

CHAPTER III
MATERIALS AND METHODS

C H A P T E R I I I

MATERIALS AND METHODS

3.1 Experimental Site

The experiments were conducted, under controlled temperature and relative humidity, in the greenhouse at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, during the post-rainy season of 1991-92. Patancheru is located on latitude 18° North and longitude 78° East at an altitude of 545 m above mean sea level. During the period of the series of experiments, the temperature and relative humidity were maintained in the greenhouse at 25 ± 5°C and 60-75% respectively. Another experiment was conducted in the laboratory on a thermogradient table at ICRISAT, to know the effect of temperature on germination.

3.2 Soil

The soil used in the experiments are classified as Alfisols, a fine mixed isohyperthermic family of Udic Rhodustalf (USDA, Soil Taxonomy, 1975) which are commonly known as red sandy loams derived from pink granite. They are medium dark, well drained, sandy loam to sandy clay loam at the surface, occurring on nearly flat to gently undulating uplands. The dominant clay mineral is kaolinite with varying but small proportion of 2:1 clay mineral, and sesquioxides. They usually contain well-defined gravel and weathered rock fragments at lower depths in the profile. They are unstable in structure, thus slaking when wet, compacting when dry and have inherently low water holding capacity.

Composite soil samples were collected at random from the field, air dried, and then seived to pass through a 2 mm mesh. The seived soil was stored in polythene bags and a portion of it was used for determining the physical and chemical characteristics prior to conducting the main pot experiments. The soil stored in the polythene bags was thoroughly mixed before samples were taken for physical and chemical analysis.

3.2.1 Soil Physical Analysis

3.2.1.1 Particle Size Analysis

Mechanical composition of the soil used in the experiments was determined using the Bouyoucos Hydrometer method as given by Bouyoucos (1962). Eighty grams of soil was weighed, to which 100 ml of sodium hexametaphosphate solution was added, stirred and kept overnight. The following day the soil mixture was stirred using a mechanical stirrer, was transferred to a 1 L jar and the volume made upto mark. The jar was shaken by turning end-over-end for 60 seconds and the first hydrometer reading was taken at 90 seconds after the shaking was stopped. Subsequent hydrometer readings were taken at 2, 3, 6, 16, 31, 61 minutes, 2, 4 and 8 hours elapsed time.

The contents were transferred on to a 75 mesh sieve, washed, dried in an oven and weighed. The samples were then sieved through a set of sieves of size 1 mm, 500 microns, 212 microns and 100 microns and the sand, silt and clay percentage were calculated.

3.2.1.2 Moisture Characteristic of the soil

Moisture content of the soil at different pressures, namely 1/3, 1, 5, 10 and 15 bars were determined by using the pressure plate apparatus in a constant temperature room maintained at 20° ± 2°C. Soil samples were pre-wetted for one day on pressure plates that have pore entry pressures greater than the required equilibrating pressure., They were then transferred together with the pressure plate into the pressure plate apparatus and the pressure was raised gradually until the required predetermined pressure was reached. The apparatus was left until equilibrium was attained between water in the soil sample and the air pressure in the chamber. This is usually achieved in about 3 days when the outflow from the pressure membrane apparatus ceases.

3.2.2 Soil Chemical Analysis

3.2.2.1 Soil Reaction (pH)

The pH of the soil was determined using 1:2 soil to water extract and a systronix pH meter (model 335) with glass electrode as described by McLean (1982). Triplicate samples of 5 g of air dry soil were weighed and 10 ml deaerated distilled water was added and shaken with a rotary shaker for 1 hour. The pH electrode was immersed in the supernatant solution and the readings were noted.

3.2.2.2 Electrical Conductivity

The electrical conductivity of the soil was determined on 1:2 soil to water extract using an electrical conductivity meter (Elica Model EM 88) as described in detail by Richards et al (1954). Triplicate samples of 5 g of air dry soil were weighed and 10 ml of deaerated distilled water was added, shaken with a rotary shaker for 1 hour, filtered and the electrical conductivity of the filtrate measured by immersing the electrode of the EC meter in the filtrate and the readings were noted.

3.2.2.3 Organic Carbon

The organic carbon content of the soil was estimated as described by Nelson and Sommers (1982). To 10 g of air dry soil, 10 ml of 1 N $K_2 Cr_2 O_7$ was added and the contents were swirled gently to disperse the soil in the solution. Then 20 ml of concentrated $H_2 SO_4$ were added rapidly. After thorough shaking of the contents, the flask was allowed to stand on asbestos sheet for 30 minutes. Three to four drops of phenanthroline indicator were added and the solution was titrated against 0.5 N Fe SO_4, until the end point of dark green colour was achieved. Organic carbon percentage was determined using the formula,

$$\text{Organic carbon \%} = \frac{(\text{meq } K_2Cr_2O_7 - \text{meq Fe } SO_4)\ (0.003)\ (100)}{\text{Soil weight}} \times f$$

where correction factor $f = 1.3$ (1)

3.2.2.4 Available Nitrogen

Available nitrogen content of the soil was determined by using potassium chloride as given by Keeney and Nelson (1982). To 10 g of soil sample placed in 250 ml wide mouth bottle, 100 ml of 2 M potassium chloride (KCl) was added. The contents were shaken on a mechanical shaker for 1 hour. The soil-KCl suspension was allowed to settle until the supernatant liquid was clear. Aliquots of the supernatant liquid were taken, to which 2-3 drops of boric acid indicator were added, and the available N was determined by titrating against standard sulphuric acid until the end point was reached.

3.2.2.5 Available Phosphorus

Available phosphorus content of the soil was determined using the method given by Olsen and Sommer (1982) with a Klett-Sommerson photoelectric colorimeter. One gram of soil was placed in an extraction bottle and 7 ml. of extracting solution (0.03 N NH_4F + 0.25 N HCl) were added. The contents were shaken for 1 minute and filtered through Whatman number 42 filter paper. To 2 ml. of the filtrate 5 ml. of distilled water and 2 ml. of ammonium paramolybdate solution were added and the contents were mixed thoroughly. Then 1 ml. of Stannous chloride was added and the solution was mixed again. After 5 minutes, the colour was measured photometrically using 660 nm incident light. The concentration of available P was calculated as follows :

$$\text{ppm of P in Soil} = \text{ppm of P in solution} \times 35 \qquad (2)$$

3.2.2.6 **Available Potassium**

Available potassium content of the soil was extracted with 1 N neutral ammonium acetate solution and potassium in the extractant was determined using a flame photometer as described by Knudsen et. al. (1982). Samples of 10 g. of soil were placed in 50 ml. centrifuge tube and 25 ml 1 N of ammonium acetate (NH_4OAc) was added. The tube was then shaken for 10 minutes. The tube was centrifuged until the supernatant liquid was clear. The supernatant liquid was decanted into a 100 ml. volumetric flask. Three additional extractions were made in a similar manner. The combined extracts were diluted to 100 ml. with NH_4OAc, mixed thoroughly and the potassium was determined by flame photometer using 766.5 nm incident light.

3.2.2.7 **Exchangeable Sodium, Calcium and Magnesium**

Exchangeable Na, Ca and Mg of the soils were determined using the method described by Thomas (1982). Samples of 10 g. soil were placed in 250 ml. flask and 25 ml. of 1 N ammonium acetate was added and shaken for 10 minutes. The solution was filtered through Whatman number 1 filter paper and the concentration of Na, Ca and Mg was determined by using the Atomic Absorption Spectrophotometer.

3.3 Crop

Pearl millet variety WCC-75 was selected for the experiments. It has excellent resistance to downy mildew and is not susceptible to ergot and smut diseases. It matures in 85-90 days.

For sorghum variety, CSH-9 was selected. It has a duration of 106-110 days. It normally grows to a height of 1.8 m.

Groundnut variety ICGS-11 was selected for the experiments. It is a spanish selection and has dark green foliage, small to medium-sized two seeded pods with tan coloured seeds about 48% oil and 70% shelling turnover. It is tolerant to bud necrosis disease under field conditions.

3.4 LABORATORY EXPERIMENT

3.4.1 Germination percentage and rate of germination experiments

A laboratory experiment was conducted to determine the viability and the rate of germination at different temperatures of the crop varieties that were selected for the greenhouse experiments. A thermogradient table, consisting of 12 compartments on either side was used for the study. Each compartment of the thermogradient table has 3 sections with different temperatures ranging from 5°C to 55°C. A Campbell CR21X micrologger with an AM32 multiplexer, was used to record the hourly temperature in the sections. Copper-constantin thermocouples (30 SWG) were used to monitor the temperature in the petri dishes. A measurable difference in temperature between the three sections of each compartment (3-5°C) allowed the use of three temperature treatments within the same compartment. The lowest temperature was set at 8°C and the highest at 53°C. There was a total of 48 sections in the thermogradient table.

Seeds which were uniform, bold, free from diseases and free from mechanical damage, were selected and placed in petri-dishes containing two Whatman No. 42 filter papers. These petri-dishes were placed in different sections of the compartments of the thermogradient table.

Two hundred seeds of sorghum and pearl millet and twenty five seeds of groundnut were put on the moist filter paper in the separate petri-dishes and placed in the compartments with the following different temperatures: 10°C, 15°C, 20°C, 25°C, 30°C and 35°C. Each crop had two replications for each temperature.

Germination count was made at hourly intervals and the germinated seeds were discarded. A seed was considered germinated when the radicle and plumule were visible and distinct from the seed. The germination attributes measured were percentage germination and rate of germination i.e., the time from start of imbibition to the time the maximum number of seeds germinated. The volume of distilled water added was slightly more than the moisture holding capacity of the filter papers and was replenished periodically.

From the rate of germination the time taken for 50% germination of seeds at different temperatures for all three crops i.e. millet, sorghum and groundnut was noted. An equation relating the percentage of seed germinated to temperature for the three crops was used to determine their base temperatures.

3.5 GREENHOUSE EXPERIMENTS

3.5.1 Experimental Setup

Altogether seven experiments of two weeks duration each, were conducted. An experimental run consisted of sixteen moisture treatments imposed on soil samples packed into the pots at three bulk densities viz., 1.45, 1.55 and 1.65 g cm^{-3}. Each bulk density with a continuum of sixteen moisture contents ranging typically from dry (0.02 gg^{-1}) to wet (0.19 gg^{-1}), were replicated thrice. The experiment was laid out in simple randomized block design with sixteen treatments. The gravimetric moisture contents varied depending upon the rate of soil evaporation occurring during the period of experimentation in the greenhouse.

3.5.2 Bulk Density Treatments

Pots of uniform 10 cm diameter size were selected and their volumes marked to a predetermined depth. The volume to that depth was measured by pouring water into the pot upto the mark and measuring the volume of water that occupied that space. Based on the measured volume, the mass of air-dry soil needed to obtain a specific bulk density was calculated using the gravimetric moisture content of the air-dry soil (Appendix I). This quantity of air-dry soil was weighed and then packed into the volume already marked in the pots to get the required bulk density.

This procedure was used to get the three bulk densities used in all the experiments. A droplet hammer was used to pack the soil to the required volume in order to obtain the required bulk density.

3.5.3 Moisture Treatments

In a preliminary experiment, the range of moisture content that can be obtained in the red sandy loam soil was determined by following the drying rate of the saturated soil over a period of time. For this purpose, a set of 144 pots of 10 cm diameter size were used. The predetermined volumes were marked in each pot. Then the mass of dry soil required to obtain bulk densities 1.45, 1.55 and 1.65 g cm^{-3} was weighed on a mettler balance. The soil was then packed into the pots and levelled to the mark. Sixteen moisture content ranges for each of the three bulk densities replicated three times, necessitated using a total of 48 pots for each of the bulk densities.

The soil in each pot was completely saturated by adding 250 ml of water. The pots were allowed to drain for 24 hours and then weighed to obtain the *gravimetric moisture content at field capacity by first calculating the equivalent mass of oven dry soil in each pot using the water content of the air-dry soil as shown in Appendix II.*

On the third day after wetting, all the pots were weighed again and the amount of water lost as a result of evaporation in a day was estimated by subtracting the previous day's weights (second day after wetting) from the third day's weights. With the exception of the first row of pots, all the other pots were rewetted to the initial field capacity water content by adding the calculated amount of water lost through evaporation. On the fourth day the first two rows were left and the remainder of the pots from the third row onwards were rewetted. This process was followed until a range of moisture contents, from air-dry to field capacity, was obtained. All the pots were weighed daily to obtain their water contents and also to enable the estimation of the amount of water needed to rewet the soils in pots to field capacity. By following this procedure a range of gravimetric moisture contents from 2% to 19% was obtained.

The above procedures were adopted in all the experiments that were conducted in order to get the desired bulk densities and desired range of moisture treatments.

3.5.4 Moisture Potential

After each experimental run in the greenhouse the moisture potential of each pot, was determined using the filter paper equilibration method as described by Greacen et al., (1987). Soil cores were taken from the pots. Four Whatman number 42 filter papers were placed in the center of each soil core. The cores were then sealed with sellotape and kept for one week to allow the soil moisture to equilibrate with the filter paper. After one week, the soil and the filter paper from the cores were removed and placed separately in cans. The 2 central filter papers devoid of soil particles were quickly weighed in aluminium cans on an electronic balance. The cans were then placed in an oven at 105°C for 24 hours, after which period their dry weights were measured. Using the moisture content of the filter paper, the matric potential was calculated from the following equation (Greacen et al., 1987) :

$$S = -3.095\,F + 5.553 \qquad (3)$$

where S = matric suction (kPa)

F = gravimetric moisture content of the filter paper

3.5.5 Main experiment 1

3.5.5.1 Effect of bulk density and moisture status on germination

Experiments for determining the effect of bulk density and moisture content and their interactions on the germination of pearl millet were conducted in pots of 10 cm diameter size. Three bulk density treatments and a range of moisture treatments from dry to wet as described in section 3.6.4 were used. Sowing was done when the desired range of moisture content was obtained.

Fifty bold and healthy seeds of pearl millet were sown in each pot. A total number of 144 pots was obtained since there were three bulk densities, 16 moisture treatments and three replications for each bulk density. Sowing was done by removing the top 2.5 cm of soil from the pots, placing the seeds in the pots at equidistance and then covering with the same soil. Thus sowing was done at a depth of 2.5 cm and the soil was then repacked to its original volume using a droplet hammer in order to get the desired bulk density. On the third day after sowing, the entire soil from each pot was removed to separate out the germinated seeds from the ungerminated ones in order to calculate the germination percentage.

Similar experiments were also conducted to determine the effect of moisture content and bulk density on the germination of sorghum and groundnut. Two depths of sowing used for sorghum were 2.5 and 5 cm. Fifty healthy sorghum seeds were selected and sown in the pots as described for pearl millet. Germination count was made on the third day after sowing. With groundnut, the depth of sowing was 5 cm and only 5 seeds were sown in the pots due to the size of the seeds.

3.5.6 Main experiment 2

3.5.6.1 Effect of bulk density and moisture status on seedling emergence

In another series of experiments to determine the effect of moisture content and bulk density on seedling emergence of all the three crops, experiments similar to the germination trials, were conducted for two weeks duration. In these experiments, the specified bulk densities were obtained by the procedure described earlier and the different levels of moisture content were obtained by monitoring the changes in weight of the pots.

Depth of sowing was 2.5 cm for pearl millet and 5 cm for sorghum and groundnut. Twenty five bold and healthy seeds each of millet and sorghum and five seeds of groundnut were selected and sown at equidistance in the pots. Sowing was done in 144 pots having 3 bulk densities, and 16 moisture treatments with three replications.

Daily counts of seedlings that emerged was recorded to get the progressive emergence for the three crop i.e. millet, sorghum and groundnut. The emergence count was recorded to obtain cumulative number of seedlings that emerged with time.

All the three experiments were terminated on the 16th day after wetting irrespective of emergence percentage.

3.6. Statistical Analysis

The experimental data were analyzed statistically by the technique of analysis of variance given by Gomez and Gomez (1984). Statistical significance was tested by F value at 0.05 level of probability. Critical differences were calculated for testing the significance. The results were further depicted by graphical representation.

CHAPTER IV
RESULTS

C H A P T E R IV

RESULTS

The results of the physical and chemical analysis of the soil samples used in the greenhouse experiments are given in Table 1. The results indicate that the soil is near neutral in reaction. Organic carbon, nitrogen and phosphorous are in the available ranges. The results of mechanical composition indicate that the soil is sandy loam in nature. The moisture characteristic of the soil is presented in Figure 1. From Figure 1 it is observed that the moisture content increases as the matric suction decreases and that there is an inflexion at a matric suction of about 100 bars indicating that most of the dominant pores in the soil drain at this suction.

4.1 LABORATORY EXPERIMENT

A laboratory experiment was first conducted to determine the influence of different temperatures on the rate of germination and the base temperatures for germination of the three crops. Figures 2, 3 and 4 present a sigmoid shaped functional relationship between germination percentage and time for the three crops at five different temperatures. It is observed from Figures 2, 3 and 4 that initiation of germination was slower at 15°C than at 35°C for all the three crops. In the case of pearl millet and sorghum,

Table 1 : Major Characteristics of the Alfisol used for the experiment at ICRISAT Center

Property	Value
a) **Physical**	
1) Mechanical Analysis	
i) Sand (%)	54.7
ii) Silt (%)	27.3
iii) Clay (%)	18.0
b) **Chemical**	
1) PH (1:2.5 water suspension)	6.2
2) Electrical conductivity (dsm^{-1}) (1:2.5 water suspension)	1.8
3) Organic Carbon (%)	0.35
4) Available N (ppm)	2.7
5) Available P (ppm)	3.5
6) Available K (ppm)	133.3
7) Exchangeable Ca (ppm)	711.4
8) Exchangeable Mg (ppm)	216.3
9) Exchangeable Na (ppm)	51.5
10) CEC (meq./100 gm)	7.6

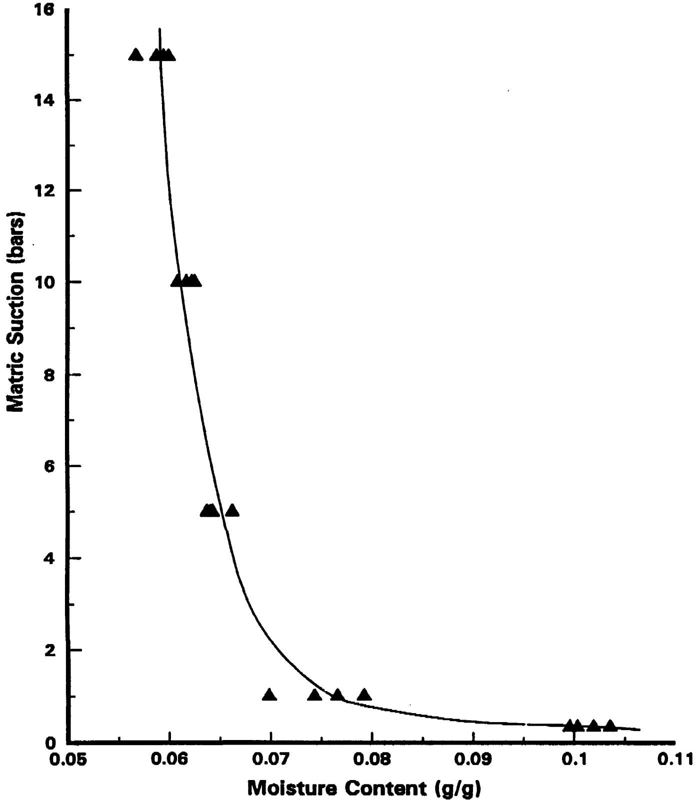

Fig. 1 Moisture characteristic of the soil

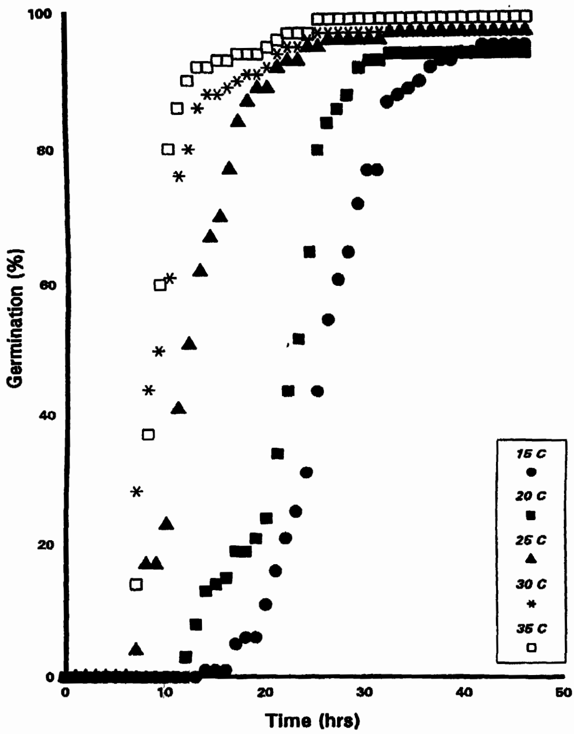

Fig.2 Germination percentage as a function of time for pearl millet at different temperatures

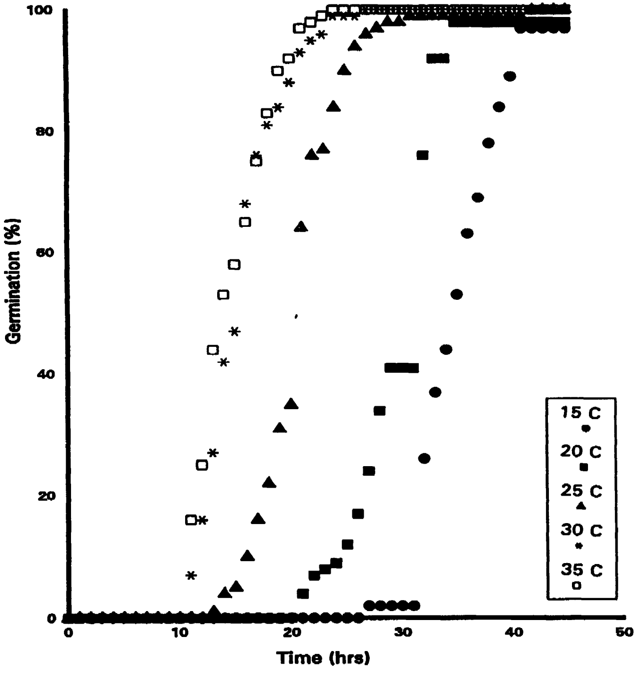

Fig.3 Germination percentage as a function of time for sorghum at different temperatures

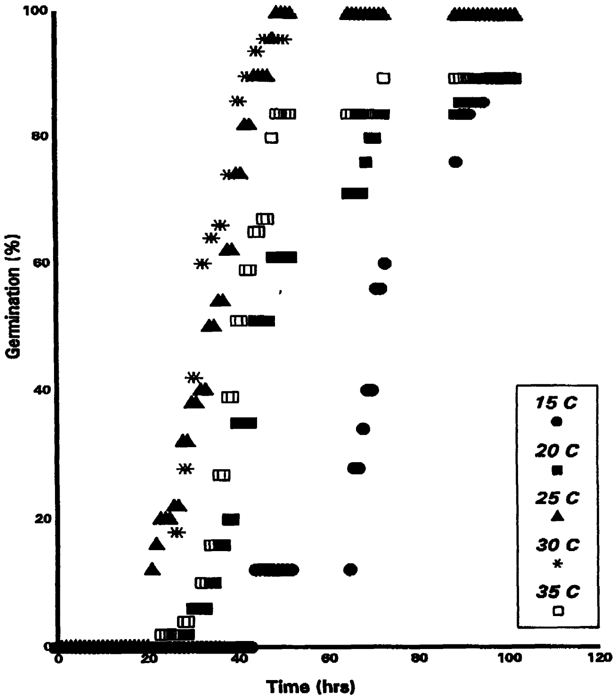

Fig.4 Germination percentage as a function of time for groundnut at different temperatures

germination at 35°C first occurred after seven and eleven hours respectively. Groundnut at the same temperature took a longer time (25 hours) to start germinating. The rate of germination was faster at 35°C and 30°C than at 20, 25 and 15°C for pearl millet and sorghum. In the case of groundnut, germination first started at 25°C, followed by 35°C and then 30°C. The rate of germination in groundnut was fastest at 30 and 25°C followed by 35, 20 and 15°C. Figures 2, 3 and 4 were used to determine the time required for 50% of the seeds to germinate at different temperatures. Inverse values of time for 50% of the seeds to germinate were plotted as a function of temperature, for the three crops as shown in Figures 5, 6 and 7. Table 2 presents data on regression of 1/t on temperature which were used to calculate the base temperatures for pearl millet, sorghum and groundnut. Calculation of base temperatures for the three crops are given in Appendix III. The germination curves (Figures 2 and 3) for temperatures 30°C and 35°C for pearl millet and sorghum are similar. Those for 30 and 25°C for groundnut (Figure 4) are also similar indicating that the rates of germination are almost equal at those temperatures. At 15°C, initiation of germination in groundnut was very slow i.e., it took more than 40 hours for groundnut to start germinating it then proceeded at a slower rate than the other temperatures. Pearl millet however took about 15 hours to start germinationg at 15°C while sorghum at the same temperature took about 27 hours. In calculating the base temperature for groundnut the 1/t value at 35°C which is an outlier due to experimental error was discarded (Figure 7).

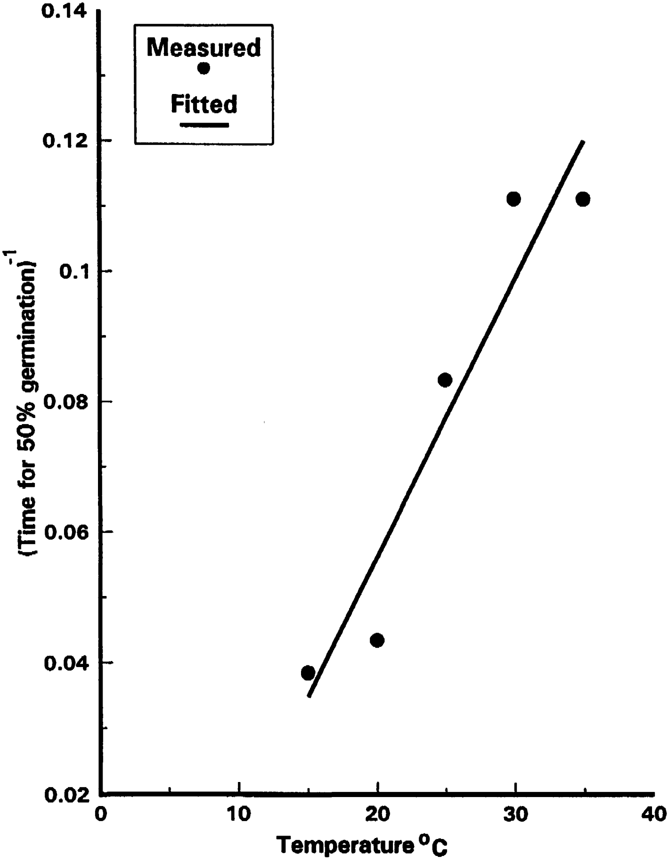

Fig.5 Inverse of time for 50% germination versus temperature for pearl millet

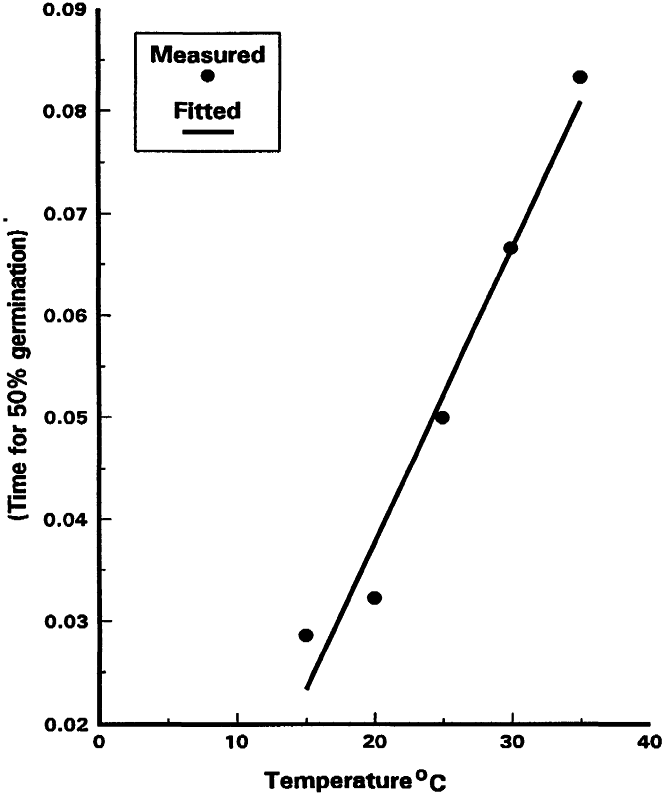

Fig.6 Inverse of time for 50% germination versus temperature for sorghum

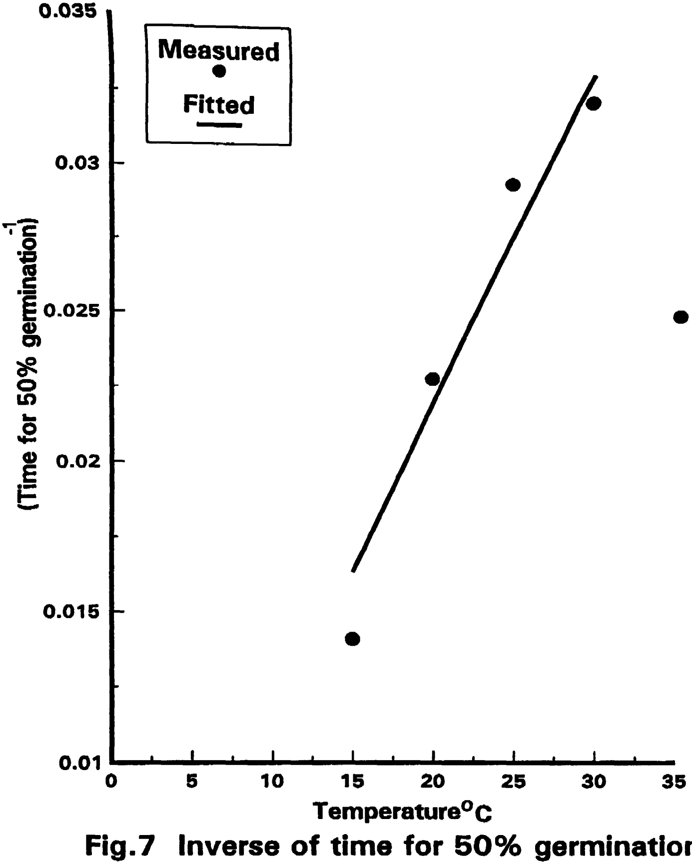

Fig.7 Inverse of time for 50% germination versus temperature for groundnut

Table 2 : Regression of the inverse of time for 50% germination (1/t) on temperatures (T).

Crop			Equation				R^2
Millet	$1/t_{50}$	=	- 0.02896	+	0.004258	T	0.91
Sorghum	$1/t_{50}$	=	- 0.01980	+	0.002878	T	0.97
Groundnut	$1/t_{50}$	=	- 0.00292	+	0.001224	T	0.96

4.2 GREENHOUSE EXPERIMENT

Experiments for the evaluation of the effect of soil moisture (both moisture content and matric potential) and bulk density on the germination and emergence of pearl millet, sorghum and groundnut was conducted in the greenhouse. It involved the estimation of the minimum moisture content and potential required for initiation of germination and emergence, moisture content and potential at which maximum germination occurred at different bulk densities and also to assess the influence of bulk density on the germination and emergence of the three crops.

Examples of the results of the preliminary experiment conducted to determine the range,of soil moisture contents that can be obtained by natural drying of the soil are depicted in Figures 8, 9 and 10. Figure 8 depicts an exponentially declining moisture content in the dry range for moisture treatment one. In moisture treatment four the moisture content was constant at 0.2 gg^{-1} for the first two days and then it decreased exponentially. Figure 9 depicts seventh and tenth moisture treatments in the medium moisture range. In this Figure it is observed that constant moisture content prevailed for about 6 days before a gradual decrease followed by a rapid decline in moisture content. From Figures 8 and 9 it is observed that there was a decrease in the moisture content as time elapsed until it reached 0.02 gg^{-1} on the 16th day of the experiment in moisture treatment one and 0.04 gg^{-1}

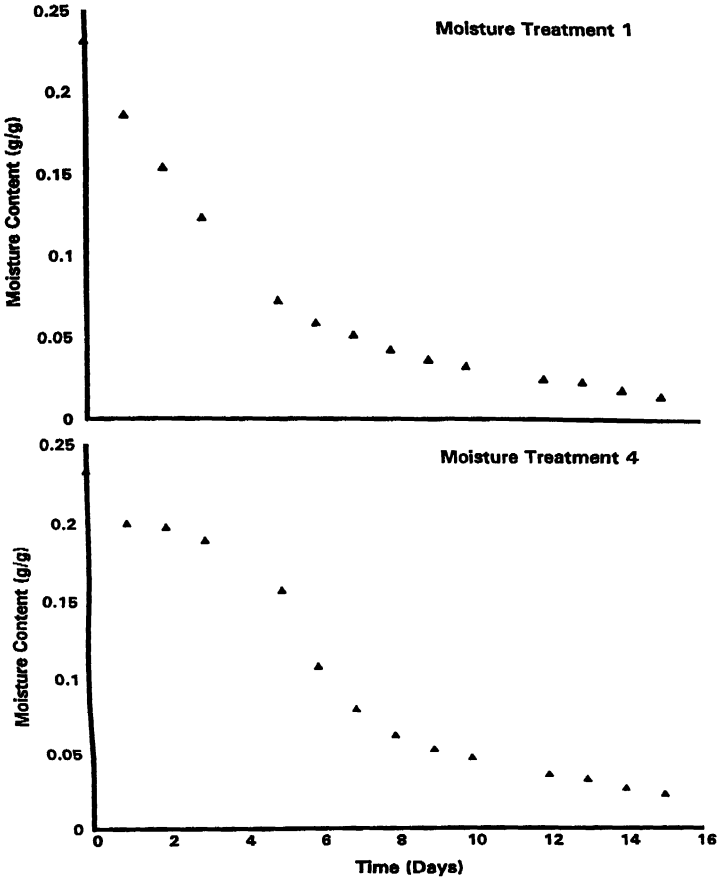

Fig.8 Moisture depletion pattern for moisture treatment 1 and 4

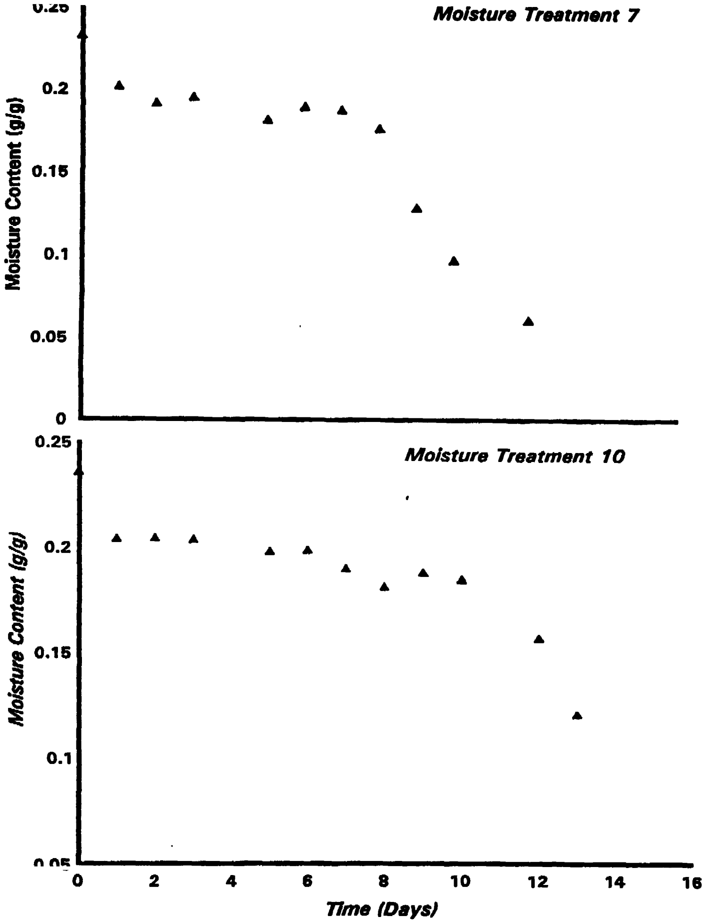

Fig.9 Moisture depletion pattern for moisture treatment 7 and 10

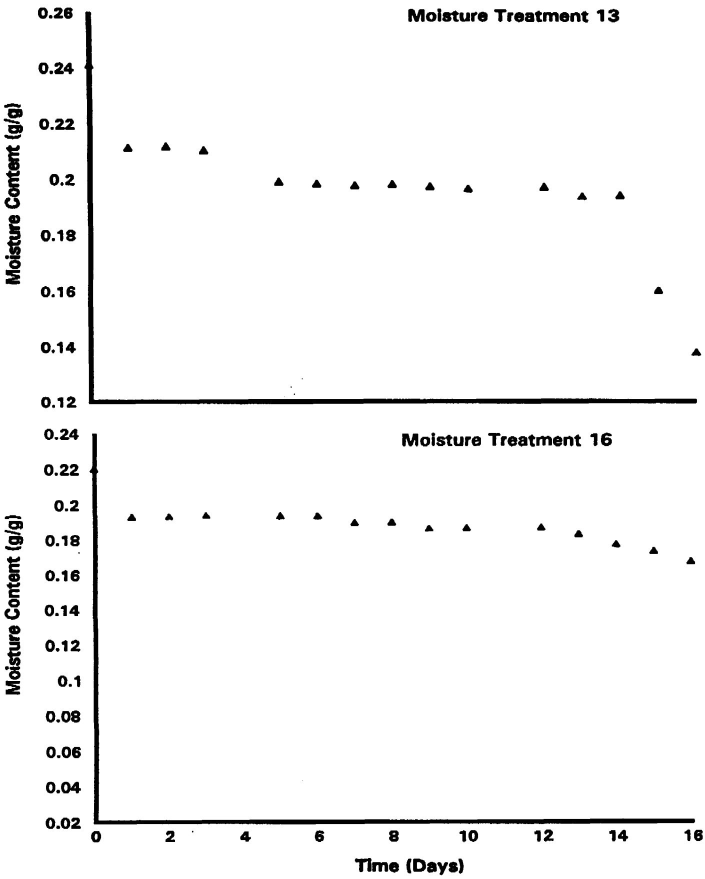

Fig. 10 Moisture depletion pattern for moisture treatment 13 and 16

in moisture treatment four. The moisture content decreased to 0.06 gg^{-1} in the seventh moisture treatment and 0.11 gg^{-1} in the tenth moisture treatment on the 16th day. Figure 10 presents the moisture content in the wet range. It is observed from Figure 10 that the moisture content remained nearly constant until about the twelfth day and then decreased slightly in the thirteenth moisture treatment. But in the sixteenth treatment the moisture content remained nearly constant throughout the period of the experiment. A statistical analysis was done for the sixteen moisture treatments, and the moisture content of each treatment was found to be significantly different from each other.

4.2.1 Influence of moisture status and bulk density on germination of Pearl Millet

The effect of increase in moisture content on germination percentage (Figure 11 and Table 1 in Appendix IV) at the 3 bulk densities indicate that at bulk densities 1.45, 1.55 and 1.65 g cm^{-3}, pearl millet required a moisture content of 0.0445, 0.0466 and 0.0577 gg^{-1} respectively to start germinating. A hundred percent germination was observed at moisture contents of 0.1444 and 0.1673 gg^{-1} for the seeds sown in soil at bulk densities 1.45 and 1.55 g cm^{-3} respectively. At bulk density of 1.65 g cm^{-3}, the maximum germination of 95% was observed at 0.1576 gg^{-1} moisture content. Germination initiated at a lower moisture content for pots maintained at a bulk density of 1.45 g cm^{-3} than those at 1.55 and 1.65 g cm^{-3}. There was a significant increase in germination as

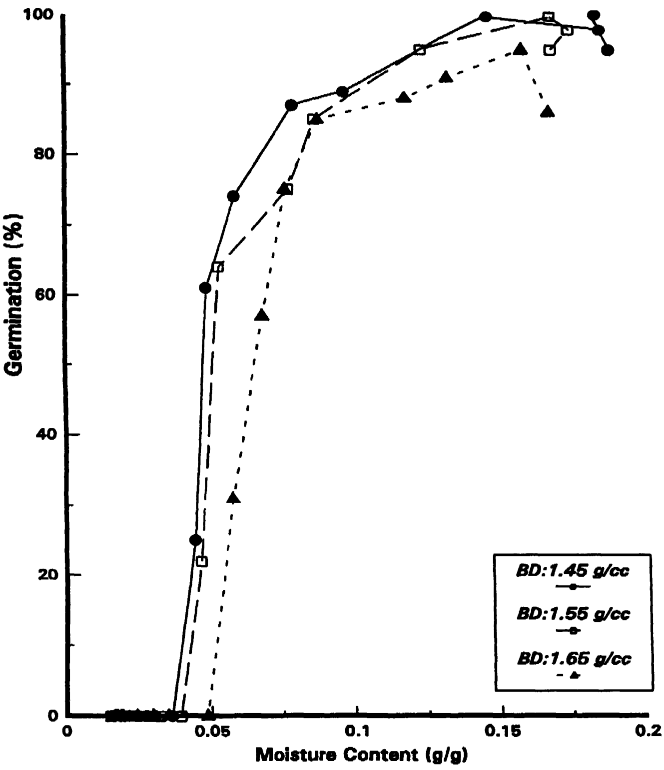

Fig.11 Germination of pearl millet as influenced by moisture content at different bulk density

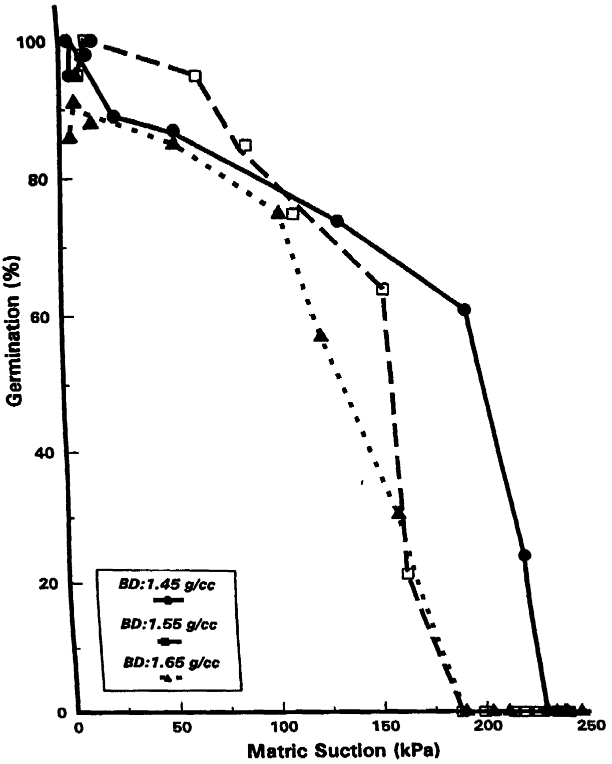

Fig.12 Germination of pearl millet as influenced by matric suction at different bulk density

gravimetric water content increased. At high moisture contents, there was a significant decrease in percent germination. There was significant decrease in germination percentage with increase in bulk density from 1.45 to 1.65 g cm^{-3}. From Figure 11, it is observed that the rate of germination of pearl millet was almost identical in pots maintained at the three different bulk densities. The relationship between matric suction and germination is given in Figure 12 and Table 2 in Appendix IV. As expected, there was no germination in all three bulk densities at higher matric suctions. The soil at the low bulk density (i.e. 1.45 g cm^{-3}) started germinating at a higher suction (222.8 kPa) than those at a bulk density of 1.55 g cm^{-3} in which germination also started at a higher suction (i.e., 164.5 kPa) than the bulk density of 1.65 g cm^{-3}. Germination started at a matric suction of 160.7 kPa for the soil packed at 1.65 g cm^{-3}. Germination increased with decrease in suction. Germination decreased significantly at moisture suctions below 4.6, 10.9 and 8.3 kPa in the bulk densities of 1.45, 1.55 and 1.65 g cm^{-3} respectively.

4.2.2 Influence of moisture status and bulk density on germination of sorghum sown at 2.5 cm and 5 cm depths.

In two separate experiments, sorghum seeds were placed one at a depth of 2.5 cm and the other at 5 cm. The data for the germination of sorghum placed at 2.5 cm depth are presented in Figures 13 and 14, Tables 3 and 4 in Appendix IV. From Table 3 in Appendix IV, it is observed that at a bulk density of 1.65 g cm^{-3}

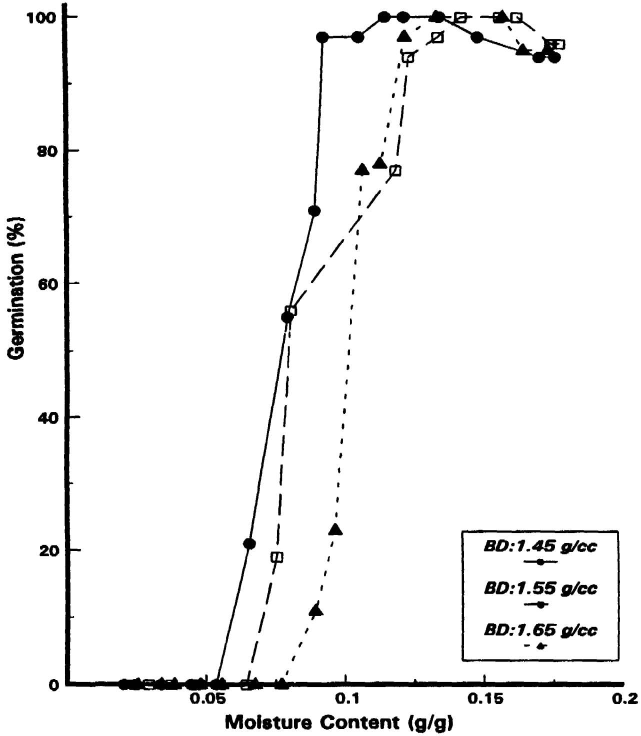

Fig.13 Germination of sorghum sown at 2.5 cm as influencd by moisture content at different bulk density

sorghum required more water (i.e. 0.0893 gg^{-1}) for germination to initiate than at the bulk densities of 1.45 and 1.55 g cm^{-3} where the gravimetric moisture content for germination to start was found to be 0.0655 and 0.0753 gg^{-1} respectively. Maximum germination of 100% was observed at a moisture content of 0.1152, 0.1427 and 0.1578 gg^{-1} for bulk densities 1.45, 1.55 and 1.65 g cm^{-3} respectively. It is observed from Figure 13 that as moisture content is increased, germination also increased. However, an increase in moisture content beyond 0.1349 gg^{-1} in the case of bulk density of 1.45 g cm^{-3}, 0.1628 gg^{-1} in the case of bulk density of 1.55 g cm^{-3} and 0.1579 gg^{-1} in the case of bulk density of 1.65 g cm^{-3} resulted in a significant decrease in germination. Low gravimetric moisture content was required for initiation of germination at bulk density of 1.45 g cm^{-3} compared with 0.0753 and 0.0893 gg^{-1} required for the initiation of germination in the bulk density of 1.55 and 1.65 g cm^{-3} respectively. The rate of germination was very slightly faster at 1.45 g cm^{-3} bulk density than at bulk densities of 1.55 and 1.65 g cm^{-3} as can be observed from the slopes in Figure 13. Generally germination in the soils packed at bulk density of 1.45 g cm^{-3} occurred at lower moisture content than for those at 1.65 g cm^{-3}. The influence of matric suction on germination is presented in Figure 14 and Table 4 in Appendix IV. Germination started at a higher matric suction of 160.3 kPa at 1.45 g cm^{-3} bulk density compared to suctions of 154.5 and 135.6 kPa for 1.55 and 1.65 g cm^{-3} bulk densities respectively. Below a matric suction of 5 kPa there was significant decrease in germination at all the three bulk densities. Maximum germination of 100% was observed at matric

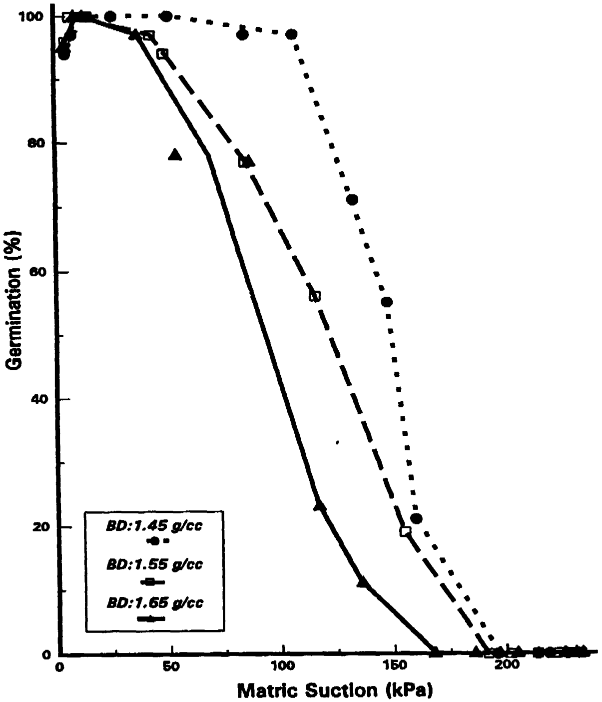

Fig.14 Germination of sorghum sown at 2.5 cm as influenced by matric suction at different bulk density

suctions of 50, 14 and 13 kPa at the three bulk densities 1.45, 1.55 and 1.65 g cm^{-3}.

The results for the germination of sorghum sown at 5 cm depth are presented in Figures 15 and 16, Tables 5 and 6 in Appendix IV. At a sowing depth of 5 cm sorghum required a moisture content of 0.0457, 0.0541 and 0.0562 gg^{-1} for germination to initiate at bulk densities of 1.45, 1.55 and 1.65 g cm^{-3} respectively. It is observed from Figures 13 and 15 (and also from Tables 3 and 5 in Appendix IV) that sorghum sown at 5 cm required lower moisture content for germination to initiate at all the three bulk densities than at 2.5 cm depth. Maximum germination, (100%) was observed at a moisture content of 0.1735 and 0.1651 gg^{-1} for the bulk densities 1.45 and 1.55 g cm^{-3}, while a maximum germination of 97.7% was obtained at a moisture content of 0.1456 gg^{-1} in the bulk density of 1.65 g cm^{-3}. Germination percentage increased significantly with increase in moisture content, remained constant and then a significant decrease was observed at high moisture contents. For example, there was a decrease in germination percentage from 100 to 96% when moisture content increased from 0.1754 to 0.1834 gg^{-1} at a bulk density of 1.45 g cm^{-3}, from 100 to 95% when moisture content increased from 0.1713 to 0.1799 gg^{-1} in the pots with a bulk density of 1.55 g cm^{-3} and from 97.7 to 95% when moisture content increased from 0.1456 to 0.1575 gg^{-1} in pots having the bulk density of 1.65 g cm^{-3}. This trend was observed in all the three bulk densities. The rate of germination followed the same trend as in sorghum sown at 2.5 cm depth (Figure 13). Unlike sorghum sown at

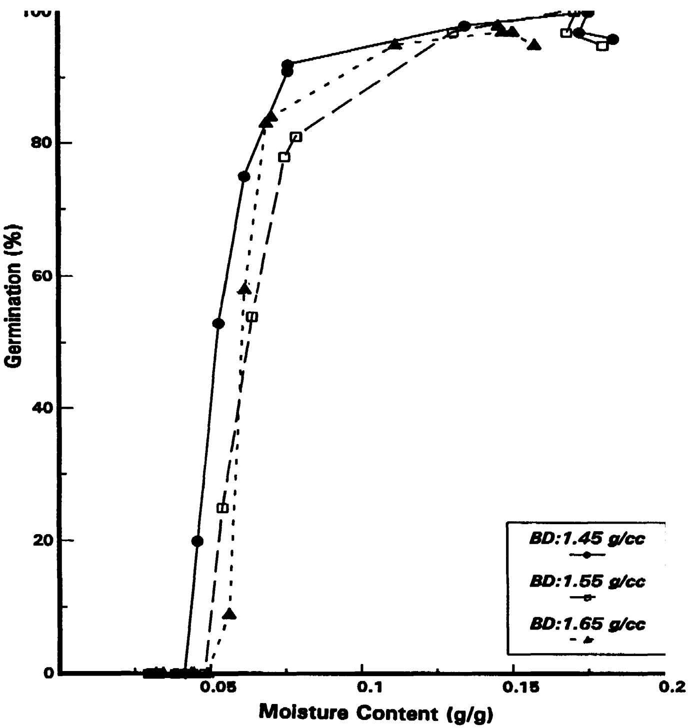

Fig.15 Germination of sorghum sown at 5cm as influenced by moisture content at different bulk density

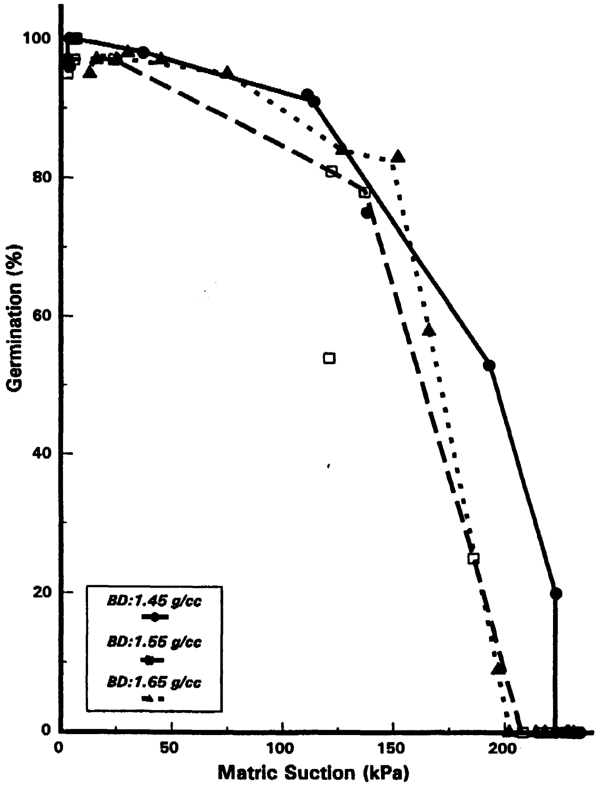

Fig.16 Germination of sorghum sown at 5 cm as influenced by matric suction at different bulk density

2.5 cm depth, maximum germination occurred at a higher moisture content for the soils at a bulk density of 1.45 g cm^{-3} than those at 1.55 and 1.65 g cm^{-3}. The effect of matric suction on germination of sorghum sown at 5 cm depth is presented in Figure 16 and Table 6 in Appendix IV. As it is observed in Figure 16, a decrease in matric suction results in an increase in the germination of sorghum. Germination initiated at matric suction of 222.8, 185.6 and 196.8 kPa for soils packed at bulk densities of 1.45, 1.55 and 1.65 g cm^{-3} respectively. Maximum germination of 100% occurred at matric suctions of 6.8 and 7.1 kPa at 1.45 and 1.55 g cm^{-3} bulk density. At a matric suction of 29.8 kPa maximum germination of 97.7% was observed in the soil at a bulk density of 1.65 g cm^{-3}.

4.2.3 Influence of moisture status and bulk density on germination of groundnut

The results of the influence of moisture and bulk density on the germination of groudnut are shown in Figures 17 and 18 and Tables 7 and 8 in Appendix IV. It is noted that lower limit moisture content of 0.0520, 0.0584 and 0.0740 gg^{-1} was necessary for groundnut to germinate in soils packed at bulk densities of 1.45, 1.55 and 1.65 g cm^{-3} respectively. These lower limit moisture contents for germination of groundnut corresponded to matric suctions of 217.4, 217.9 and 201.6 kPa for the bulk densities 1.45, 1.55 and 1.65 g cm^{-3} respectively. Germination percentage increased with increase in moisture content but at high gravimetric moisture contents, the germination percentage decreased. A similar trend

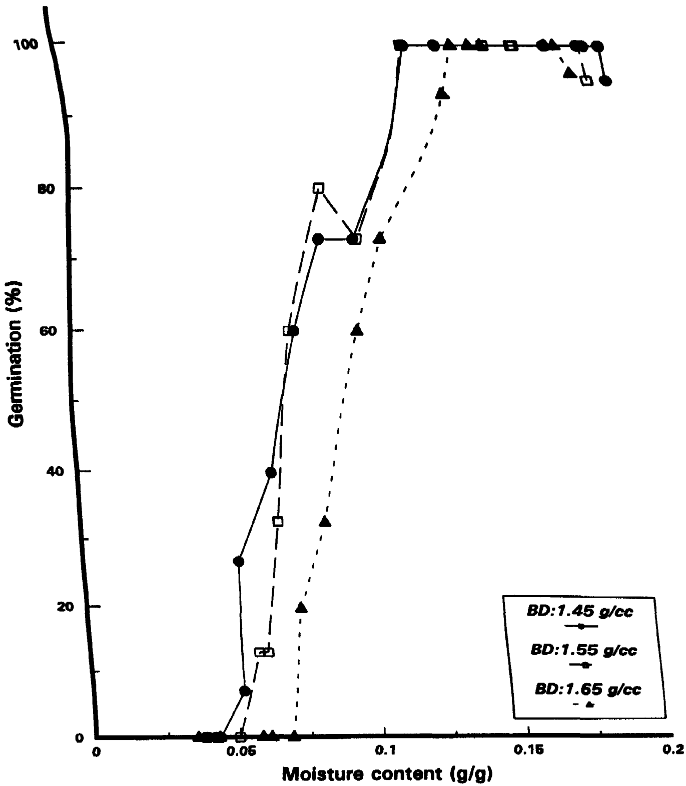

Fig.17 Germination of groundnut as influenced by moisture content at different bulk density

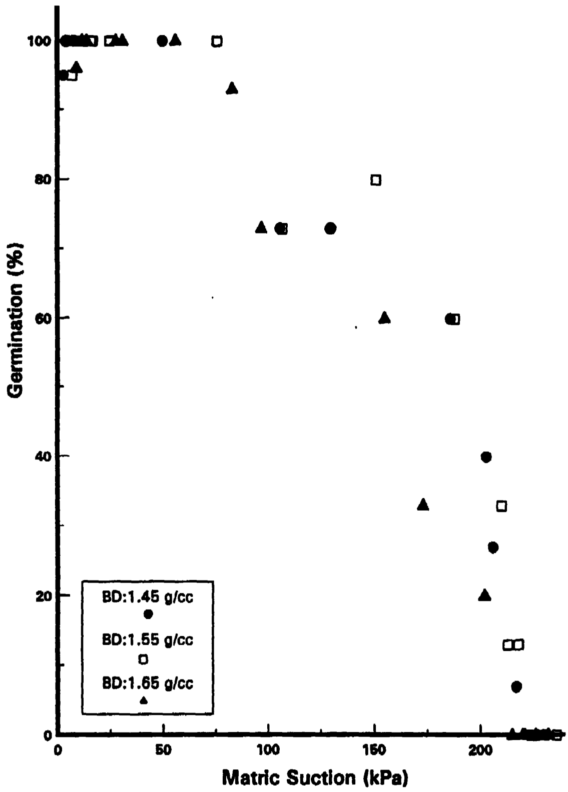

Fig.18 Germination of groundnut as influenced by matric suction at different bulk density

was observed for all the three bulk densities. Maximum germination of 100% occured at moisture contents of 0.1186, 0.1450 and 0.1342 gg^{-1} for 1.45, 1.55 and 1.65 g cm^{-3} bulk densities respectively. The rate of germination appeared to be similar for all three bulk densities. Figure 17 indicates that a lower moisture content is required for germination to initiate at a bulk density of 1.45 g cm^{-3} than at either 1.55 or 1.65 g cm^{-3}. There was no influence of bulk density on germination at bulk densities 1.45 and 1.55 g cm^{-3}. However, a slight decrease in germination was observed at a bulk density of 1.65 g cm^{-3}. Figure 18 shows the influence of matric suction on germination of groundnut. With increase in suction, germination decreased. Maximum germination of 100% was observed at suctions of 50.4, 76.4 and 55.9 kPa for the three bulk densities of 1.45, 1.55 and 1.65 g cm^{-3}. However, a decrease in suction below 4.1 kPa in the case of 1.45 g cm^{-3}, 8.4 kPa in the case of 1.55 g cm^{-3} and 11.9 kPa in the case of 1.65 g cm^{-3} bulk density resulted in significant decrease in the germination percentage.

4.2.4 Influence of moisture status and bulk density on emergence of pearl millet

The data for emergence of pearl millet are presented in Figures 19 and 20, Tables 9 and 10 in Appendix IV. Emergence was observed on the fourth day after sowing in all the three bulk densities. About 3% of the germinated seeds started emerging from the soil at a bulk density of 1.45 g cm^{-3} when the moisture content was 0.0707 gg^{-1}. In the case of soils at bulk densities 1.55 and

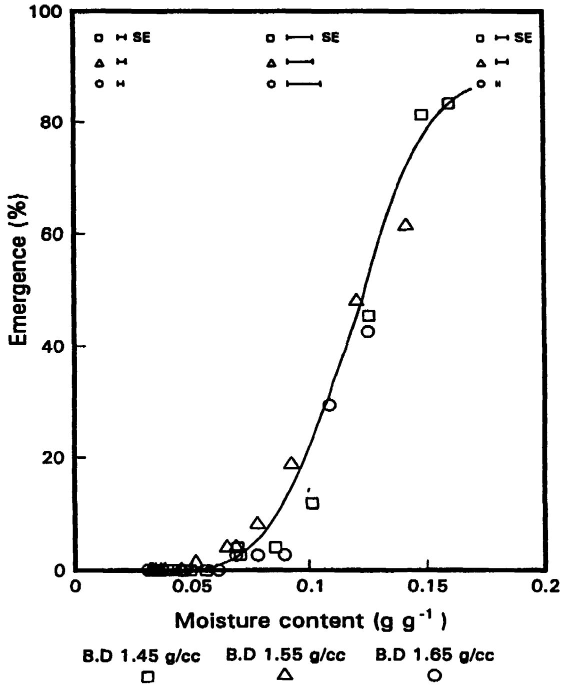

Fig. 19 Influence of moisture content on pearl millet emergence at different bulk density

1.65 g cm^{-3}, 4 and 3% emergence were observed at moisture contents of 0.0651 and 0.0690 gg^{-1} respectively. Figure 19 indicates that the percent emergence increased significantly with increase in moisture content. Maximum emergence was 93.3% at a moisture content of 0.1687 gg^{-1} on the soil at bulk density of 1.45 g cm^{-3}. At bulk density of 1.55 g cm^{-3} maximum emergence of 84% was observed when the moisture content was 0.1630 gg^{-1}, while a maximum emergence of 63% was observed for the bulk density of 1.65 g cm^{-3} at a moisture content of 0.1483 gg^{-1}. At high moisture contents, a significant decrease in emergence was observed. Emergence percent decreased from 93.3% to 61.4% as moisture content increased from 0.1687 to 0.1754 gg^{-1} for soils at bulk density of 1.45 g cm^{-3} and from 84% to 65.4% as moisture increased from 0.1630 to 0.1661 gg^{-1} for soils at bulk density of 1.55 g cm^{-3}. It is observed from Figure 19 that bulk density did not have any influence on changes in emergence of pearl millet with changes of moisture content. The change of percent emergence with changes in water content was similar for all the three bulk densities as can be observed from the slopes in Figure 19. The low emergence at bulk density of 1.65 g cm^{-3} (63%) might be due to bulk density effect.

Matric suction influenced emergence of pearl millet (Figure 20 and Table 10 in Appendix IV). With decrease in suction, emergence increased. Emergence initiated at 195.3, 215.9 and 194.7 kPa suction for the three bulk densities 1.45, 1.55 and 1.65 g cm^{-3} respectively. Maximum emergence of 93.3% was observed at a suction of 16 kPa for 1.45 g cm^{-3}, 84% at a suction of 17.7 kPa for 1.55 g

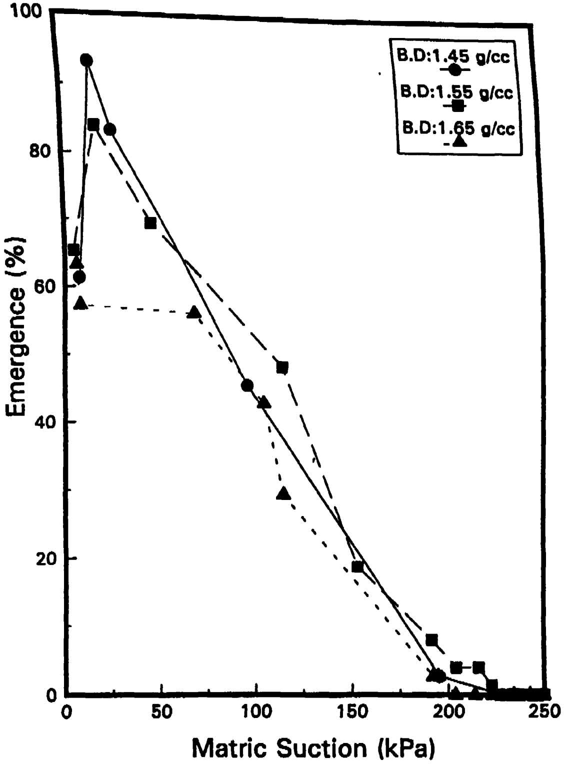

Fig.20 Influence of matric suction on pearl millet emergence at different bulk density

cm^{-3} and 63.3% at a suction of 6.1 kPa for 1.65 g cm^{-3} bulk density. At bulk densities of 1.45 and 1.55 g cm^{-3} emergence decreased significantly when the matric suction was less than 16 kPa.

4.2.5 Influence of moisture status and bulk density on emergence of sorghum

Emergence of sorghum was observed on the fifth day after sowing. Results of the influence of moisture and bulk density and the emergence of sorghum are presented in Figures 21 and 22, Tables 11 and 12 in Appendix IV. Emergence of sorghum (8%) started at a gravimetric moisture content of 0.0484 gg^{-1} for the soil at a bulk density of 1.45 g cm^{-3}. However, emergence was only 4% at moisture contents of 0.0514 and 0.0479 gg^{-1} for the higher bulk densities of 1.55 and 1.65 g cm^{-3}. Figure 21 indicates that changes in emergence ddue to changes in water content were influenced by bulk density. As observed from the slopes in Figure 21, at bulk density of 1.65 g cm^{-3} emergence changed less with changes in water content compared to that at 1.45 g cm^{-3}. Emergence increased with increase in moisture content. At bulk density of 1.45 g cm^{-3} maximum emergence of 84% was obtained at a moisture content of 0.1004 gg^{-1}. Maximum emergence of 78.7% was obtained at a moisture content of 0.1407 gg^{-1} for the soil at bulk density of 1.55 g cm^{-3}. However at bulk density of 1.65 g cm^{-3} the maximum emergence obtained was 22.7% within a moisture range of 0.0468 and 0.0836 gg^{-1}. There was a further decrease in emergence as moisture content increased upto 0.1189 gg^{-1}. Beyond this moisture content emergence increased again

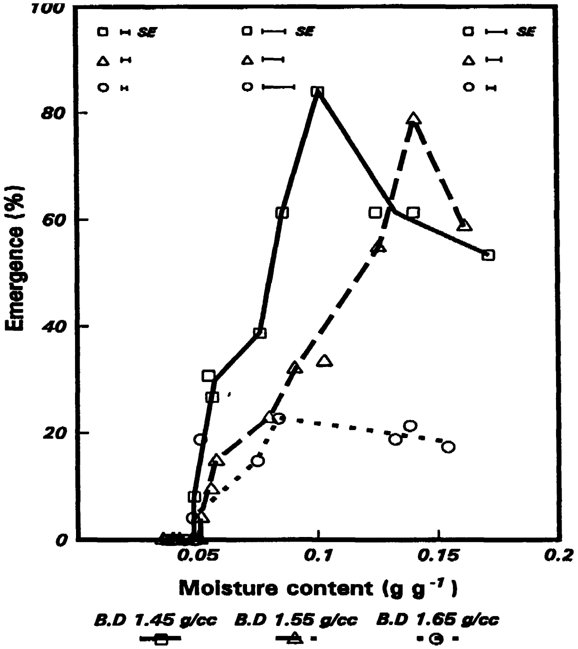

Fig.21 Influence of moisture content on sorghum emergence at different bulk density

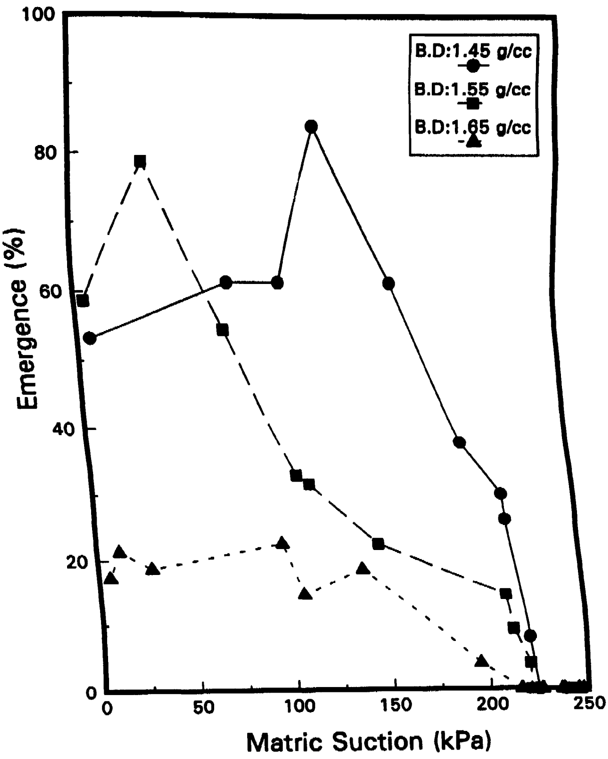

Fig.22 Influence of matric suction on sorghum emergence at different bulk density

from 12% to 18.7% for the soil at bulk density of 1.65 g cm^{-3}. At bulk densities 1.45 and 1.55 g cm^{-3} the emergence decreased to 53.3 and 58.7% respectively at moisture contents above 16%. Effect of matric suction on sorghum emergence is shown in Figure 22. Emergence started at a suction of 221 kPa at bulk densities 1.45 and 1.55 g cm^{-3} with 8 and 4% emergence. At bulk density of 1.65 g cm^{-3} 4% emergence was observed at a suction of 195.3 kPa. Emergence increased with decrease in suction. From Figure 22 it is observed that the changes in emergence as a result of changes in matric suction was fast at 1.45 g cm^{-3} and slower at 1.65 g cm^{-3} bulk density. Maximum emergence was only 22.7% at 96.8 kPa suction for the bulk density of 1.65 g cm^{-3}. Whereas maximum emergence of 84% and 78.7% was observed at suctions of 126.3 and 36.8 kPa for the bulk densities 1.45 and 1.55 g cm^{-3} respectively.

4.2.6 Influence of moisture status and bulk density on emergence of groundnut

Emergence was observed on the eighth day after sowing for groundnut. The results presented in Figures 23 and 24, Tables 13 and 14 in Appendix IV show that emergence (20%) started at a moisture content of 0.0439 and 0.0510 gg^{-1} for bulk densities 1.45 and 1.55 g cm^{-3} respectively. At bulk density of 1.65 g cm^{-3} emergence of 13.3% was first observed at a moisture content of 0.0455 gg^{-1}. No emergence was observed below 4% moisture content. Emergence increased with increase in moisture content (Figure 23). The trend followed by emergence as moisture content increased was

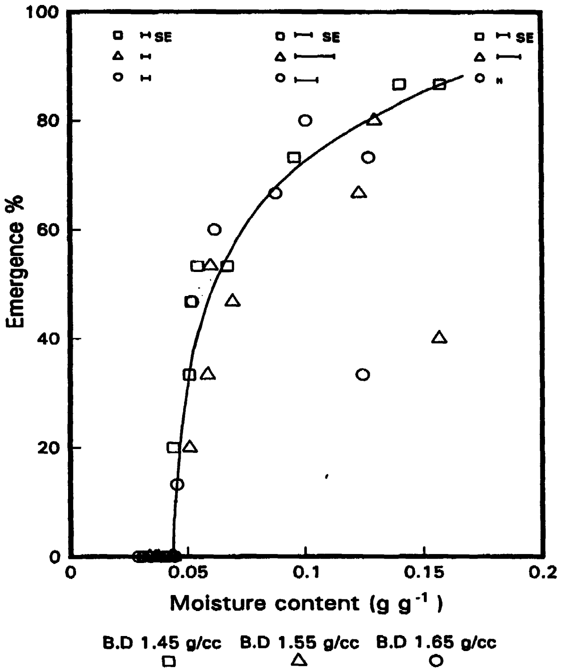

Fig.23 Influence of moisture content on groundnut emergence at different bulk density

similar for all the three bulk densities as can be observed from Figure 23. Two outliers resulting possibly from experimental error were discarded in fitting a smooth curve to Figure 23 by eye. Maximum emergence of 86.7% was observed at a moisture content of 0.1401 gg^{-1} for bulk density of 1.45 g cm^{-3}, whereas maximum emergence of 80% occurred at a moisture content of 0.1293 and 0.1004 gg^{-1} for the other two bulk densities of 1.55 and 1.65 g cm^{-3} respectively. Emergence decreased from 80% to 33.3% as moisture content increased from 0.1004 to 0.1245 gg^{-1} for soils at bulk density of 1.65 g cm^{-3} and from 80% to 40% as moisture content increased from 0.1293 to 0.1566 gg^{-1} for soil at a bulk density of 1.55 g cm^{-3}.

Matric suction was also observed to influence emergence. With decrease in matric suction, emergence increased significantly (Figure 24). Emergence started at matric suctions of 212.8, 197.5 and 163.1 kPa for the bulk densities of 1.45, 1.55 and 1.65 g cm^{-3} respectively. At bulk density of 1.45 g cm^{-3} maximum emergence of 86.7% was observed at 94.7 kPa suction. Maximum emergence of 80% was observed at matric suctions of 33.7 and 55.1 kPa for bulk densities 1.55 and 1.65 g cm^{-3}. There was a significant decrease in emergence at matric suctions below 33.7 and 55.1 kPa for bulk densities of 1.55 and 1.65 g cm^{-3} respectively. It is observed from Figure 24 that changes in emergence as a function of changes in matric suction is faster at bulk density 1.45 g cm^{-3} than at either 1.55 or 1.65 g cm^{-3} when matric suction is considered. Percent seedlings of groundnut that emerged is significantly higher for

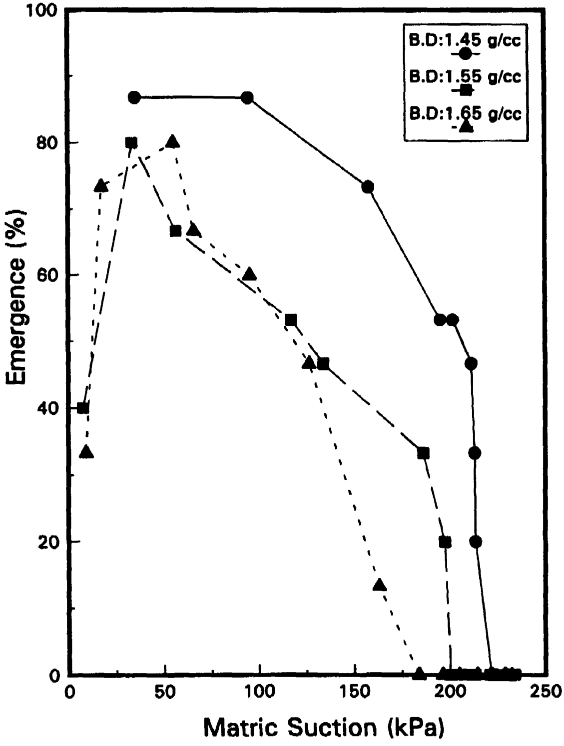

Fig.24 Influence of matric suction on groundnut emergence at different bulk density

soils at bulk density of 1.45 g cm^{-3} than those at either 1.55 or 1.65 g cm^{-3}. Emergence for groundnut seedlings in the soils at bulk densities of 1.55 and 1.65 g cm^{-3} was very similarly at matric suctions less than 125 kPa and were only different at matric suctions higher than 125 kPa. No groundnut seedlings emerged in all the three bulk densities when the matric suction was greater than 223 kPa.

CHAPTER V
DISCUSSION

CHAPTER V

DISCUSSION

5.1 LABORATORY EXPERIMENT

Temperature effect on germination of millet, sorghum and groundnut

The results obtained from the experiments on temperature effect on germination indicated that percent germination increases as temperature increases. This is because physiological and biological transformations and activities are accelerated by increase in temperature. Germination started 7 hrs after millet seeds were soaked and maintained at 25, 30 and 35°C whereas the seeds started germinating at 12 and 14 hrs after soaking when temperature was maintained at 20 and 15°C respectively. At 10°C, no seeds had germinated even after 48 hrs.

Base temperature corresponds to zero development rate and was determined following the linear regression method suggested by Brar et al., (1991). The time taken for 50% of the millet seeds to germinate was 9, 9, 12, 23 and 26 hrs after soaking for 35, 30, 25 20 and 15°C respectively. The time taken for 50% of the seeds to germinate for sorghum was 12, 16, 21, 32 and 35 hrs whereas groundnut seeds took 40, 32, 34, 44 and 71 hrs after soaking at 35, 30, 25, 20 and 15°C respectively. The inverse values of time for

50% germination (1/t) as a function of temperature (T) (Figures 5, 6 and 7) was used to calculate the base temperature for the three crops (Appendix III). Using the model in equation 1 (Appendix III) Kanemasu et al. (1975) found that the base temperature for sorghum is 9.9°C. Garcia-Huidobro et al., (1982) found the base temperature of pearl millet (cv. BK 560) to be 11.5°C. Using the linear regression model of Brar et al., (1991) the base temperatures were calculated (Appendix III) and found to be 6.8, 6.9 and 2.5°C for pearl millet, sorghum and groundnut respectively.

The rate of germination as a function of temperature increased linearly with increase in temperature for millet and sorghum and it differed slightly for groundnut crop. This response of rate of germination to temperature is consistent with that described by Khalifa and Ong (1990) and Garcia-Huidobro et al., (1982) for all the 3 crops.

Sorghum and groundnut took longer time to germinate at 15°C than millet. This implies that pearl millet is more capable of germinating under lower temperatures than sorghum and groundnut. Similar results were obtained by Smith, et. al. (1989).

As temperature decreased for all the three crops, greater time was required to reach maximum germination. This indicates that at lower temperatures, germination was delayed, possibly because of inability of the seeds to utilize their carbohydrate reserves due to low temperatures. For most crops, the viability of seeds can be maintained by storing them at low temperatures thus preventing them from germinating.

5.2 GREENHOUSE EXPERIMENT

5.2.1 Influence of moisture status and bulk density on germination of pearl millet

Table 1 in Appendix IV shows that at soil bulk density of 1.45 g cm^{-3}, pearl millet required a minimum gravimetric moisture content of about 4% for germination to start and that seeds failed to germinate at soil moisture contents below this initial value. Increase in moisture content enhanced germination. Further increase beyond an optimum moisture content of 14% when 100% germination was obtained, resulted in a significant decrease in germination. Increasing moisture content from 0.0445 to 0.0487 gg^{-1} resulted in an increase of germination from 25% to 61%. Further increase in moisture content to 0.0585 gg^{-1} increased germination to 74%. However, at high moisture contents of 0.1874 gg^{-1} germination decreased significantly to 95%. This decrease of germination at high moisture content may be the result of decreased oxygen (as the pores are filled with water) which is necessary for germination to

As the bulk density increased the volumetric water content required for germination to start also increased. For example at the bulk density of 1.45 g cm^{-3} germination started at volumetric water content of 0.0638 cm^3 cm^{-3} while at bulk densities of 1.55 and 1.65 g cm^{-3} germination started at volumetric water content of 0.0722 and 0.0954 cm^3 cm^{-3} respectively. This result was unexpected because one expects that the seed-soil contact would be better at 1.65 g cm^{-3} than at bulk density of 1.45 g cm^{-3} and that this good seed-soil contact at the high bulk density would enable initiation of germination to occur at lower volumetric water content in soils with bulk density of 1.65 g cm^{-3} than those at 1.45 g cm^{-3}. Similarly the optimum volumetric moisture content for 100% germination increased from 0.2094 cm^3 cm^{-3} for bulk density of 1.45 g cm^{-3} to 0.2593 cm^3 cm^{-3} for 1.55 g cm^{-3}. At bulk density of 1.65 g cm^{-3} however the volumetric moisture content at which a maximum germination of 95% was obtained, was not very different from that for 1.55 g cm^{-3} bulk density (i.e. 0.2598 cm^3 cm^{-3}).

Because the initial processes in germination involves imbibition of water and therefore the flux density of water from the soil to the seed, water content *per se* does not very well explain the process that are taking place. However, when the water contents are examined together with the matric suctions an interesting scenario emerges. It is noted that because of the effect of soil structure on the moisture characteristics of the soil, the volumetric moisture content of 0.0638 cm^3 cm^{-3} at which germination started in the soils packed at 1.45 g cm^{-3} corresponds to a matric suction of 223 kPa. In bulk density of 1.55 g cm^{-3} and 1.65 g cm^{-3} the volumetric moisture content (i.e. 0.0722 cm^3 cm^{-3} for 1.55 and 0.0954 cm^3 cm^{-3} for 1.65 g cm^{-3}) correspond to matric suctions of 165 and 161 kPa respectively. Assuming then that the matric suction in the seeds is the same for all the seeds (since they were at the same moisture content) then the flux of water to the seeds, which depends on the gradient of moisture suction between the soil and the seed, would be greater in the soils at bulk density of 1.65 g cm^{-3} than those at bulk densities of 1.45 and 1.55 g cm^{-3}, since the gradient of matric suction in the soil at 1.65 g cm^{-3} bulk density is greater than in the soil at either 1.55 or 1.45 g cm^{-3} bulk densities. The greater flux of water at bulk density of 1.65 g cm^{-3} then would result in more water movement to the seeds and therefore higher moisture content required for initiation of germination. Maximum germination of 100% was observed at 16 and 13 kPa for bulk densities of 1.45 and 1.55 g cm^{-3}, while for the bulk density of 1.65 g cm^{-3}, the maximum germination of 95% was observed at a suction of 8 kPa, indicating that fairly wet soil conditions prevailed to enhance germination, and that at matric suction of 8 kPa, the soils were too wet and thus possibly interfering with the oxygen supply to the seeds sown at bulk density of 1.65 g cm^{-3}, resulting in 95% and not 100% germination.

As with pearl millet sown at a bulk density of 1.45 g cm^{-3}, initial germination in the other two bulk densities was fast. Thus at bulk density of 1.55 g cm^{-3}, an increase in the gravimetric moisture content by 0.0063 gg^{-1} (i.e. from 0.0466 to 0.0529 gg^{-1}) resulted in an increase of 42% germination. Similarly when the gravimetric water content in the soil at 1.65 g cm^{-3} bulk density increased from 0.0486 to 0.0682 gg^{-1}, germination (which was practically zero at the former water content) increased to 31% because of a burst of biochemical activities as water was suddenly made available to the dry seed culminating in accelerated cell division and its resultant emergence of the plumule and radicle from the testa.

Germination was poor at matric suctions ranging from 160 to 240 kPa for the three bulk densities. This may be attributed to unavailability of sufficient moisture at those matric suctions. At high bulk densities of 1.65 g cm^{-3}, germination was retarded as a result of insufficient aeration and lack of optimum conditions for the seeds to germinate. High moisture contents also caused a decrease in germination at all the three bulk densities. This decrease in germination may be the result of inhibition of respiration of the seeds at high soil moisture due to inadequate levels of oxygen. Similar results were obtained by Fawusi and Agboola (1980), Rao and Dao (1987) and Mali and Varade (1981).

5.2.2 Influence of moisture status and bulk density on germination of sorghum sown at 2.5 and 5 cm depth

Sorghum sown at 2.5cm depth required a minimum moisture content of 0.0655 gg^{-1} for germination to initiate at bulk density of 1.45 g cm^{-3} whereas higher moisture contents of 0.0753 and 0.0893 gg^{-1} were required for initiation of germination at bulk densities of 1.55 and 1.65 g cm^{-3} respectively. The movement of water from soil to seed depends on two factors : (i) gradient of moisture suction and (ii) the hydraulic conductivity of the soil which is a function of water content. Due to high compaction at bulk density of 1.65 g cm^{-3}, the movement of water to the seeds might be restricted which may cause decrease in germination percent. Similar observations were made by Huges et al., (1966) and Mali et al., (1977). The optimum gravimetric moisture content required for 100% germination of sorghum sown at 2.5cm depth was within the range of 13 to 15% at all the three bulk densities. However, an increase in gravimetric moisture content beyond 17% resulted in significant decrease in the germination percentage of sorghum sown in soils at the three bulk densities.

Bulk density was also found to influence germination. At nearly the same moisture content, i.e., 0.0896, 0.0809 and 0.0893 gg^{-1}, the germination percent was 71%, 56% and 11% respectively for 1.45, 1.55 and 1.65 g cm^{-3} bulk densities respectively (Table 3 in Appendix IV). Thus with increase in bulk density, the germination percent decreased. However, the effect of bulk density on germination varied with the moisture content of the soil.

Since imbibition is involved in germination which depends on the moisture suction of soil as well as the seed, matric suction studies were also conducted. Movement of water occurs from a lower matric suction to higher matric suction. Seeds which are dry and at high matric suction imbibe water from the soil which is at a lower moisture suction. Germination initiated at a matric suctions of 160.3, 154.5 and 135.5 kPa which correspond to moisture contents of 0.0655, 0.0753 and 0.0893 gg^{-1} at the bulk densities of 1.45, 1.55 and 1.65 g cm^{-3} respectively. No germination occurred at matric suctions above 196 kPa for soils packed at bulk density of 1.45 and 1.55 g cm^{-3} and above 167 kPa for soils at bulk density of 1.65 g cm^{-3}. This might be attributed to lack of availability of sufficient water because of inadequate gradient of moisture suction from the soils to seeds. Decrease in suction below 5 kPa resulted in significant decrease in germination for all three bulk densities. Due to lack of oxygen at high moisture contents (moisture suctions less than 5 kPa) germination percentage of sorghum sown at 2.5cm depth decreased.

At high bulk densities, water is held with more energy due to compaction of the soil and small sizes of pores, whereas at lower bulk density water is held with less energy because of the loose nature of the soil and the comparatively large pores. Therefore the seeds were able to absorb moisture more easily at lower bulk density and germinate at lower moisture content than at high bulk densities. At bulk density of 1.65 g cm^{-3}, the seeds had to exert more energy to absorb moisture at high moisture suctions, hence germination started at higher moisture contents. Lack of aeration due to low total porosity may account for suppressed germination at bulk density of 1.65 g cm^{-3}. Similar results were obtained by Hudspeth and Taylor (1961), Fawusi and Agboola (1980) and Smith et al., (1989).

Sorghum sown at 5cm depth required lesser gravimetric moisture content for germination to initiate at all the three bulk densities than sorghum sown at 2.5cm depth (Tables 3 and 5 in Appendix IV). From Figure 15, it can be observed that germination percent increased with increase in moisture content. The rate of germination followed the same trend as that observed for sorghum sown at 2.5cm depth (Figure 13). At high moisture contents, germination decreased significantly. The only difference between sorghum sown at 2.5 and 5cm depth was the moisture content for initiation of germination and for maximum germination but the trend followed was nearly similar. Germination of 100% was not observed at bulk density of 1.65, g cm^{-3} for sorghum sown at 5 cm depth, only 97% germination was obtained within a moisture range of 0.1468 to 0.1503 gg^{-1} and at moisture content of 0.1575 gg^{-1} germination decreased to 95%. As with sorghum sown at 2.5 cm germination started at a lower moisture content at bulk density of 1.45 g cm^{-3} than at 1.55 and 1.65 g cm^{-3} (Table 3). Rate of germination was also faster at bulk density of 1.45 g cm^{-3} followed by 1.55 and 1.65 g cm^{-3} as can be observed from Figure 15.

Matric suction also influenced germination (Figure 16). At matric suction greater than 223 kPa, no germination was observed. Germination started at suctions of 222, 185 and 196 kPa at the three bulk densities for sorghum sown at 5 cm whereas germination initiated at lower matric suctions (less than 160 kPa) for sorghum sown at 2.5cm depth. These observations indicate that when seeds

Table 3 : Moisture content required for initiation of germination and maximum germination with corresponding matric suction at different bulk density for pearl millet, sorghum and groundnut

Crop	Moisture content (gg^{-1}) for germination to initiate at bulk densities ($g\ cm^{-3}$)			Corresponding matric suction (kPa) for germination to initiate at bulk densities ($g\ cm^{-3}$)			Moisture content (gg^{-1}) for maximum germination at bulk densities ($g\ cm^{-3}$)			Corresponding matric suction kPa for maximum germination at bulk densities ($g\ cm^{-3}$)		
	1.45	1.55	1.65	1.45	1.55	1.65	1.45	1.55	1.65	1.45	1.55	1.65
Pearl millet	0.0445	0.0466	0.0578	222.8	164.5	160.7	0.1444	0.1673	0.1576*	16.0	13.3	8.3*
Sorghum at 2.5 cm depth	0.0655	0.0753	0.0893	160.3	154.5	135.6	0.1152	0.1427	0.1338	50.8	14.9	13.3
Sorghum at 5 cm depth	0.0457	0.0541	0.0562	222.8	185.6	196.8	0.1735	0.1651	0.1456**	6.8	7.1	29.8**
Groundnut	0.0519	0.0584	0.0739	217.4	217.9	201.6	0.1186	0.1178	0.1342	50.4	76.4	55.9

Maximum germination = 95%

** Maximum germination = 97.7%

are sown at greater depth, they are able to germinate even at high moisture suctions (i.e. 222 kPa suction) (Table 3). Lack of availability of sufficient moisture for imbibition by the seeds causes poor germination at high matric suctions because of low suction gradients between the soil and the seed. Decrease in germination at low matric suction (high soil moisture content) might be attributed to lack of sufficient oxygen for the seeds to respire and germinate, since all or most of the pores are filled with moisture.

5.2.3 Influence of moisture status and bulk density on germination of groundnut

Interaction of bulk density and moisture content was observed to have a significant influence on germination of groundnut. At 5% gravimetric moisture content, germination started at lower bulk density (1.45 g cm^{-3}) whereas initiation of germination at higher bulk density (1.65 g cm^{-3}) required 7% moisture content. Germination increased with increase in moisture content. From Figure 17 it is observed that the rate of germination is nearly same at all the three bulk densities indicating that bulk density did not have a major effect on germination of groundnut. This might be due to its large seed size and its food reserves which provided enough energy to overcome the bulk density effect. At gravimetric moisture contents less than 5%, germination did not occur due to insufficient moisture for the seeds to imbibe and germinate. The moisture was not sufficient for the seeds to utilize in order to mobilize the food reserve for germination. Germination decreased significantly at gravimetric moisture content above 17% which may be attributed to lack of oxygen as a result of insufficient aeration. Figure 18 shows the influence of matric suction on groundnut germination. With decrease in suction, germination increased. At suction greater than 217 kPa which corresponds to gravimetric moisture contents less than 5%, germination did not occur. At suction values less than 4 kPa corresponding to 17% gravimetric moisture content, germination decreased slightly.

5.2.4 Influence of moisture status and bulk density on emergence of pearl millet

Emergence of pearl millet seedlings started at lower moisture content for bulk density of 1.55 g cm^{-3} but required more time for emergence to occur. With increase in moisture content emergence increased and at high moisture content emergence decreased significantly. Most of the pearl millet seedlings had emerged on the fourth and fifth days after sowing (DAS) at bulk density of 1.45 g cm^{-3} whereas 2 more days were required for most of the seedlings to emerge at 1.65 g cm^{-3}. Emergence percent was lowest (63.3%) for bulk density 1.65 g cm^{-3} and highest (93.3%) for bulk density 1.45 g cm^{-3}. These observations indicate that bulk density plays a major role in the emergence of pearl millet due to the small size of the seed. At high bulk densities such as 1.65 g cm^{-3}, there was a decrease in emergence of pearl millet seedlings due to increase in soil strength and compaction. The energy required for emergence of seedlings increases with increase in bulk density. At high bulk densities, the pearl millet seedlings were unable to develop sufficient force to overcome the mechanical impedance resulting in poor emergence (Mali et. al. 1977). Various factors such as cracking of soil, emergence force and emergence behaviour of the seedlings play an important role in effecting seedling emergence at high bulk densities. At higher bulk density the total porosity decreases and this reduces aeration as well as the water retention capacity of the soil, leading to decreased emergence of pearl millet as reflected by the observation that only 63% emergence was obtained at bulk density of 1.65 g cm^{-3}. Similar results were obtained by Stout et al., (1961). The movement of water and air is also restricted at high bulk densities and account for decrease in the availability of water to the seeds, leading to a decrease in emergence. These results are in agreement with those reported by Hegarty and Royale (1978) and Maiti et. al. (1986). Though change in emergence with respect to change in moisture contents was not much affected as observed from the slopes of the curves in Figure 19.

When adequate moisture was available, the emergence of seedlings was restricted by compaction caused by high bulk density, as the seedlings were unable to penetrate the compacted soil at bulk density of 1.65 g cm^{-3} and moisture content of 12 to 15%. These results are consistent with those obtained by Stout et al., (1961). For most of the moisture contents more seed emerged at bulk density of 1.45 g cm^{-3} than at 1.55 or 1.65 g cm^{-3}. The seedling emergence in the dry range was reduced as a result of insufficient moisture for the seeds to imbibe and for germination to occur leading to emergence.

Soil moisture was also found to have a significant influence on emergence. Lower emergence (4%) was obtained at lower gravimetric moisture content (6%) and higher emergence (60-90%) was obtained at higher moisture contents (14-16%). As moisture content varied, the rate of moisture imbibition and germination also varied. Decrease in emergence at low soil moisture levels less than 5% was due to insufficient available water. At moisture contents of 17% and above, lack of sufficient aeration led to a decrease in emergence. Emergence decreased from 93.3% to 61.4% at bulk density of 1.45 g cm^{-3} and from 84% to 65.4% at 1.55 g cm^{-3} as the gravimetric moisture content increased above 16%.

5.2.5 Influence of moisture status and bulk density on emergence of sorghum

Moisture is held with less energy at lower bulk densities hence absorption of moisture by seeds is easier at lower bulk density than at higher bulk density. Consequently, higher emergence (84%) was observed at lower bulk density i.e. 1.45 g cm^{-3} than at higher bulk density (i.e. 1.65 g cm^{-3}) which showed only 23% emergence. Change in emergence of sorghum seedlings with respect to changes in moisture contents was higher at bulk density of 1.45

g cm^{-3} than at bulk densities 1.55 and 1.65 g cm^{-3}. Optimum moisture for maximum emergence of 84% was observed to be 0.1004 gg^{-1} at 1.45 g cm^{-3} and 0.1407 gg^{-1} at bulk density of 1.55 g cm^{-3} which had an emergence of 78.7%. Maximum emergence was only 23% at bulk density of 1.65 g cm^{-3}, and moisture content of 0.0836 gg^{-1}. This might be attributed to high mechanical impedance caused by high bulk density. The sorghum seedlings had to exert a lot of force in order to overcome the impedance, and they may not have been able to develop sufficient pressure to emerge. At high gravimetric moisture contents greater than 16%, there was a significant decrease in emergence. Lack of aeration as a result of high moisture content affected the respiration of the germinating seeds. As a consequence, emergence decreased. Therefore lower emergence occurred at high moisture contents which correspond to matric suctions less than 16 kPa.

At a soil matric suction of 221 kPa emergence of 8% and 4% were observed at bulk densities of 1.45 and 1.55 g cm^{-3} respectively. Emergence initiated at matric suction of 195 kPa at 1.65 g cm^{-3} bulk density. Maximum emergence was 84% at a soil moisture suction of 126 kPa for 1.45 g cm^{-3} bulk density. At lower suctions less than 106 kPa, emergence decreased significantly. At bulk density of 1.55 g cm^{-3}, the maximum emergence observed at a moisture suction of 37 kPa was 79%. Below this moisture suction, emergence decreased significantly. Maximum emergence of 23% was observed at a suction of 97 kPa at bulk density of 1.65 g cm^{-3}. Emergence decreased significantly at moisture suction equal to or less than 54 kPa.

Sorghum emergence varied with increase in moisture content at the three bulk densities. Both moisture and bulk density had a significant influence on emergence of sorghum. It was observed during the course of the experiment that most of the seedlings had emerged in the first two days at bulk density 1.45 g cm^{-3}. However, at bulk density 1.65 g cm^{-3} two more days elapsed before most of the seedlings emerged; even then, the maximum emergence was only 23%. The rate and percent of sorghum seedlings that emerged were reduced drastically at higher bulk density. At high bulk densities such as 1.65 g cm^{-3} used in this experiment, soil compaction was very high. As a consequence, the mechanical impedance increased, and in turn affected seedling emergence. The seedlings had to exert greater force to emerge and those that were unable to overcome the mechanical impedance did not emerge. These results are in agreement with those of Hegarty and Royale (1978). The total porosity and pore size were very much reduced at high bulk density of 1.65 g cm^{-3}, thus restricting the supply of oxygen as well as nutrients. Consequently, the respiration of the germinating seeds was affected and they were not able to emerge from the soil (Archer and Smith, 1972). For seedlings to emerge they must germinate and penetrate through the soil. Mali et al., (1977), Maiti et al., (1986) and Mali and Varade, (1981) also reported that increase in bulk density, increases mechanical impedance and soil strength resulting in the inability of seedlings to emerge.

The interaction of soil moisture and bulk density also had a significant influence on the emergence of sorghum seedlings. At low soil moisture contents corresponding to matric suctions less than 221 kPa there was no emergence in all the three bulk densities. Emergence was higher at 1.45 g cm^{-3} than at bulk densities of 1.55 and 1.65 g cm^{-3}. The reduction in emergence was more at bulk density 1.65 g cm^{-3} in the dry moisture range than at 1.45 g cm^{-3}. This might be attributed to high mechanical impedance and lack of water. The change in emergence of sorghum seedlings was also influenced by changes in moisture content and bulk density. Change in emergence of sorghum was faster at 1.45 g cm^{-3} than 1.65 g cm^{-3} with changes in soil moisture. Similar results were observed by Huges, et. al. 1966.

Moisture also had a significant influence on emergence of sorghum seedlings. Emergence of sorghum seedlings was found to decrease at the lower as well as the higher soil moisture content. Rate of moisture imbibition and germination varied with moisture content. At low soil moisture contents, due to lack of sufficient moisture, very little imbibition occurred and as a result germination and emergence did not occur, leading to damage of the seeds by micro organisms (Wright et al., 1978). Emergence was low at soil moisture contents below 4% whereas at higher soil moisture contents (10 to 16%), emergence was higher. These results are in agreement with those obtained by Brar, et. al. (1982) in experiments conducted on cotton.

In studies of this nature, it is difficult to separate the effect of bulk density and moisture content on emergence. As bulk density increased, soil compaction also increased and in turn increased mechanical impedance leading to a reduction in the emergence of seedlings. Increased bulk density also reduced the total porosity of the soil thus decreasing the water holding capacity of the soil, which subsequently decreased the emergence of seedlings at high bulk densities. At nearly the same moisture content of 0.0759, 0.0796 and 0.0748 gg^{-1}, emergence of sorghum was found to be 38.7, 22.7 and 14.7% at bulk densities of 1.45, 1.55 and 1.65 g cm^{-3} respectively. This shows that emergence of sorghum seedlings decreased with increase in bulk density at nearly the same moisture content (Table 11 in Appendix IV). Hanks and Thorp (1956) observed similar results in experiments conducted on seedling emergence of wheat. At low matric suctions below 16 kPa, there was a significant reduction in emergence as was in the case of pearl millet, which might be due to lack of aeration. The small seed size of sorghum may be an additional factor increasing the adverse effects of high bulk density on seedling emergence. These results are consistent with those obtained by Soman et al., (1984).

5.2.6 Influence of moisture status and bulk density on emergence of groundnut

The interaction of matric suction, bulk density and moisture content caused a significant variation in the emergence of groundnut seedlings. Similar results were observed by Hunter and

Erickson (1972) in wheat crop. Excessive dryness was also detrimental in groundnut seedling emergence. The rate of moisture absorption by the seeds also depends on external factors such as the capillary flow of water through the soil. At low soil moisture content the rate of movement of soil water (hydraulic conductivity) would be too slow to supply sufficient water to the immediate environment of the seed for its germination and subsequent emergence within a short time. The replenishment of water in the vicinity of the seed would also be slower. Hence the seed may take longer time to germinate with the result that seedling emergence may or may not take place at the low moisture status. The emergence of groundnut seedlings was relatively fast initially but it slowed down with time as most of the seedlings emerged. The groundnut seedlings failed to emerge at low moisture contents due to lack of sufficient moisture. At high moisture contents, there was a significant decrease in emergence due possibly to inadequate aeration and lack of sufficient oxygen. As a result some of the seedlings were unable to germinate and emerge. Similar observations were reported by Painuli and Abrol (1984) on maize crop.

The interaction of moisture and bulk density had a great influence on emergence of groundnut seedlings. The effect of bulk density on emergence varied with the moisture content. As bulk density increased, the soil strength and mechanical impedance increased but due to large seed size, groundnut seedlings were able to overcome the mechanical impedance caused by high bulk density of 1.65 g cm^{-3} easily. Since increase in bulk density causes an increase in compaction, which decreases the total porosity, (from 0.453 in 1.45 g cm^{-3} to 0.377 in 1.65 g cm^{-3}) the water holding capacity of the soil decreased. Hence more moisture is required for emergence to initiate at high bulk density. At 1.65 g cm^{-3} bulk density emergence initiated at a moisture content of 7% whereas only 5% of moisture content was required for emergence to initiate at lower bulk density of 1.45 g cm^{-3}. Supply of oxygen and nutrients will also be restricted at high bulk density. These may cause a decrease in emergence of groundnut seedlings at high bulk densities (Mali and Varade, 1981; Venkaiah, 1985; Ahmed, et. al. 1989). At low moisture contents emergence percentage was poor and at high moisture contents higher emergence percentage was observed.

Figure 24 shows the influence of matric suction on groundnut emergence. At lower bulk density of 1.45 g cm^{-3} emergence was faster even at higher matric suction (above 225 kPa). At bulk densities 1.55 and 1.65 g cm^{-3} emergence followed nearly the same trend at the lower matric suctions between 0 to 100 kPa. Above 100 kPa the emergence was lower for bulk density 1.65 g cm^{-3} and higher for bulk density 1.55 g cm^{-3}. Maximum emergence (86.7%) was observed at higher matric suction (94.7 kPa) for bulk density 1.45 g cm^{-3} and maximum emergence of 80% was observed at lower matric suctions (below 50 kPa) for bulk densities 1.55 and 1.65 g cm^{-3} indicating that emergence started at lower moisture content at bulk density of 1.45 g cm^{-3} and higher moisture content was required for emergence at higher bulk densities (i.e. 1.55 and 1.65 g cm^{-3}).

CHAPTER VI
SUMMARY

C H A P T E R V I

SUMMARY

The principal goal of this research was to determine the influence of moisture status and bulk density on germination and emergence of pearl millet, sorghum and groundnut, in greenhouse experiments conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Soil used was an Alfisol which commonly occur in the semi-arid tropics.

A laboratory experiment was first conducted to determine the rate of germination at different temperatures. Lesser time was required for maximum germination at higher temperatures such as 25, 30 and 35°C whereas at lower temperatures of 20 and 15°C longer time was required for maximum germination. Rate of germination was also observed to be more rapid at the higher temperatures than at 20 and 15°C. The base temperature at which germination does not occur was calculated using a linear regression model and was found to be 6.8, 6.9 and 2.4°C for pearl millet, sorghum and groundnut respectively.

Moisture contents ranging from 0.0200 gg^{-1} to 0.1900 gg^{-1} were taken as one factor and their interactions with three bulk densities 1.45, 1.55 and 1.65 g cm^{-3} were studied as the second factor. Each experiment was of two weeks duration.

Bulk density and moisture content were found to have a significant influence on germination of pearl millet. Germination started at a lower soil moisture content for the bulk density of 1.45 g cm^{-3}. A higher soil moisture content was required for the initiation of germination at bulk densities of 1.55 and 1.65 g cm^{-3}. Maximum germination was also observed at lower moisture content for bulk density of 1.45 g cm^{-3}. With increase in soil moisture content, germination also increased. But at very high moisture contents, there was a significant decrease in germination. Similar trends were observed for all the three bulk densities. Bulk density had a negative influence on germination. At the same moisture content with increase in bulk density germination decreased. Germination involves imbibition of water therefore the matric suction plays an important role in the movement of water from lower matric suction to higher matric suction. For millet germination occurred at suctions below 223 kPa. At low matric suctions below 8 kPa the soil was too wet, leading to reduced germination due to lack of supply of oxygen.

In the case of sorghum crop, two depths of sowing i.e., 2.5cm and 5cm were investigated. In sorghum also, germination increased with increase in moisture content. At very high moisture contents germination decreased significantly. Similar trends were observed for both the depths. It was observed that higher moisture content was required for germination to initiate at 2.5cm depth than at 5cm depth in all the three bulk densities. At 2.5cm depth, 6% soil moisture was required for germination to initiate at bulk density of 1.45 g cm^{-3} whereas 7% and 8% soil moisture contents were required for germination to initiate in sorghum seed sown at bulk density of 1.55 and 1.65 g cm^{-3}. In the case of sorghum sown at 5cm depth, germination initiated at 4% soil moisture for bulk density 1.45 g cm^{-3} and 5% soil moisture for bulk densities 1.55 and 1.65 g cm^{-3}. Maximum germination occurred at lower moisture contents for sorghum sown at 2.5cm and higher soil moisture contents was required for maximum germination at 5cm depth. Bulk density was observed to have a negative influence on germination. At higher bulk density, germination decreased, bulk density 1.45 g cm^{-3} was found to be optimum but bulk density of 1.65 g cm^{-3} was found to suppress germination. For sorghum sown at 5cm depth germination started at higher matric suctions (i.e. 222 kPa) whereas for sorghum sown at 2.5cm depth germination started at lower matric suctions (i.e. 160 kPa). At suctions below 10 kPa germination decreased significantly at all the three bulk densities for sorghum sown at 2.5 as well as 5cm depth.

Bulk density had a negligible influence on germination of groundnut. However, the interaction of bulk density with soil moisture had a significant influence. Germination started at lower moisture content for bulk density of 1.45 g cm^{-3}. Moisture suction was observed to have a negative influence on germination. Germination started at matric suctions of less than 200 kPa for groundnut. With increase in suction, germination decreased. In very dry range of soil moisture, no germination was observed. Soil moisture was observed to have more effect on germination of groundnut. Rate of germination was more rapid at bulk density of 1.45 g cm^{-3} than at 1.55 and 1.65 g cm^{-3}.

Emergence of pearl millet was observed on the fourth day after sowing. In the dry range emergence was delayed by one or two days at bulk density of 1.65 g cm^{-3}. At bulk density of 1.65 g cm^{-3} lowest emergence count (63.3%) was obtained while the highest emergence count (93.3%) was obtained at bulk density of 1.45 g cm^{-3}. Change in emergence with respective change in moisture content was rapid at the lower bulk density and slower at the higher bulk densities. Emergence increased with increase in moisture content. A bulk density of 1.65 g cm^{-3} decreased the seedling emergence count due to increase in soil strength.

Sorghum emergence was influenced more by bulk density. Maximum emergence was only 22.7% at bulk density of 1.65 g cm^{-3} as compared to 84% emergence at bulk density 1.45 g cm^{-3}. Emergence was observed on the fifth day after sowing in all the three bulk densities. At the dry range of soil moisture emergence was delayed by one or two days in the soils packed at bulk densities 1.55 and 1.65 g cm^{-3}. Change in emergence was rapid at the bulk density of 1.45 g cm^{-3} at changes in all the soil moisture levels compared to the bulk density of 1.65 g cm^{-3}. Emergence increased with increase in moisture content. At soil moisture contents greater than 16%, a decrease in emergence due to lack of aeration was observed.

Emergence occurred on the eighth day after sowing for groundnut at all the three bulk densities. Bulk density had a negligible influence on emergence of groundnut. The large seed size of groundnut and small size of pots may be responsible for this observation. High soil moisture resulted in increasing emergence. Emergence was rapid at the high soil moisture content compared to dry moisture content. Emergence decreased as moisture increased above 15% at bulk density 1.55 and 1.65 g cm^{-3}. At bulk density of 1.45 g cm^{-3}, maximum emergence of 86.7% was observed whereas 80% was the maximum emergence observed at bulk densities of 1.55 and 1.65 g cm^{-3}.

The above results indicated that 1.45 g cm^{-3} was optimum bulk density for germination as well as emergence for millet and sorghum. Soil moisture of at least 4% was required for germination to initiate at bulk density 1.45 g cm^{-3} for all the three crops. At bulk density of 1.55 g cm^{-3}, soil moisture of 5% to 7% was required for germination to initiate for the three crops. Very high moisture contents of 17% to 20% reduced germination in the three crops possibly due to insufficient oxygen for seeds to respire. Emergence of pearl millet and sorghum decreased with increase in bulk density. Due to small seed size, the adverse effects of bulk density, such as increase in mechanical impedance, led to a decrease in emergence at bulk density of 1.55 and 1.65 g cm^{-3}. As soil moisture content increased emergence counts also increased. However, moisture contents above 17% caused a decrease in emergence of seedlings for all the three crops.

BIBLIOGRAPHY

BIBLIOGRAPHY

Agarwal R P, Jhorar B S, Maiti R K, Raju P S and Peacock J M 1986 Effect of soil crusting on seedling emergence in sorghum genotypes. International Journal of Tropical Agriculture. Vol IV No 1 : 15-22.

Ahmed R S, Raju A P and Sathe A 1989. Effect of soil compaction on active root distribution of groundnut (variety JL-24) in red sandy loam soil under irrigated condition. Journal of Nuclear Agric. Biol. Vol 18 : 246-248.

Archer J R and Smith P D 1972 The relation between bulk density, available water capacity and air capacity of soils. Journal of Soil Science. Vol 23 (4) : 475-480.

Bouaziz A and Bruckler L 1989 Modeling wheat seedling growth and emergence I. Seedling growth affected by soil water potential. Soil Science Society of America Journal. Vol 53 : 1832-1838.

Bouyoucos G J 1962 Hydrometer method improved for making particle size analysis of soils. Agronomy Journal Vol 54 : 464-465.

Brar G S, Steiner J L, Unger P W and Prihar S S 1991 Modelling sorghum seedling establishment from soil wetness and temperature of drying seed Zones. Unpublished.

Brar G S, Sikhon N and Singh N T 1982 Emergence of cotton seedlings as influenced by soil moisture and seedling depth. Journal of Indian Society of Soil Science. Vol 30 (2) : 122-124.

Collis-George N and Sands J E 1959 The control of seed germination by moisture as a soil physical property. Australian Journal Agricultural Research Vol 10 : 628-636.

Collis-George N 1987 Effects of soil physical factors on imbibition, germination, root elongation and shoot movement. AIAS occasional publication No. 34 : 23-41.

Dewez J 1964 Water uptake and heat evolution by germinating cotton seeds. Plant Physiology Vol 39 : 240-244.

Doneen L D and Mac Gillivary J H 1943 Germination (emergence) of vegetable seeds as affected by different soil moisture conditions. Plant Physiology Vol 18 : 524-529.

Evans W F and Stickler F C 1961 Grain sorghum seed germination under moisture and temperature stresses. Agronomy Journal Vol 53 : 369-372.

Fawusi M O A and Agboola A A 1980 Soil moisture requirements for germination of sorghum, millet, tomato and celosia. Agronomy Journal Vol 72 : 353-357.

Garcia-Hudiobro J, Monteith J L and Squire G R 1982 Time temperature and germination of pearl millet (Pennisetum typhoids S and H). 1. Constant temperature. Journal of Experimental Botany Vol 33 : 288-296.

Gomez A K and Gomez A A 1984 Statistical procedures for agricultural research. A. Wiley Interscience publications New York.

Goyal M R 1979 Crusted soils affect seedling emergence. The crops and soils magazine, Madison 53711. April-May 1979 Vol 31(6) : 27.

Goyal M R, Gordon L N and Drew L O 1981 Moisture and Soybean seedling emergence. Transaction of the American Society of aGricultural Engineering Paper No 79-1013 : 1432-1435

Goyal M R 1982 Soil Crust Vs. Seedling Emergence : Review. Agricultural mechanisation in Asia, Africa and Latin America Vol : 62-78.

Greacen E L, Walker G R and Cook P G 1987 Evaluation of the filter paper method for measuring soil water suction. Proceedings of International Conference on Measurement and Plant Water Status, Centennial of Utah State Unviersity, USA. July 6-10 1987 Vol 1 : 137-143.

Hadas A 1969 Effects of soil moisture stress on seed germination. Agronomy Journal Vol 61 : 325-327.

Hadas A and Russo D 1974 Water uptake by seeds as affected by water stress, capillary conductivity, and seed soil water contact I. Experimetnal study Agronomy Journal Vol 65 : 643-647.

Hadas A and Stibbe E 1977 Soil crusting and emergence of wheat seedlings. Agronomy Journal Vol 69 : 547-550.

Haller E 1984 Effect of the germinating seed environment on crop yields II. Effect of the water and air regime during germination on cereal yields. Experimental Agriculture Vol 20 : 235-243.

Hanks R J and Thorp F C 1956 Seedling emergence of wheat as related to soil moisture content, bulk density, oxygen diffusion rate and crust strength. Soil Science Society of American Proceedings Vol. 20, Pages : 307 to 310.

Hanks R J and Thorp F C 1957 Seedling emergence of wheat, grain sorghum and soybeans as influenced by soil crust strength and moisture content. Soil Science Society of American Proceedings Vol 21 : 357-359.

Hegarty T W and Royle S M 1978 Soil impedance as a factor reducing crop seedling emergence and its relation to soil conditions at sowing and to applied water. Journal of Applied Ecology Vol 15 : 897-904.

Hudspeth E B and Taylor H M 1961 Factors affecting seedling emergence of blackwell switchgrass. Agronomy Journal Vol 55 : 331-335.

Huges R M, Colman R L and Lovell J V 1984 Effects of temperature and moisture stress on germination and seedling growth of four tropical species. Australian Journal of Experimental Agriculture and Animal Husbandry Vol 24 : 396-402.

Huges T D, Stone J F, Wayne W Huffine and Gingrich J R 1966 Effect of soil bulk density and soil water pressure on emergence of grass seedlings. Agronomy Journal Vol 58 : 549-553.

Hunter J R and Erickson A E 1952 Relation of seed germination to soil moisture tension. Agronomy Journal Vol 44 : 107-109.

Kanemasu E T, Bark D L and Chin Choy E 1975 Effect of soil temperature on sorghum emergence. Plant and soil Vol 43 : 411-417.

Keeney D R and Nelson D W 1982 Nitrogen-Inorganic forms. In A L Page R H Miller and D R Keeney (eds.) Methods of soil analysis Part 2. Agronomy 9 : 643-698. American Society of Agronomy Madison Wisconsin USA.

Khalifa F M and Ong C K 1990 Effects of supra-optimal temperatures on germination of pearl millet (Pennisetum glaucum (L) R.B.R.) Hybrids. Unpublished.

Knudsen D, Peterson G A and Pratt P F 1982 Lithium, sodium and potassium. In A L Page R H Miller and D R Keeney (eds.) Methods of soil analysis Part 2. Agronomy 9 : 225-246. American Society of Agronomy Madison Wisconsin USA.

Livingston N J and De Jong E 1990 Matric and osmotic potential effects on seedling emergence at different temperatures. Agronomy Journal Vol. 82, Pages : 995-998.

Maiti R K, Raju P S and Peacock J M 1986 Effect of soil crusting on seedling emergence in sorghum genotypes. International Journal of Tropical Agriculture Vol IV(1) : 15-22.

Mali C V, Musande V G and Varade S B 1977 Influence of soil bulk density on seedling emergence of sorghum. Journal of Maharashtra Agricultural University Vol 2(3) : 193-195.

Mali C V and Varade S B 1981 Rice seedling emergence as influenced by soil moisture, bulk density and seedling depth. Journal of Indian Society of Soil Science Vol 29(4) : 433-436.

Martin J H, Taylor J W and Leukel R W 1935 Effect of soil temperature and depth of planting on the emergence and development of sorghum seedlings in the greenhouse. Journal of American Society of Agronomy Vol 27 : 660-665.

Mclean E O 1982 Soil pH and lime requirement in A L Page R H Miller and D R Keeney (eds.) Methods of soil analysis Part 2. Agronomy 9, American Society of Agronomy Madison Wisconsin USA : 199-224.

Nelson D W and Sommers L E 1982 Total carbon, organic carbon and organic matter. In A L Page R H Miller and D R Keeney (eds.), Methods of soil analysis Part 2. Agronomy 9. American Society of Agronomy Madison Wisconsin USA : 639-679.

Olsen S R and Sommers L E 1982 Phosphorous In A L Page R H Miller and D R Keeney (eds.), Methods of soil analysis Part 2. Agronomy 9. American Society of Agronomy Madison Wisconsin USA : 403-430.

Ong C K and Monteith J L 1985 Response of pearl millet to light and temperature. Field crops research. Vol 11 : 141-160.

Painuli D K and Abrol I P 1984. Emergence behavior of maize, cowpea and pearl millet (bajra) under different degrees of surface crusting and moisture conditions in the seed zone. Annals of Arid Zone Vol 23(3) : 189-198.

Parker J J Jr and Taylor H M 1965 Soil strength and seedling emergence relation I. Soil type, moisture tension, temperature and planting depth effects. Agronomy Journal Vol 57 : 289-291.

Peacock J M 1981 Response and tolerance of sorghum to temperature stress. 1981. Sorghum in eighties. Proceedings of the International Symposium on Sorghum Vol 1 : 143-159. 2-7 Nov 1981. ICRISAT Center Patancheru A P India.

Rao S C and Dao T H 1987 Soil water effects on low temperature seedling. Emergence of five Brassica Cultivars. Agronomy Journal Vol 79 : 517-519.

Reusche G A 1982 Germination and emergence of sorghum (Sorghum bicolor (L.) moench) genotypes under varying levels of soil water and osmotic potential. (En) Ph.D. Thesis Mississippi State University Mississippi USA. : 136.

Richards L A, Allison L E and Bornestein 1954 Diagnosis and improvement of saline and alkali soils. Oxford and Indian Book House Publishing Company New Delhi.

Smith R L and Hoveland C S 1986 Effects of temperature and water stress on seed germination and seedling depth on emergence of pearl millet and sorghum. In Agronomy Abstracts ASA Madison WI. : 94.

Smith R L, Hoveland C S and Hanna W W 1989 Water stress and temperature in relation to seed germination of pearl millet and sorghum. Agronomy Journal Vol 81 : 303-305.

Soman P, Peacock J M and Bidinger F R 1984 A field technique to screen seedling emergence of pearl millet and sorghum through soil crusts. Experimental Agriculture Vol 20 : 327-334.

Soman P and Peacock J M 1985 A laboratory technique to screen seedling emergence of sorghum and pearl millet at high soil temperature. Experimental Agriculture Vol 21 : 335-341.

Soman P Jayachandran R and Peacock J M 1992 Effect of soil crusting on seedling growth in contrasting sorghum lines. Experimental Agriculture Vol 28 : 49-55.

Stout D G, Simpson G M and Flotre D M 1980 Drought resistance of sorghum bicolour (L). Moench. 3. Seed germination under osmotic stress. Canadian Journal of Plant Science, Vol 60 : 13-24.

Thomas G W 1982 Exchangeable cations In A L Page R H Miller and D R Keeney (eds.) Methods of Soil Analysis Part 2. Agronomy 9. American Society of Agronomy Madison Wisconsin USA : 159-165.

Venkaiah K 1985 Effect of bulk density on growth and yield of groundnut. Indian Journal of Agronomy Vol 30(2) : 278-280.

Wilson G L and Eastin J D 1981 The plant and its environment. Sorghum in eighties. Proceedings of International Symposium on Sorghum Vol I : 101-119. 2-7 Nov 1991. ICRISAT Center Patancehru A P India.

Wilson G L, Raju P S and Peacock J M 1982 Effect of soil temperature on seedling emergence in sorghum. Indian Journal of Agricultural Science. Vol 52(12) : 848-851.

Wright D L, Blaser R E and Woodruff J M 1978 Seedling emergence as related to temperature and moisture tension. Agronomy Journal Vol 70 : 709-712.

APPENDICES

Appendix I

CALCULATION OF BULK DENSITY OF THE SOIL

By definition bulk density (ρb) of a soil is given as

$$\rho b = \frac{Mo}{Vt} \qquad (1)$$

where Mo = Mass of oven dry soil (g)

Vt = Total volume of the soil (cc)

Similarly by definition the gravimetric moisture content (θa) of the air dry soil

$$\theta a = \frac{Ma - Mo}{Mo} \qquad (2)$$

where Ma is mass of air-dry soil (g)

Upon rearrangement, equation (2) gives

$$Mo = \frac{Ma}{\theta a + 1} \qquad (3)$$

Equation (1) was also used to calculate the total volume (Vt) By rewriting, equation (1) gives

$$Vt = \frac{Mo}{\rho b} \qquad (4)$$

Appendix II

CALCULATION OF THE EQUIVALENT MASS OF OVEN DRY SOIL AND THE GRAVIMETRIC WATER CONTENT OF THE SATURATED SOIL

By definition, gravimetric water content (θa) of air-dry soil is

$$\theta a = \frac{Ma - Mo}{Mo} \qquad (1)$$

where Ma is the mass of air-dry soil (g) and

Mo is the mass of oven-dry soil (g)

Upon rearrangement, equation (1) gives

$$Mo = Ma/(1 + \theta a) \qquad (2)$$

Similarly by definition the gravimetric water content (θs) of the saturated soil is

$$\theta s = \frac{Ms - Mo}{Mo} \qquad (3)$$

which upon substitution of Mo from equation (2) yields

$$\theta s = \frac{Ms - Ma/(1 + \theta a)}{Ma/(1 + \theta a)}$$

$$\theta s = \frac{Ms}{Ma/(1 + \theta a)} - 1 \qquad (4)$$

In equation (4), Ms is the mass of the saturated soil.

Equation 4 was also used to calculate the water content of the soil in the pots at various stages of dryloss during the experiments. By rewriting θs as θ in which case equation 4 can be recasted as

$$\theta = \frac{Mw}{Ma/(1 + \theta a)} - 1 \qquad (5)$$

in which θ = water content g g^{-1}, and Mw is mass of wet soil

Appendix III

Calculation of Base Temperatures

a) Millet

The model for calculating base temperature is

$$T = b_o + b\, t^{-1} \qquad (1)$$

where

T is Temperature (°C)

b_o is Base temperature (°C)

b is Slope of the curve

t is Time for 50% of seeds to germinate

The equation has two unknown values b_o and b. From the straight line graph (Figure 5) two points are selected, using these the base temperature is calculated as follows :

$$T_1 = b_o + \frac{b}{t_1} \qquad (2)$$

$$15 = b_o + 0.03491\, b$$

$$T_2 = b_o + \frac{b}{t_2} \qquad (3)$$

$$30 = b_o + 0.09878\ b$$

Substract equation 3 from 2

$$30 - 15 = (b_o - b_o) + (0.09878b - 0.03491b)$$

$$15 = 0.06387\ b$$

$$\text{Therefore} \quad b = \frac{15}{0.06387} = 234.852 \qquad (4)$$

Substitute b value in equation 2 to get :

$$15 = b_o + 234.852 \times 0.03491$$

$$15 = b_o + 8.19$$

$$b_o = 15 - 8.19 = 6.81°C \qquad (5)$$

By substituting the values of b and b_o, Equation (1) is finally written as

$$T = 6.8 + 234.852\ t^{-1} \qquad (6)$$

b) Sorghum

$$T = b_o + b\, t^{-1} \quad (1)$$

The equation has two unknown values b_o and b. From the straight line graph (Figure 6) two points are selected, using these the base temperature is calculated as follows :

$$T_1 = b_o + \frac{b}{t_1} \quad (2)$$

$$15 = b_o + 0.02335\ b$$

$$T_2 = b_o + \frac{b}{t_2} \quad (3)$$

$$30 = b_o + 0.06652\ b$$

Substract equation 3 from 2

$$30 - 15 = (b_o - b_o) + (0.06652b - 0.02335b)$$

$$15 = 0.04318\ b$$

$$\text{Therefore}\quad b = \frac{15}{0.04318} = 347.342 \quad (4)$$

Substitute b value in equation 2 to get :

$$15 = b_0 + 347.342 \times 0.02335$$

$$15 = b_0 + 8.10$$

$$b_0 = 15 - 8.10 = 6.9°C \qquad (5)$$

By substituting the values of b and b_0, Equation (1) is finally written as

$$T = 6.9 + 347.342\ t^{-1} \qquad (6)$$

c) Groundnut

$$T = b_0 + b\ t^{-1} \qquad (1)$$

The equation has two unknown values b_0 and b. From the straight line graph (Figure 7) two points are selected, using these the base temperature is calculated as follows :

$$T_1 = b_0 + \frac{b}{t_1} \qquad (2)$$

$$15 = b_0 + 0.01544\ b$$

$$T_2 = b_o + \frac{b}{t_2} \qquad (3)$$

$$25 = b_o + 0.02768\ b$$

Substract equation 3 from 2

$$25 - 15 = (b_o - b_o) + (0.02768b - 0.01544b)$$

$$10 = 0.01224\ b$$

$$\text{Therefore} \quad b = \frac{10}{0.01224} = 816.99 \qquad (4)$$

Substitute b value in equation 2 to get :

$$15 = b_o + 816.99 \times 0.01544$$

$$15 = b_o + 12.61$$

$$b_o = 15 - 12.61 = 2.4°C \qquad (5)$$

By substituting the values of b and b_o, Equation (1) is finally written as

$$T = 2.4 + 816.99\ t^{-1} \qquad (6)$$

Appendix IV

Table 1 : Germination of pearl millet as influenced by bulk density at different moisture contents

Sl.No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)
1	0.0160	0.0	0.0153	0.0	0.0168	0.0
2	0.0188	0.0	0.0195	0.0	0.0175	0.0
3	0.0215	0.0	0.0208	0.0	0.0188	0.0
4	0.0239	0.0	0.0215	0.0	0.0194	0.0
5	0.0274	0.0	0.0241	0.0	0.0244	0.0
6	0.0304	0.0	0.0282	0.0	0.0297	0.0
7	0.0362	0.0	0.0323	0.0	0.0351	0.0
8	0.0445	25.0	0.0394	0.0	0.0486	0.0
9	0.0487	61.3	0.0466	22.0	0.0578	31.3
10	0.0585	74.3	0.0529	64.3	0.0682	57.0
11	0.0786	86.7	0.0771	75.3	0.0761	75.0
12	0.0964	89.0	0.0861	85.0	0.0872	84.7
13	0.1443	100.0	0.1229	95.3	0.1172	88.0
14	0.1843	98.0	0.1673	100.0	0.1319	91.3
15	0.1816	100.0	0.1735	98.7	0.1575	95.3
16	0.1874	94.7	0.1677	94.7	0.1667	86.3
SE (±)	0.001448	1.41	0.001448	1.41	0.001448	1.41
CD (0.05)	0.00287	2.8	0.00287	2.8	0.0016	2.8

Table 2 : Germination of pearl millet as influenced by bulk density at different matric suction

Sl. No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)
1	240.2	0.0	240.1	0.0	246.2	0.0
2	233.3	0.0	236.9	0.0	238.3	0.0
3	237.6	0.0	224.7	0.0	238.9	0.0
4	235.2	0.0	218.7	0.0	233.6	0.0
5	233.9	0.0	213.5	0.0	230.4	0.0
6	229.1	0.0	217.7	0.0	211.5	0.0
7	234.1	0.0	199.5	0.0	203.0	0.0
8	222.8	25.0	188.5	0.0	190.1	0.0
9	196.2	61.3	164.5	22.0	160.7	31.3
10	133.6	74.3	155.7	64.3	125.4	57.0
11	54.4	86.7	112.4	75.3	105.1	75.0
12	25.7	89.0	89.4	85.0	53.7	84.7
13	16.0	100.0	65.3	95.3	14.7	88.0
14	13.2	98.0	13.3	100.0	6.9	91.3
15	4.3	100.0	10.9	98.7	8.3	95.3
16	4.6	94.7	9.2	94.7	4.7	86.3
SE (±)	1.754	1.41	1.754	1.41	1.754	1.41
CD (0.05)	3.483	2.8	3.483	2.8	3.483	2.8

Table 3 : Germination of sorghum as influenced by bulk density at different moisture levels at 2.5 cm depth

Sl.No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)
1	0.0205	0.0	0.0242	0.0	0.0255	0.0
2	0.0247	0.0	0.0294	0.0	0.0339	0.0
3	0.0338	0.0	0.0375	0.0	0.0386	0.0
4	0.0447	0.0	0.0474	0.0	0.0479	0.0
5	0.0535	0.0	0.0547	0.0	0.0555	0.0
6	0.0655	20.7	0.0645	0.0	0.0676	0.0
7	0.0796	55.0	0.0753	19.0	0.0771	0.0
8	0.0896	71.3	0.0809	56.0	0.0893	11.0
9	0.0929	97.3	0.1189	76.7	0.0965	22.7
10	0.1057	96.7	0.1237	93.7	0.1069	77.0
11	0.1152	100.0	0.1344	96.7	0.1133	78.0
12	0.1221	100.0	0.1427	100.0	0.1224	96.7
13	0.1349	100.0	0.1565	100.0	0.1338	100.0
14	0.1487	97.3	0.1628	100.0	0.1579	100.0
15	0.1708	94.0	0.1751	95.7	0.1651	94.7
16	0.1766	94.0	0.1781	96.0	0.1741	94.7
SE (±)	0.000964	0.6032	0.000964	0.6032	0.00096	0.6032
CD (0.05)	0.001907	1.1979	0.001907	1.1979	0.001907	1.1979

Table 4 : Germination of sorghum as influenced by bulk density at different matric suction at 2.5 cm depth

Sl. No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)
1	232.3	0.0	232.8	0.0	234.4	0.0
2	226.7	0.0	228.1	0.0	230.9	0.0
3	218.9	0.0	223.4	0.0	226.3	0.0
4	214.4	0.0	213.9	0.0	204.9	0.0
5	196.2	0.0	202.0	0.0	197.2	0.0
6	160.3	20.7	192.5	0.0	185.7	0.0
7	147.9	55.0	154.5	19.0	167.8	0.0
8	132.7	71.3	116.4	56.0	135.6	11.0
9	107.3	97.3	85.1	76.7	116.8	22.7
10	85.1	96.7	48.7	93.7	87.5	77.0
11	50.8	100.0	42.7	96.7	54.0	78.0
12	25.3	100.0	14.9	100.0	36.5	96.7
13	15.2	100.0	11.8	100.0	13.3	100.0
14	7.9	97.3	6.8	100.0	8.7	100.0
15	5.3	94.0	4.6	95.7	5.1	94.7
16	4.6	94.0	4.5	96.0	3.7	94.7
SE (±)	1.271	0.6032	1.271	0.6032	1.271	0.6032
CD (0.05)	2.525	1.1979	2.525	1.1979	2.525	1.1979

Table 5 : Germination of sorghum as influenced by bulk density at different moisture levels at 5 cm depth

Sl.No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)
1	0.0298	0.0	0.0294	0.0	0.0318	0.0
2	0.0309	0.0	0.0325	0.0	0.0342	0.0
3	0.0333	0.0	0.0328	0.0	0.0343	0.0
4	0.0386	0.0	0.0382	0.0	0.0435	0.0
5	0.0413	0.0	0.0439	0.0	0.0444	0.0
6	0.0457	20.0	0.0479	0.0	0.0488	0.0
7	0.0530	53.0	0.0541	25.0	0.0562	8.8
8	0.0616	74.7	0.0639	53.7	0.0616	57.7
9	0.0762	91.0	0.0750	78.0	0.0689	82.6
10	0.0763	91.7	0.0788	81.0	0.0706	84.0
11	0.1346	98.0	0.1307	96.7	0.1115	95.0
12	0.1735	100.0	0.1651	100.0	0.1468	96.7
13	0.1743	100.0	0.1676	100.0	0.1501	97.0
14	0.1754	100.0	0.1713	100.0	0.1503	97.0
15	0.1723	97.0	0.1681	97.0	0.1456	97.7
16	0.1834	96.0	0.1799	95.0	0.1575	95.0
SE (±)	0.002162	0.916	0.002162	0.916	0.002162	0.916
CD (0.05)	0.00429	1.819	0.00429	1.819	0.00429	1.819

Table 6 : Germination of sorghum as influenced by bulk density at different matric suction at 5 cm depth

Sl. No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)
1	233.7	0.0	232.5	0.0	231.4	0.0
2	231.1	0.0	228.4	0.0	228.2	0.0
3	233.0	0.0	227.1	0.0	228.7	0.0
4	228.9	0.0	219.0	0.0	217.7	0.0
5	223.3	0.0	216.4	0.0	213.8	0.0
6	222.8	20.0	208.1	0.0	202.3	0.0
7	192.9	53.0	185.6	25.0	196.8	8.8
8	138.0	74.7	120.5	53.7	165.6	57.7
9	114.3	91.0	137.2	78.0	151.7	82.7
10	111.1	91.7	122.4	81.0	127.1	84.0
11	37.1	98.0	23.9	96.7	74.5	95.0
12	6.8	100.0	7.1	100.0	45.4	96.7
13	4.1	100.0	6.3	100.0	25.1	97.0
14	3.5	100.0	4.6	100.0	15.9	97.0
15	3.0	97.0	5.8	97.0	29.8	97.7
16	3.8	96.0	2.9	95.0	12.5	95.0
SE (±)	3.100	0.916	3.100	0.916	3.100	0.916
CD (0.05)	6.157	1.819	6.157	1.819	6.157	1.819

Table 7 : Germination of groundnut as influenced by bulk density at different moisture levels

Sl.No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)	Moisture content (gg^{-1})	Germination (%)
1	0.0383	0.0	0.0382	0.0	0.0353	0.0
2	0.0413	0.0	0.0419	0.0	0.0427	0.0
3	0.0431	0.0	0.0497	0.0	0.0578	0.0
4	0.0519	6.7	0.0584	13.3	0.0609	0.0
5	0.0531	26.7	0.0615	13.3	0.0685	0.0
6	0.0662	40.0	0.0676	33.3	0.0739	20.0
7	0.0764	60.0	0.0744	60.0	0.0843	33.3
8	0.0847	73.3	0.0842	80.0	0.0986	60.0
9	0.0963	73.3	0.0975	73.3	0.1055	73.3
10	0.1186	100.0	0.1178	100.0	0.1280	93.3
11	0.1291	100.0	0.1450	100.0	0.1342	100.0
12	0.1649	100.0	0.1548	100.0	0.1402	100.0
13	0.1776	100.0	0.1541	100.0	0.1444	100.0
14	0.1756	100.0	0.1540	100.0	0.1654	100.0
15	0.1826	100.0	0.1760	100.0	0.1682	100.0
16	0.1828	95.0	0.1766	94.7	0.1717	96.0
SE (±)	0.001081	3.1422	0.001081	3.142	0.001081	3.142
CD (0.05)	0.002147	6.240	0.002147	6.240	0.002147	6.240

Table 8 : Germination of groundnut as influenced by bulk density at different matric suctions

Sl. No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)	Matric suction (kPa)	Germination (%)
1	230.0	0.0	235.7	0.0	232.0	0.0
2	227.4	0.0	230.3	0.0	225.6	0.0
3	223.3	0.0	224.3	0.0	221.2	0.0
4	217.4	6.7	217.9	13.3	219.7	0.0
5	205.9	26.7	212.6	13.3	214.8	0.0
6	203.0	40.0	209.6	33.3	201.6	20.0
7	185.5	60.0	188.1	60.0	173.3	33.3
8	130.1	73.3	150.7	80.0	154.7	60.0
9	106.3	73.3	106.9	73.3	96.7	73.3
10	50.4	100.0	76.4	100.0	82.7	93.3
11	8.2	100.0	25.2	100.0	55.9	100.0
12	5.5	100.0	16.7	100.0	30.7	100.0
13	5.0	100.0	15.6	100.0	27.8	100.0
14	4.2	100.0	12.3	100.0	13.7	100.0
15	4.1	100.0	8.4	100.0	11.9	100.0
16	3.1	95.0	7.1	94.7	8.8	96.0
SE (±)	2.341	3.142	2.341	3.142	2.341	3.142
CD (0.05)	4.649	6.240	4.649	6.240	4.649	6.240

Table 9 : Effect of moisture content on emergence of pearl millet at different bulk densities

Sl. No.	Bulk density 1.45 g/cc		Bulk density 1.55 g/cc		Bulk density 1.65 g/cc	
	Moisture content (g/g)	Emergence (%)	Moisture content (g/g)	Emergence (%)	Moisture content (g/g)	Emergence (%)
1	0.0354 (0.0003)	0.0	0.0330 (0.0003)	0.0	0.0311 (0.0003)	0.0
2	0.0357 (0.0004)	0.0	0.0321 (0.0003)	0.0	0.0334 (0.0002)	0.0
3	0.0372 (0.0005)	0.0	0.0345 (0.0006)	0.0	0.0342 (0.0006)	0.0
4	0.0396 (0.0008)	0.0	0.0368 (0.0008)	0.0	0.0347 (0.0007)	0.0
5	0.0421 (0.0010)	0.0	0.0383 (0.0009)	0.0	0.0373 (0.0009)	0.0
6	0.0494 (0.0019)	0.0	0.0455 (0.0018)	0.0	0.0473 (0.0019)	0.0
7	0.0561 (0.0027)	0.0	0.0516 (0.0032)	1.3	0.0456 (0.0021)	0.0
8	0.0707 (0.0035)	2.7	0.0651 (0.0030)	4.0	0.0616 (0.0027)	0.0
9	0.0697 (0.0044)	4.0	0.0690 (0.0038)	4.0	0.0690 (0.0031)	2.6
10	0.0859 (0.0053)	4.0	0.0783 (0.0055)	8.1	0.0783 (0.0038)	2.6
11	0.1015 (0.0057)	11.9	0.0928 (0.0060)	18.7	0.0897 (0.0054)	2.7
12	0.1257 (0.0127)	45.4	0.1205 (0.0136)	48.0	0.1090 (0.0092)	29.3
13	0.1485 (0.0122)	81.3	0.1416 (0.0118)	61.4	0.1254 (0.0105)	42.6
14	0.1599 (0.0090)	83.4	0.1554 (0.0083)	69.4	0.1380 (0.0065)	56.0
15	0.1687 (0.0030)	93.3	0.1630 (0.0028)	84.0	0.1436 (0.0029)	57.4
16	0.1754 (0.0026)	61.4	0.1661 (0.0030)	65.4	0.1483 (0.0026)	63.3
SE (±)		2.884		2.884		2.884
CD (0.05)		5.728		5.728		5.728

Figures in brackets are standard errors of the mean

Table 10 : Emergence of pearl millet as influenced by bulk density at different matric suction levels

Sl. No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Matric suction (kPa)	Emergence (%)	Matric suction (kPa)	Emergence (%)	Matric suction (kPa)	Emergence (%)
1	248.0	0.0	253.4	0.0	253.2	0.0
2	245.4	0.0	250.0	0.0	250.1	0.0
3	243.2	0.0	248.8	0.0	249.8	0.0
4	236.0	0.0	243.2	0.0	242.6	0.0
5	234.3	0.0	237.3	0.0	234.1	0.0
6	231.9	0.0	226.8	0.0	222.6	0.0
7	227.9	0.0	222.6	1.3	213.9	0.0
8	195.3	2.7	215.9	4.0	203.6	0.0
9	121.6	4.0	204.0	4.0	194.7	2.7
10	104.2	4.0	191.3	8.0	192.0	2.7
11	104.4	12.0	152.8	18.7	134.1	2.7
12	95.7	45.3	114.2	48.0	114.5	29.3
13	87.3	81.3	105.5	61.3	104.3	42.7
14	26.3	83.3	45.4	69.3	67.8	56.0
15	16.0	93.3	17.7	84.0	8.2	57.3
16	7.7	61.3	4.7	65.3	6.1	63.3
SE (±)	1.116	2.884	1.116	2.884	1.116	2.884
CD (0.05)	2.216	5.728	2.216	5.728	2.216	5.728

Table 11 : Effect of moisture content on emergence of sorghum at different bulk densities

Sl. No.	Bulk density 1.45 g/cc		Bulk density 1.55 g/cc		Bulk density 1.65 g/cc	
	Moisture content (g/g)	Emergence (%)	Moisture content (g/g)	Emergence (%)	Moisture content (g/g)	Emergence (%)
1	0.0372 (0.0005)	0.0	0.0393 (0.0005)	0.0	0.0375 (0.0006)	0.0
2	0.0369 (0.0007)	0.0	0.0353 (0.0008)	0.0	0.0390 (0.0008)	0.0
3	0.0392 (0.0009)	0.0	0.0398 (0.0009)	0.0	0.0393 (0.0008)	0.0
4	0.0415 (0.0014)	0.0	0.0421 (0.0013)	0.0	0.0400 (0.0014)	0.0
5	0.0449 (0.0017)	0.0	0.0474 (0.0018)	0.0	0.0444 (0.0017)	0.0
6	0.0488 (0.0023)	0.0	0.0508 (0.0024)	0.0	0.0489 (0.0022)	0.0
7	0.0484 (0.0028)	8.0	0.0514 (0.0027)	4.0	0.0479 (0.0024)	4.0
8	0.0560 (0.0037)	26.7	0.0555 (0.0033)	9.3	0.0512 (0.0030)	18.7
9	0.0545 (0.0041)	30.7	0.0576 (0.0039)	14.7	0.0468 (0.0034)	22.7
10	0.0759 (0.0083)	38.7	0.0796 (0.0100)	22.7	0.0748 (0.0065)	14.7
11	0.0853 (0.0102)	61.3	0.0903 (0.0086)	32.0	0.0836 (0.0081)	22.7
12	0.1004 (0.0158)	84.0	0.1026 (0.0136)	33.3	0.1031 (0.0107)	16.0
13	0.1243 (0.0240)	61.3	0.1253 (0.0172)	54.7	0.1189 (0.0164)	12.0
14	0.1401 (0.0244)	61.3	0.1337 (0.0198)	40.0	0.1321 (0.0151)	18.7
15	0.1477 (0.0196)	73.3	0.1407 (0.0176)	78.7	0.1383 (0.0115)	21.3
16	0.1714 (0.0140)	53.3	0.1615 (0.0105)	58.7	0.1542 (0.0111)	17.3
SE (±)		1.033		1.033		1.033
CD (0.05)		2.051		2.051		2.051

Figures in brackets are standard errors of the mean

Table 12 : Emergence of sorghum as influenced by bulk density at different matric suction levels

Sl. No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Matric suction (kPa)	Emergence (%)	Matric suction (kPa)	Emergence (%)	Matric suction (kPa)	Emergence (%)
1	245.7	0.0	246.4	0.0	247.7	0.0
2	241.0	0.0	243.6	0.0	245.3	0.0
3	238.2	0.0	242.2	0.0	236.6	0.0
4	239.1	0.0	238.9	0.0	237.8	0.0
5	225.3	0.0	223.4	0.0	226.6	0.0
6	224.7	0.0	220.8	0.0	215.9	0.0
7	221.0	8.0	220.9	4.0	195.3	4.0
8	214.1	26.7	212.7	9.3	137.5	18.7
9	213.2	30.7	210.3	14.7	123.2	22.7
10	195.2	38.7	147.2	22.7	105.8	14.7
11	165.1	61.3	112.9	32.0	96.8	22.7
12	126.3	84.0	106.7	33.3	53.8	16.0
13	106.1	61.3	75.0	54.7	45.4	12.0
14	78.9	61.3	68.6	40.0	27.7	18.7
15	16.4	73.3	36.8	78.7	11.7	21.3
16	6.5	53.3	4.9	58.7	5.8	17.3
SE ($\pm$)	1.262	1.033	1.262	1.033	1.262	1.033
CD (0.05)	2.506	2.051	2.506	2.051	2.506	2.051

Table 13 : Effect of moisture content on emergence of groundnut at different bulk densities

Sl. No.	Bulk density 1.45 g/cc		Bulk density 1.55 g/cc		Bulk density 1.65 g/cc	
	Moisture content (g/g)	Emergence (%)	Moisture content (g/g)	Emergence (%)	Moisture content (g/g)	Emergence (%)
1	0.0319 (0.0005)	0.0	0.0338 (0.0006)	0.0	0.0289 (0.0003)	0.0
2	0.0329 (0.0005)	0.0	0.0336 (0.0007)	0.0	0.0310 (0.0005)	0.0
3	0.0336 (0.0006)	0.0	0.0361 (0.0007)	0.0	0.0306 (0.0007)	0.0
4	0.0373 (0.0009)	0.0	0.0372 (0.0010)	0.0	0.0338 (0.0009)	0.0
5	0.0403 (0.0012)	0.0	0.0442 (0.0014)	0.0	0.0392 (0.0012)	0.0
6	0.0375 (0.0012)	0.0	0.0429 (0.0016)	0.0	0.0444 (0.0015)	0.0
7	0.0439 (0.0025)	20.0	0.0437 (0.0019)	0.0	0.0422 (0.0016)	0.0
8	0.0509 (0.0033)	33.3	0.0510 (0.0042)	20.0	0.0409 (0.0025)	0.0
9	0.0515 (0.0037)	46.7	0.0587 (0.0061)	33.3	0.0455 (0.0029)	13.3
10	0.0542 (0.0068)	53.3	0.0543 (0.0062)	53.3	0.0522 (0.0059)	46.7
11	0.0670 (0.0093)	53.3	0.0693 (0.0060)	46.7	0.0606 (0.0081)	33.3
12	0.0956 (0.0086)	73.3	0.0597 (0.0087)	53.3	0.0617 (0.0070)	60.0
13	0.1254 (0.0118)	60.0	0.0931 (0.0135)	46.7	0.0877 (0.0092)	66.7
14	0.1401 (0.0176)	86.7	0.1228 (0.0154)	66.7	0.1004 (0.0144)	80.0
15	0.1481 (0.0155)	73.3	0.1293 (0.0108)	80.0	0.1270 (0.0123)	73.3
16	0.1571 (0.0070)	86.7	0.1566 (0.0072)	40.0	0.1245 (0.0058)	33.3
SE (±)		4.636		4.636		4.636
CD (0.05)		9.207		9.207		9.207

Figures in brackets are standard errors of the mean

Table 14 : Emergence of groundnut as influenced by bulk density at different matric suction levels

Sl. No.	Bulk density 1.45 g cm^{-3}		Bulk density 1.55 g cm^{-3}		Bulk density 1.65 g cm^{-3}	
	Matric suction (kPa)	Emergence (%)	Matric suction (kPa)	Emergence (%)	Matric suction (kPa)	Emergence (%)
1	231.9	0.0	233.9	0.0	232.3	0.0
2	230.6	0.0	232.7	0.0	228.7	0.0
3	229.2	0.0	227.0	0.0	221.8	0.0
4	222.4	0.0	220.7	0.0	221.1	0.0
5	221.8	0.0	213.2	0.0	214.3	0.0
6	223.2	0.0	207.6	0.0	204.9	0.0
7	212.8	20.0	200.5	0.0	196.3	0.0
8	213.6	33.3	197.5	20.0	183.8	0.0
9	211.4	46.7	186.2	33.3	163.1	13.3
10	201.8	53.3	151.5	53.3	126.6	46.7
11	195.3	53.3	133.9	46.7	105.2	33.3
12	157.7	73.3	117.2	53.3	95.4	60.0
13	104.7	60.0	105.5	46.7	65.9	66.7
14	94.7	86.7	56.5	66.7	55.1	80.0
15	44.4	73.3	33.7	80.0	17.4	73.3
16	35.2	86.7	7.7	40.0	9.1	33.3
SE (±)	1.580	4.636	1.580	4.636	1.580	4.636
CD (0.05)	3.138	9.207	3.138	9.207	3.138	9.207