EFFECT OF SEEDBED CONDITIONS, PLANTING RAIN, AND SEED VIGOUR ON ESTABLISHMENT OF MAIZE

STANLEY GODFREY NOAH

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ABSTRACT

A study was conducted to evaluate the effect of (a) moisture content at cultivation on the resulting seedbed conditions, (b) seedbed conditions to establishment of low and high vigour maize seeds, (c) planting rain on the establishment of maize seedlings, and (d) interaction between seedbed, planting rain and seed vigour on establishment. Two mainplots, each with 5 subplots, were laid out. Water equivalent to 50 mm rain was applied uniformly at each of the two mainplots on the same day. A day after application of 50 mm equivalent of water, ploughing was undertaken sequentially, a subplot every day, for 5 days resulting in 5 seedbed conditions (SBC) giving treatments SBC 1-5. High and low vigour maize seeds were planted. Planting rain equivalent to either 40 mm or 15 mm was applied to one of the two mainplots.

Bulk density (φ_b), aggregate size distribution and penetration resistance (PR) were employed to evaluate the effect of soil moisture content at cultivation on the resulting SBC, and its effect on the establishment of maize. Results were that, φ_b was significantly ($P<0.05$) higher than in the virgin land only in the 40 mm planting rain treatments. Aggregate sizes $\leq$ 0.6 mm, 2 mm, 4 mm, 6.3 mm, 11 mm, 20 mm and >20 mm were categorised. Aggregates $\leq$ 6.3 mm in diameter were 72 and 63% (in low and high planting rain treatments respectively) in SBC 3 and were higher than in other SBCs. PR at 4 mm depth was lowest ($\leq$ 1 MPa) in SBC 3 in both mainplots.

Overall emergence was low for low vigour seeds compared to high vigour seeds. Best emergence was observed in SBC 3 which had lowest PR and high percentage of aggregates ≤ 6.3 mm diameter in both planting rain treatments. This was followed by SBC 4 in 40 mm planting rain treatments. Poor emergence was observed in SBC 1 and 5 in 15 mm planting rain plots and in SBC 1, 2 and 5 in 40 mm planting rain plots. Seedbeds with poor emergence had high PR values (>2 MPa) and high percentage of large aggregates (> 6.3 mm diameter).

Significant ($P<0.05$) differences in shoot height and in number of leaves per plant were only observed when vigour categories were compared. The interaction between seedbed, planting rain and seed vigour had no significant effect on establishment of maize.

Conclusions from this study are that: for ploughing to result into a SBC which favours crop establishment in the study area, it should be undertaken 3 and at most 4 days after high rains (50 mm). High planting rain (40 mm) resulted in best emergence in a seedbed ploughed 3-4 days after watering at a gravimetric soil moisture content of 23 to 20%. Seeds should be tested for vigour before being marketed or planted to reduce poor establishment due to low vigour seeds. Further research should be carried out in other areas to quantify the contribution of the studied factors on crop establishment so as to provide appropriate intervention measures.

DECLARATION

I, STANLEY GODFREY NOAH, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my original work and has not been submitted in any other University for a degree award.

Date....30.7.1997.... Signature ....

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ANOVA= analysis of variance

CRBD = completely randomized block design

DAP = days after planting

DAW = days after watering

GDP = gross domestic product

ISTA = International Seed Testing Association

LSD = least significant difference

P = probability level

PR = penetration resistance

SAT = semi-arid tropics

SBC = seedbed condition

SUA = Sokoine University of Agriculture

TANSEED = Tanzania Seed Company

USDA = United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

The Tanzania economy, as in many developing countries, is dependent mainly on agriculture, most of which is at subsistence level (Ellis, 1982). Approximately, 90% of the population is engaged directly or indirectly in agricultural activities which provide 50% of the GDP and more than 85% of foreign exchange earnings (Ministry of Agriculture, 1983). The population increase rate in Tanzania is 2.8% (Bureau of Statistics, 1992). Food crop production to feed the growing population is faced with a number of limitations including drought, fertility, pest and diseases, and poor establishment (Mascanrenhas, 1982; Weaich *et al.*, 1992; Weaich, 1993).

Maize (*Zea mays* L.) is a widely grown crop with an annual worldwide production of 468 Mt which rank only behind wheat (593 Mt) and rice (511 Mt) in cereal production (USDA, 1990). Maize crop yields in many subtropical and tropical regions are substantially lower than those obtained in temperate areas (Fisher and Palmer, 1983). Poor seedling emergence has been widely identified as one of the major constraints to higher maize production (Buckle, 1969; Done *et al.*, 1985).

Poor crop establishment is a widespread problem in the semi-arid tropics (SAT) (Arndt, 1965; Done *et al.*, 1985; Lal, 1974). The success of crop establishment has a substantial impact on the final crop yield (Wood, 1987). Crop establishment is largely determined by seedbed conditions which can be characterized by factors such as soil temperature, strength, aeration and matric potential (Collis-George, 1987), and seed-soil water contact (Hadas and Russo, 1974).

Emergence may be limited by poor germination due to high temperatures (Wilson *et al.*, 1982; O'Neil and Diaby, 1982) or water stress (Gurmu and Naylor, 1991) or seed source (Nirval *et al.*, 1990). Poor establishment results into sub-optimal plant stands which reduce yield and profitability. The information pertaining to establishment of maize particularly in relation to seedbed condition, planting rain and seed vigour is important to enhance crop establishment.

Literature on crop establishment, particularly for maize in Tanzania, when considering seed vigour, planting rain and moisture content at cultivation is scant. Reported studies on maize include that by Rwehumbiza (1987) which all the same considered only water stress as a factor limiting growth and grain yield after establishment. Resource poor farmers cultivate their crop fields at soil moisture contents ranging from very wet to very dry, depending on the availability of labour, time and the size of the field. The subsequent seedbed condition and establishment problems following cultivation at unfavourable moisture content are not known. The absence of vigour tests for the certified seeds, and planting of farmers seeds which are not tested, allow the sowing of seeds with a range of vigour whose establishment under different seedbed conditions and variable planting rain has not been studied. The erratic nature of the rainfall in SAT and the insufficiency of tillage facilities result in land preparation at various moisture conditions. The resulting seedbed conditions may affect germination and/or emergence of maize.

The present study was carried to investigate the effect of the above factors on establishment of maize. Results from this study will provide that basis for instituting proper intervention measures.

The objectives of this study were therefore:

1. To determine the effect of matric potential (moisture content) at cultivation on seedbed condition.
2. To investigate the effect of seedbed condition on establishment of low and high vigour maize seeds.
3. To investigate the effect of planting rain on the establishment of maize seedlings.
4. To study the interaction between seedbed, seed vigour and the amount of planting rain on establishment.

CHAPTER TWO

LITERATURE REVIEW

Crop establishment is a sequential process of germination. emergence and seedling growth involving a number of individual factors that all interact in a complex way to determine the final field establishment (Hooke, 1987; Wood, 1987). According to Hooke (1987), crop establishment is the foundation on which all other factors affecting final crop yield are dependent. Seed quality and the environment of the germinating seed and emerging seedlings are the main factors affecting establishment.

Each seed contains an embryonic plant complete with rudimentary shoot, leaves, root and a supply of food. After these embryonic plants reach a certain stage, their development is suspended before they leave the parent plant. The embryonic plant will remain dormant until situations become satisfactory to initiate growth. It will then establish itself as a separate plant much resembling its parent plant (Trouse, 1971).

Suitable environmental conditions for crop establishment include: (a) a moisture regime that favours germination and subsequent growth of roots and coleoptile, (b) a temperature regime in the top 100 mm of soil, that is close to the optimal for germination and growth, and (c) either a soil structure with spaces large enough for roots and the coleoptiles to enter or, a structure with smaller pores but which is mechanically weak enough for the roots and coleoptile to deform it (Collis-George, 1987). Crop failure due to poor establishment is a result of many factors acting singly or interacting. The factors affecting crop establishment are discussed briefly in this chapter.

2.1 Seed germination

Germination is defined as a protrusion of part of the embryo from the seedcoat. There is no general rule as to which portion of the embryo protrude first After "growth" is initiated in the seed, germination does occur. and this growth may result from cell elongation due to imbibition or from cell formation or from combination of both mechanisms (Trouse, 1971).

Viable seeds usually start to germinate when provided with appropriate conditions of moisture, temperature, oxygen and in some cases light (ISTA, 1985). The germination of seeds consist of at least three stages (Hadas and Russo, 1974):

(i) Imbibition, during which seeds absorb water, the tissues swell and the seedcoat becomes soft and elastic

(ii) Development or pause during which enzymatic transformation and initiation of meristematic activities take place. Some of the enzymes are believed to be responsible for weakening the seed coat and allowing the root tip to burst through,

(iii) Growth, which begins with radicle elongation and emergence through the seed coat.

Growth requires energy for cell initiation, division and elongation and for development of the required thrust to pierce the seedcoat (Trouse, 1971). Respiration is a process capable of supplying this energy. In respiration, oxygen and complex food molecules of the seed are utilized to produce energy, carbon dioxide and other simple compounds for release. Depending on whether the cotyledons of the seed are carried above the soil (epigeal germination) or stays in the soil within the seedcoat (hypogeal germination), the nature and extent of establishment problems encountered in each case are quite different.

Hypogeal germination occurs with the majority of monocotyledons, for example cereals like maize (Bekendam and Grob, 1979). After the embryo has emerged from the seed coat, germination is considered complete. The radicle end of the hypocotyl and the plumule end of a hypogeal seedling must continue to develop for emergence (Trouse, 1971). Both centres of growth are no longer protected by the seed coat and come into the actual contact with the soil environment. There is little elongation of the hypocotyl and the endosperm remain within the seedcoat in the soil (Bekendam and Grob, 1979). The radicle, as it is now unprotected by the seed coat, needs to force the soil aside to develop its rudimentary root system to form a base from which to develop the upward thrust needed by the plumule to break through the soil surface (Trouse, 1971). The epicotyl in some monocots (e.g. *Asparagus*) elongates commonly forming an arch and pulls the young shoot above the soil surface.

Emergence of the seedling depends upon many factors, like; the quantity of the reserve food supply, the efficiency of food conversion to energy, the area of plant in contact with the soil, the resistance by the soil to penetrate, the lateral pressure which may limit the hypocotyl bending, and the ability of the soil environment to meet the physiological requirement for growth. The individual fine seedling has little lifting power and so may fail to emerge from a crusted soil (Sinclair, 1985) or from soil with high strength (Weaich *et al.*, 1992) leading to poor establishment

A complete stand can be ensured only by a complete and fast germination (Hadas and Russo, 1974). This depends on many factors including the type of germination, seed vigour and viability, and seedbed condition.

2.2 Seed factors

One of the greatest hazard in agriculture is sowing seeds which have no capacity to provide abundant seedlings of the required crop cultivar. A good quality seed is: Genetically true to species or cultivar; has a capacity for high germination; free from disease and insects; and free from other crop seeds, weed seeds and inert and extraneous materials (Hartmann and Kester, 1968). Low seed quality can lead to poor emergence resulting to loss of production due to resowing costs.

Seed testing has been developed to minimize the risk of crop loss or failure due to poor quality seedlot by assessing the quality of the seed before it is sown (ISTA, 1985), where the major attributes of seed quality are high levels of purity, viability and vigour

2.2.1 Seed purity

Seed purity is the percentage composition by weight of the pure seed. Pure seed refers to the species stated and all botanical varieties and cultivars of that species. It excludes other seeds or any inert matter which include seed units and all other matters and structures not defined as pure seed (ISTA, 1985). Low purity seed lots are likely to lead to poor establishment because of germination of off type plants and due to no germination of inert matter sown (Rwehumbiza, 1994).

2.2.2 Seed viability

Seed viability (McDonald, 1994), is the ability of the seed to be alive and elicit some levels of gemination and field performance. It is represented by the germination percentage which expresses the number of seedlings which can be produced by a given number of seeds under optimum conditions. Seed germination or viability tests have been used to predict field performance. The test (Isely, 1958; McDonald, 1994) does not simulate the actual field condition so that it might often fail to predict field performance. This is because the test is run under optimum conditions, a situation rarely possible under field condition. But better quality seeds should be sown to ensure good field performance. Blacket (1987), suggests two germination checks should be undertaken, one after harvest and prior to grading, and the second prior to planting.

Under non-optimum conditions where moisture and temperature vary, viability of the seed decreases with time Roberts (1973), developed a viability equation which can be used to predict viability period (time for a seed to lose 50% viability) of various seeds as follows: $\log p = K_v - C_1 m - C_2 t$, where p is the mean viability period, m is seed moisture content (percent on fresh weight basis), t is the temperature in degrees Celsius, and K_v, C_1 and C_2 are constants. An example of uses of this equation is shown in Table 2.1 from constants developed for wheat seeds (Roberts and Ellis, 1977).

2.2.3 Seed vigour

Seed vigour, the ability of a seed to perform and produce a normal plant in the field is also an aspect of field performance (McDonald, 1994). According to Perry (1972), viable seeds in some seedlots as substantiated by laboratory gemination tests

Table 2.1. Prediction of mean viability (time to lose 50% viability) of wheat seed. (Based on formula by Roberts, 1973)

Seed moisture %	Temperature °C	Mean viability Period
17.5	50	4 8 days
	25	84.5 days
	0	4 1 years
12	50	18.7 days
	25	332 days
	0	16.2 years
9	50	39.4 days
	25	1 9 years
	0	34.1 years

can in some cases show considerable differences in field emergence. This means that, it is not always a good advice to predict field emergence from viability test results. This inconsistent correlation between laboratory viability test and field emergence has lead to the development of the concept of seed vigour. According to Perry (1975), from a practical viewpoint, the most important effects of vigour are those on seedling emergence and growth in the field. However, the expression of these effects is often dependent on the prevailing environment at, and immediately after sowing, and two seedlots of similar performance under favourable conditions may be dissimilar when conditions are adverse. Seed vigour is an important factor for field establishment, that is, proper plant populations (Mwageni, 1978). Parent plant nutrition, genetic constitution, stage of maturity at harvest, mechanical integrity, pathogens, ageing in storage and seed size affect this quality attribute. Of these aspects, seed size appeared to be the most important in wheat (Naylor and Munro, 1992).

2.2.3.1 Vigour differences between seedlots

According to Perry (1975), several causes of vigour differences among seedlots have been identified and they fall naturally into two groups: (i) intrinsic variations due to genotype, and (ii) variations induced by the external environment interacting upon the genotype.

The maximum possible vigour is determined by the genotype, but it may be modified by the environment during maturation on the mother plant, during harvest, and during handling and storage These environmental factors acting either separately or together result in seed immaturity, variations in seed size, mechanical damage, deterioration in storage (seed ageing), or invasion by seedbone fungi. Although various mechanisms cause loss of vigour, they all affect the performance of the seed when it germinates.

2.2.3.2 Seed deterioration

Roberts (1986) noted that, as soon as seed matures on the mother plant, it begins to deteriorate at a rate which is dependent on the environmental conditions. Many symptoms of seed deterioration exist, most of which appear to be a consequence of loss of membrane integrity, changes in the molecular structure of nucleic acids, and reduction in enzyme activity. These changes lead to reduced rates of germination and seedling growth, decreased ability to germinate under stressful conditions, increased probability of the development of morphologically abnormal seedlings, and lower percentage field emergence. According to Roberts (1986), this syndrome is described as poor vigour. As deterioration continues, the cellular system from which these symptoms arise become so disorganised that the seed is incapable to germinate. This ultimate catastrophe is described as viability loss or seed death.

Various theories have been proposed by various workers as being responsible for seed deterioration (Roos, 1986),

(i) Depletion of food reserves: This is the earliest idea which argued that, seed deterioration occurred because food reserve in the embryo were gradually depleted. However, Barton (1961) observed that, examination of just a few nonviable seeds convinces one that there is still plenty of reserve food left.

(ii) Alteration of chemical composition. This theory suggests that, food reserves of the seed may be altered chemically so that they were no longer useful as energy sources. This is supported by the concept of Crocker and Groves (1915) that seed death result from "coagulation of protein". Roos (1986) noted that, lipids undergo oxidation and an increase in fat acidity is associated with deterioration. Proteins also undergo changes during storage as seen by (a) decreased solubility,

(b) partial breakdown, (c) decreased digestibility, and many more other compounds may undergo changes during seed storage (Barton, 1961).

(iii) Membrane alteration. This is a more popular theory of seed deterioration due to alteration or loss in integrity of the various seed membranes. Membranes are comprised of a lipid bilayer containing both extrinsic and intrinsic protein. This bilayer act as a barrier to the general diffusion of materials into and out of the cells (Clarkson, 1984). A loss of integrity of the plasmalemma and tonoplast in aged seeds is implied from the observation that more substances leak into the imbibition medium from such seeds than from unaged seeds (Parrish and Leopold, 1978). Leakage from deteriorated seeds may be respirable substrates from some species, whereas others lose more amino acids than sugars. Increased leakage of some metabolites may in some cases lead to damaging effect by encouraging growth of microorganisms on the seed surface (Roos, 1986).

(iv) Enzyme alteration. Respiration and enzyme activity are important in the preservation of vigour. It has been shown that deteriorated seed has decreased enzyme activities (Stewart and Bewley, 1980). Some enzymes activities which have been proved to be decreased by seed ageing include; DNA polymerase, peptidases, dehydrogenases and DNA lipase.

(v) Genetic damage. In this theory, it is pointed out that, genetic mutations occur in the deteriorating seed which result in loss of the ability of the cell to duplicate and divide and thus grow. Deteriorating seed produce an abundance of chromosomal aberrations as seen in root tips of germinating seeds (Roos, 1982).

Seed ageing has come to be recognised as a major cause of reduced seed vigour in many species. Ageing involves the accumulation of degenerative changes until eventually the ability to germinate is lost. Maximum seed quality occurs at physiological maturity, after which vigour and viability decline both before and after harvest (Delouche, 1980; Powell and Mathews, 1984). The existence of vigour differences among crop seed lots is a natural consequence of the way populations of seed die (Mathews, 1980). Aged (low vigour) seeds are more sensitive to stress factors than fresh (high vigour) seeds during germination (Gurmu and Naylor, 1991). Low seed vigour is one of the main problems that limit grain millet production because of its effect in crop establishment (Mwageni, 1978).

Harrington (1972) developed two rules which relate the effects of seed moisture and storage temperature to the rate of seed ageing. In the first rule, for each 1% of increase in seed moisture, the life span of the seed is halved. This rule is valid between 5 and 14% seed moisture. The second rule states that, for each 5°C increase in temperature, life-span of the seed is halved (between 0-50°C). This is an indication that, temperature and moisture content influence the rate of seed deterioration. At low storage moisture content and temperature, cytoplasms of various seeds, maize being inclusive, is in glassy state which slows down all the cellular activities responsible for seed deterioration. Temperature and moisture in seed storage stores therefore, need to be controlled not to influence seed deterioration which can lead to loss of vigour, and thereafter cause poor establishment.

There is a growing body of evidence that crop establishment problems in this country are linked to seeds obtained from TANSEED due to natural ageing in storage (Rwehumbiza, pers. comm.). Natural ageing in storage for the seeds from this seed company, may be due to uncontrolled temperature and relative humidity in the seed stores and especially at Morogoro where during a greater part of the year, both parameters are very high.

The assessment of seed vigour is therefore an important component of seed quality control programmes. Vigour tests have been designed and used to provide information about the expected level of field performance of seed lots which cannot be obtained from germination test (Perry, 1975).

There are various vigour testing methods including: Hiltner, Cold, Electrical conductivity, accelerated ageing, Controlled deterioration, Topographical tetrazolium, and Aleurone tetrazolium tests (McDonald, 1994; Perry, 1981). Of these tests, Accelerated Ageing and Controlled Deterioration are more popular (Mathews, 1980). There is no vigour test for certified seeds in Tanzania. Thus, low vigour seeds find their way to farmers leading to establishment problems.

2.3 Seedbed condition

Tillage in crop production is performed in order to create suitable soil conditions for crop growth. It is associated with seedbed preparation and weed control (Lal, 1978).

Tillage affect germination, seedling emergence, growth and yield of a crop through its influence on the soil physical, chemical and biological properties. In general, tillage modifies soil structure which governs retention and movement of water, aeration and degree of compaction (Mayona, 1988). Common methods of seedbed preparation are based on experience. Tillage operation is undertaken at various soil moisture regimes (this determines the outcome of the tillage operation) which can have an impact on germination or emergence of seedlings. Tillage is undertaken at various moisture contents because: (i) In some areas, tillage facilities like tractors, are insufficient, such that, ploughing will be undertaken whenever a tractor is available, irrespective of field moisture condition, and (ii) small holder farmers may have a large area to till, and especially with a hand hoe, it may take time to complete tillage operations before the onset of rains.

When the soil is tilled at unfavourable moisture condition, on drying, surface crusting may develop. McIntyre (1958), described a likely sequence of events for crust formation under field conditions as (a) breakdown of soil aggregates by slaking or by raindrop impact, (b) movement of fine particles into the upper few centimetres of soil, (c) compaction of the soil surface to form a thin film which restricts further entry of water and movement of fine particles, (d) deposition of fine particles on the surface from soil suspensions. Crust strength reduce emergence of large variety of crops (Richards, 1953; Townend, *et al.*, unpublished). Parker and Taylor (1965) found for instance, that, as penetration resistance (PR) of a sandy loam soil increased to 1.8 MPa, emergence of sorghum seedlings ceased. When the soil is tilled under dry condition, the consistency may be hard, producing large clods (Brady, 1984), for the emerging shoot to lift or penetrate, especially with low rains. If tilled when wet the soil may puddle with compaction, and as it dries, it may develop high strength enough to impede seedling emergence.

Compacted soils can lead to an increase in soil strength high enough to affect crop establishment through poor root or shoot growth. Several explanations have been given on poor root growth on compacted zones, including (i) inadequate aeration within or below the compacted zone (Gill and Miller, 1956), (ii) small pore spaces within the compacted zone for root caps to enter (Meredith and Patrick, 1961), (iii) increase in bulk density to exceed some critical values (Veihmeyer, 1948), (iv) as roots penetrate clods or horizons that lack wide pores, soil may resist the deformation and growth may be prevented if soil strength is sufficiently high (Barley *et al.*, 1965).

Increase in soil strength in compacted soils have been associated to increase in bulk density. According to Williams and Shykewich (1971), bulk density is some function of tension and its resultant influence on tension is superimposed on the tension-strength relationship. Taylor and Gardner (1963) found an increase in soil strength as bulk density increased. The bulk density-soil strength relationship has an influence on root penetration. Taylor and Gardner (1963) reported a decrease in root penetration by 30% at a soil PR of 1 MPa and bulk density of 1.55 g cm^{-3}, and a 70% decrease in root penetration at a soil PR of 2 MPa and a bulk density of 1.75 g cm^{-3}. Barley *et al.* (1965) observed a reduction in root penetration and root length in high bulk density of 1.7 g cm^{-3} and a suction of 0.07 MPa which was attributed to increase in soil strength. Some values of resistance-bulk density relationship at which growth of some crop seedlings ceased have been observed. These include, (i) cotton radicles grown in sandy loam at a bulk density of 1.55-1.85 g cm^{-3} and a soil PR of 3.4 MPa (Taylor and Gardner, 1963), (ii) Pear and wheat radicles in loam soils at a bulk density of 1.5-1.7 g cm^{-3} and a soil PR of 3.6 MPa (Barley *et al.*, 1965).

Increase in bulk density also depends on soil moisture content. Camp and Gill (1969) found an increase in bulk density as soil moisture content decreased. For instance, in clay soil, bulk density varied from 1.54 -1.73 g cm^{-3} within a gravimetric soil moisture range of 28-0%, in silt soil, bulk density varied from 1.45-1.50 g cm^{-3} within a gravimetric soil moisture content of 28% to about 0%. Therefore, the magnitude of soil bulk density effects upon root penetration depends upon soil moisture content.

2.3.1 Mechanisms for seedling emergence through crusts

Taylor (1971), outlined a number of possible reactions that occur when an elongating shoot encounters the crusted soil surface layer as; (i) the shoot may strike a high-strength portion of the crust and be diverted horizontally until the shoot encounters a crack through which it can emerge, (ii) the shoot may happen to grow upward into a surface crack large enough to accommodate the emerging plant parts, (iii) the seedling may strike a crust of high enough strength to slow the rate of emergence, but of low enough strength to allow almost all seedlings to finally penetrate (Parker and Taylor, 1965), (iv) the seedling may strike a crust of sufficient strength and horizontal extent to preclude emergence, and (v) a group of seedlings may jointly exert thrust on a small area of the crust. Edwards (1966) found that the maximum thrust of one, two and three cotton seedlings acting on a single force transducer was 3.8 N, 5.8 N and 8.5 N respectively. The author concluded that a satisfactory stand of cotton could be obtained in crusted clay with groups of three seeds planted in a hill as opposed to single plants which could not exert sufficient trust to emerge.

The size of the aggregates produced during seedbed preparation may have an impact on germination and subsequent emergence of the seed, first through seed-soil water contact for imbibition and second the easiness or difficulty for the emerging shoot to push through. A seedbed composed of soil aggregates <5 mm geometric mean diameter, provide the optimum combination of seed-soil contact and hydraulic conductivity (Larson, 1964). A study by Schneider and Gupta (1985) found that, aggregate sizes 0.5 and 11.1 mm respectively, affect maize emergence. The delayed maize emergence in large aggregates (11.1 mm), was probably due to poor seed-soil contact. While with the 0.5 mm aggregates, the soil consolidated to form a massive clod during water sorption and desorption. Fifty-six percent (56%) of seeds planted in cores containing these aggregates (0.5 mm) germinated but shoots failed to penetrate the massive clods to emerge. Schneider and Gupta (1985) also observed that aggregate size distributions with a diameter of 1 to 6.8 mm provide conditions (good soil-maize seed contact) favourable for early emergence.

2.3.2 Influence of soil moisture matric potential on germination

Soil-water matric potential controls hydraulic conductivity, effective stress, aeration and seed-soil liquid contact area in addition to determining the water potential of a soil system. According to Collis-George and Hector (1966), matric potential can be regarded as of major consequence in seed germination because of three possible causal factors. (1) the direct effect of energy on water uptake by the seed, (2) the indirect effect of controlling wetted area of contact between soil and seed, and (3) the indirect mechanical effect of controlling soil strength. Studies by Hunter and Erickson (1952); Williams and Shykewich (1971), clearly indicate that both the rate of germination and total germination are significantly reduced with increasing soil moisture stress. For instance, germination of a rape is reduced with decreasing matric potential as from -0.06 MPa to -1.08 MPa, and beyond produced a dramatic reduction in both rate and total germination. In their study, Williams and Shykewich (1971) found that, total germination was reduced from 100% to about 85% at 1.08 MPa, and to 25% at a suction of 1.51 MPa.

For each seed species there is a soil matric potential value below which no germination will occur, this is called critical matric potential. For legumes (for example, chickpeas and peas) water potential, at least down to -0.06 MPa does not impair either imbibition or germination time (Hadas and Russo, 1974), -0.7 MPa for rice and -1.25 MPa for maize (Hillel, 1972). According to Hadas and Stibble (1973), once a seed attains a critical value of hydration (about 72 to 75% of dry weight for chickpeas seed) it will proceed towards fast germination.

The effect of soil moisture content at which the seedbed is prepared on seedbed condition (soil structure, aggregate size distribution, soil strength, bulk density) and subsequently on establishment is thus worthy studying.

2.4 Planting rain

Crop production in Tanzania is predominantly rainfed. The success or failure of the cultivated crops in India, like in Tanzania, depends on the pattern of the rains (Nirval *et al.*, 1995). The rainfall varies in amount, duration and in intensity, decreasing yield due to such errant behaviour. In Morogoro region for instance, weather records (Directorate of Meteorology, 1995) indicate that, planting rains, which are expected in mid February, vary from no rains to high amounts on a mean value of 15 days as from 10 - 25 february (that is, 32 mm in 1990, no rains in 1991, 1.8 mm in 1992, 89.8 mm in 1993, 11 mm in 1994, and 19.4 mm in 1995).

Low planting rains may lead to a matric potential at which seeds will not imbibe enough water for germination. Low water availability can affect germination by delaying initiation of germination, by increasing the time period between the first seed to germinate and the last, or by decreasing final germination percentage (Evans and Stickler, 1961). For instance sorghum seeds germination decreased progressively with increasing moisture tension as from 94% at 0 MPa to 92% (0 5 MPa), 79% (1 MPa), and 67% (1.5 MPa). For maize seeds, soil matric potential should not be less than -1 25 MPa (Naylor and Gurmu, 1990). With low rainfall and large soil aggregates, seed-soil water contact will be poor (Schneider and Gupta, 1985), leading to low imbibition and hence poor or delayed germination and emergence.

High amounts of planting rains, may cause the aggregates to collapse, reducing the air pores as well as oxygen level, which will have an effect on germination and establishment of the crop. For instance, Grable and Siemer (1968) observed that, poor emergence in soils at or near saturation appears to have been due to reduced oxygen diffusion as a result of thick water films around the seed. One of the problems associated with seeds planted under high water content or submerged condition is the necessity to ensure or provide aerobic conditions (Naylor, 1991).

Collapsing of the aggregates may also increase the bulk density which measures the amount of pore spaces in the soil. It has been observed that, high bulk densities inhibit the emergence of seedlings (Flocker and Nelson, 1962). High bulk densities may offer increased mechanical resistance to root penetration and also influence the rate of diffusion of oxygen into the soil pores, and root respiration is directly related to a continuing and adequate supply of this gas (Tisdale and Nelson, 1971). According to Letey *et al.* (1961), increase in soil oxygen level from 4% to 15% increased plant height of snapdragon plants from 10 cm to 18 cm. High rainfall amount may also lead to soil crust formation. Robbins *et al.* (1972), outlined the mechanisms involved in the crust formation as: (i) mechanical destruction of aggregates and simultaneous compaction of the surface by raindrop impact, (ii) washing of fine particles into the interaggregate spaces, and (iii) rupture of soil aggregates by air entrapment during wetting. As the soil dries, the crusting which results may be of high magnitude to affect seedling emergence. Taylor *et al.* (1966) found that, at penetrometer resistance of 0.7 MPa and above, germination of cereals including maize decreased rapidly and ceased at 1.5 MPa.

2.5 Summary

Crop establishment is a foundation on which all other factors affecting final crop yield are dependent (Hooke, 1987). Seed quality and the environment of the germinating seed and the emerging seedlings are the main factors affecting crop establishment.

Seed vigour, the ability of the seeds to perform and produce a normal plant in the field (McDonald, 1994), is a quality aspect which can be used as an indicator of the expected crop establishment in the field. High vigour seeds, contain seed attributes which favour stand establishment under unfavourable field conditions (Isely, 1958). As seed matures on the mother plant it begins to deteriorate at a rate which is dependent on the environmental conditions (Roberts, 1986). As seed deteriorate its vigour decreases which also reduce its ability to perform better under field condition. Seeds in storage are also prone to vigour deterioration due to natural ageing of the seeds. Vigour test allows vigour discrimination among seedlots, that, only high vigour seeds will be planted for successful crop establishment. There is no vigour test for the certified seeds in Tanzania, thus low vigour seeds find their way to farmers leading to establishment problems whose extent has not been evaluated.

Tillage in SAT is undertaken under various soil moisture conditions due to insufficiency of tillage facilities and inability of the small holder farmers to complete tillage before the onset of rains. The effect of undertaking tillage under various moisture contents on the resulting seedbed condition (soil structure, aggregate size distribution, soil strength, bulk density), and subsequently on crop establishment is worthy studying.

Crop production in Tanzania is rainfed which varies in amount, duration and intensity to affect yield of the cultivated crops. Low planting rain can lead to poor seed - soil water contact (Schneider and Gupta, 1985), leading to poor imbibition and hence poor or delayed germination and emergence. High planting rain as well may cause the aggregates to collapse reducing the air pores as well as oxygen level which will affect establishment of the crop. Previous studies in Tanzania considered the effect of water stress on growth and grain yield of maize after supporting the crop with moisture to establishment level (Rwehumbiza, 1987). Due to the errant rainfall behaviour of rainfed crop areas, where the planting rains can also be the emergence rains, the amount of planting rain can also be an establishment problem in the semi arid tropics, and hence, is a subject worth studying.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Experimental site

The study was conducted at Sokoine University of Agriculture (SUA) farm during a dry season. The area is located at 6°29'S and 37°9'E, and at an elevation of 526m above sea level The site lies within the Usagaran system of the Basement complex. The soils of the area are believed to have developed from colluvial material derived from Uluguru mountains of the same complex, but also in situ decomposition of the original rocks (Kasseba *et al.*, 1972). The rainfall is bimodal (short rains in November-January and long rains in March-May), with average annual rainfall of 837 mm.

The study area was under fallow for about 20 years. Some physical and chemical characteristics (Table 3.1) of the surface soil on the experimental site were reported by Shayo-Ngowi and Mtakwa (1994). The soils have been classified as Typic Acrorthox (Kasseba *et al.*, 1972).

Table 3.1 Summary of the analytical data of the soils of the site (soil sampled from 0-10 cm depth)

pH in 1 2.5 H_2O	O.C %	Exchangeable cations in me/100g soil				Total CEC me/100g	%BS	Particle size Distribution in %		
		Ca	Na	Mg	K			sand	clay	silt (0.002-0.02)
5.8	3 9	3 2	0 5	1 3	1 4	8 5	75	62	8 0	30

SOURCE Shayo-Ngowi and Mtakwa (1994)

3.1.2 Seeds

Improved maize seeds (staha variety) obtained from Tanzania Seed Company (TANSEED) were used as a test crop in this study The seeds were tested for germination and vigour. Low vigour and high vigour seeds were used in this study (Table 3.2)

Table 3.1 Summary of the analytical data of the soils of the site (soil sampled from 0-10 cm depth)

pH in 1:2.5 H_2O	O.C %	Exchangeable cations in me/100g soil				Total CEC me/100g	%BS	Particle size Distribution in %		
		Ca	Na	Mg	K			sand	clay	silt (0.002-0.02)
5.8	3.9	3.2	0.5	1.3	1.4	8.5	75	62	8.0	30

SOURCE: Shayo-Ngowi and Mtakwa (1994)

3.1.2 Seeds

Improved maize seeds (staha variety) obtained from Tanzania Seed Company (TANSEED) were used as a test crop in this study. The seeds were tested for germination and vigour. Low vigour and high vigour seeds were used in this study (Table 3.2).

Table 3.2 Initial characteristics of the seeds used in the study

Seed category	Germination of the seeds			Remarks
	%	Method	Seed mc(%)	
High vigour	97	Standard germination test (ISTA, 1985)	11.25	Fresh seeds obtained from TANSEED stored under room temperature
Low vigour	69	Standard germination test (ISTA, 1985)	11.98	Seeds subjected to artificial ageing for two days at 21% seed mc and 45°C temperature using controlled deterioration method (Mathew, 1980)

3.2 METHODS

3.2.1 Land preparation and field layout

Land preparation began by clearing the bushes and cutting of trees. The stumps were dug out and removed from the site. Two main plots each measuring 3.5 m x 17.5 m, were laid out and each had a 0.3 m band around. Each mainplot was sub-divided into five subplots of size 3.5 m x 3.5 m also with a 0.3 m band around.

3.2.2 Treatments

Treatments were 5 levels of seedbed conditions, 2 levels of planting rain and 2 levels of seed vigour. The study was designed to investigate the effect ploughing at different seedbed conditions (that is, soil moisture content at cultivation), amount of planting rain and seed vigour on the establishment of maize.

3.2.3 Application of water before ploughing

Before ploughing, all the plots were watered with an equivalent of 50 mm equivalent of rain. The water was applied using watering cans discharging water in fine droplets.

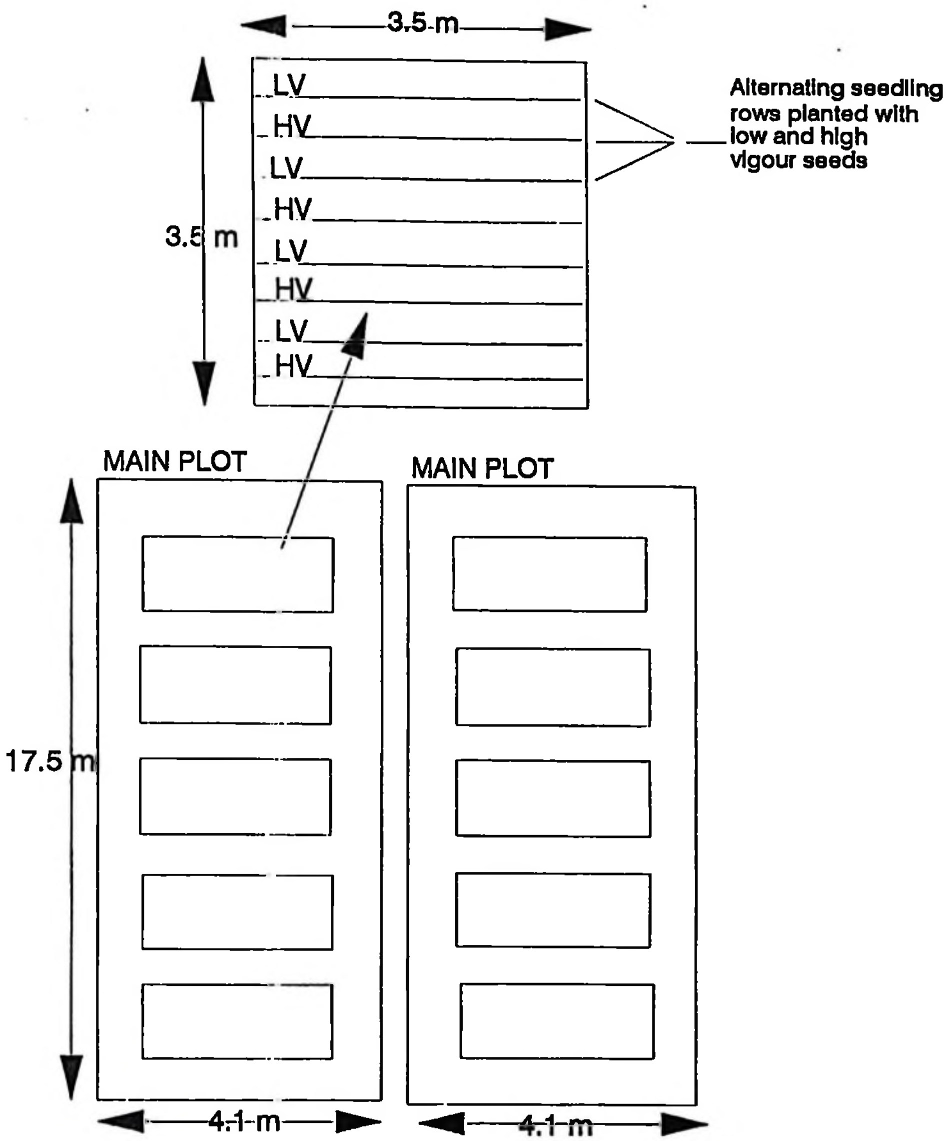


Figure 3.1 Layout of the experimental plots
LV = low vigour, HV = high vigour

3.2.4 Ploughing at different soil moisture conditions

A day after application of a uniform water, the subplots were sequentially ploughed after every day using a handhoe, that is, subplot 1 was tilled after one day, subplot 2 after two days, upto the 5th subplot ploughed after five days. Tilling of the soil on different days allowed ploughing of the subplots under varying soil moisture condition due to drying.

3.2.5 Seeding

Seeding was at a spacing of 40 cm x 30 cm achieving 10 seeds per line. Seeding was done on the same day after the fifth plot was tilled. Planting holes were dug using a hand hoe. Seeds were planted one per hill and at a depth of 5 cm followed by firming. Seeds from two vigour categories (low and high vigour) were sown in each subplot in separate alternating lines, which were replicated four times (Fig. 3.1).

3.2.6 Planting rain

All plots were watered immediately after cultivation of the 5th subplot. Two levels of water, equivalent to 15 mm (920 litres of water) and 40 mm (2450 litres) were applied, one in either of the mainplots to simulate low planting rain and high planting rain respectively. Size of the plots is given in section 3.2.1. Watering cans discharging water in fine droplets, were used to apply water on the plots.

3.2.7 Statistical design

The field study was a factorial experiment in a split - split plot design (Gomez and Gomez, 1984). Planting rain was the main plot at two levels, seedbed condition as subplots at five levels, and seed vigour at two levels as sub-subplot, with four replications. The model of the design was:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \tau_k + (\alpha\beta)_{ij} + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\alpha\beta\tau)_{ijk}$$

Where: Y_{ijk} = Response (extent of emergence)

μ = overall mean

α_i = treatment effect for i^{th} factor α (planting rain)

β_j=treatment effect for j^{th} factor β (seedbed condition)

τ_k = treatment effect for k^{th} factor τ (seed vigour)

$\alpha\beta_{ij}$ = effect due to i^{th} factor α and j^{th} factor β

$\alpha\tau_{ik}$ = effect due to i^{th} factor α and k^{th} factor τ

$\beta\tau_{jk}$ = effect due to j^{th} factor β and k^{th} factor τ

$\alpha\beta\tau_{ijk}$ =effect due to i^{th}, j^{th} and k^{th} factors α, β, and τ

3.2.8 Soil physical parameters studied

3.2.8.1 Matric suction (Ψm) and gravimetric soil water content determination

Three soil samples were taken from each subplot immediately after ploughing (at a depth of 0-10 cm) for the estimation of soil matric suction. Matric suction was determined in the laboratory using the filter paper technique (Deka *et al.*, 1995).

The method involves placing a filter paper in contact with the soil sample in a moisture box. A moisture box was half filled with soil and then a filter paper was placed in before toping up the other half with soil material. The cap of the moisture box was then replaced. Since equilibrium can only proceed smoothly if there are no sudden changes in temperature of the soil after sampling, the moisture boxes were then transferred into an insulated box to allow moisture equilibration between the soil and the filter paper for four days. Calibrated Whatman no. 42 filter papers were used. Using tweezers, the filter papers were removed from the moisture boxes. Tweezers were used to avoid touching of the filter papers by hand which could have elevated moisture content of the filter papers. Soil particles adhering to the filter paper were brushed off using a small fine brush. The filter papers were immediately transferred in a pre-weighed moisture boxes replacing the caps immediately and weighed. The process of transferring filter papers from the moisture boxes to weighing was done in a wooden box lined with moistened cloths to avoid loss of moisture from the filter papers. After oven-drying for overnight at 105°C while the bottles' caps were removed, the bottles were allowed to cool in a desiccator and weighed with and without the filter papers. Gravimetric water content of the filter papers was then determined. Using the equation $ln\ (\Psi m) = a + bm$ (Deka *et al.*, 1995), where, Ψm = matric suction, a and b are constants, and m water content, gravimetric water content of the filter papers were converted to matric suctions. Three separate soil samples were also collected (using moisture boxes) for gravimetric soil moisture content estimation at cultivation. The samples were weighed in the laboratory before ovendrying at 105° C for 24 hours. The moisture boxes were cooled in a desiccator then weighed with and without the soil material. The gravimetric soil moisture content was then estimated from:

$$W_1 - W_2 / W_2 - W_3$$

Where, ' W_1 ' is the weight moist soil + moisture box, ' W_2 ' is the weight of dry soil + moisture box, and ' W_3 ' is the weight of empty moisture box.

3.2.8.2 Aggregate size distribution

Samples for aggregate size distribution were collected two days after the application of planting rain. Each subplot was provided with an area, not sown with seeds, for soil sample collection. Soil samples were collected from each sub-plot by removing the top 10 cm of soil with a handhoe into a bucket. A dry sieving method (Njos and Singh, 1980) was used to separate aggregates into different size groups.

Sieves of mesh size 20 mm, 11 mm, 6.3 mm, 4 mm, 2 mm and 0.6 mm were used in this exercise. Soil samples were air dried in the laboratory and passed through the biggest sieve first. Particles which did not pass through the sieve were weighed. Soil sample that passed through the first sieve was sieved through the second sieve. Particles that passed through the second sieve were sieved through the third, fourth, and fifth sieves respectively and finally through the finest sieve. Amounts left over in each sieve were weighed accordingly Aggregate categories were expressed by calculating each fraction as a percentage of the total sample. Thus, seven aggregate size categories were obtained.

3.2.8.3 Bulk density determination

Bulk density of the virgin land in the study area was estimated through core sampling, using 5.6 cm x 4 cm cores. The exercise was repeated two days after applying the planting rains. The delaying in sampling for bulk density estimation was to allow soil drying for two days after application of the planting rain so as to avoid compressing the wet soil during core sampling. Compression of the soil would have introduced errors in bulk density.

3.2.8.4 Soil strength determination

Core sampling (three samples in each subplot) at a depth of 0-4 cm, was done everyday, for four consecutive days, after application of planting rain for soil strength determination using needle penetrometer resistance (PR). The needle used for testing soil penetration resistance had a diameter of 2 mm and at an angle of 15° with a relieved shaft. It was held by a 1412 g weight, counterbalanced by a mass of 736 g. The motor was run by a lead - acid battery.

The needle was held in position by tightened set screw. The counterweight was allowed to hang freely. This acted as a plumb line to give verticality. A digital balance (top loading type with a capacity of 4100 g) was placed on the board (Fig. 3.2) a core with soil sample on it and re-zeroed. The core was covered with a polythene paper (to reduce water loss) with three small holes for needle penetration, held in position by a rubber band. The needle was lined with a respective hole and the motor was started. Before running a proper test, a dry run was performed on a separate sample to calibrate the rate of release (that is, depth per time in seconds). The releasing rate was found to be 10 mm per minute. After the needle had just penetrated the soil, the displayed weight from the balance was recorded every after 36 seconds upto 3 minutes 36 seconds. A total of 6 readings were taken equivalent to a penetration depth of 36 mm. The motor was then stopped and the core was held with one hand while the needle weight was lifted with the other, allowing the string to slip over the pulley.

Needle PR was calculated from:

$$PR = 4\ F / \Pi\ d^2$$

Where ' **F** ' is the force required to penetrate the core and ' **d** ' is the diameter of the needle core.

3.2.9 Plant growth parameters studied

3.2.9.1 Germination and seedling emergence

Each day after planting, emergence counts were taken and recorded. Seeds which had not emerged after 21 days were excavated and observed for germination in the field.

3.2.9.2 Shoot system parameters

Maize seedlings were uprooted after 21 days. Shoot height for the emerged seedlings was determined using a ruler. The criterion for shoot height was by measuring the height from the first node through the tip of the longest leaf.

3.2.9.3 Number of leaves

The number of leaves per seedling was counted at harvest 21 days after planting.

3.2.10 Data analysis

Analysis of variance was run using Statgraphics computer software for the observed parameters (bulk density (bd), moisture (mc), seedling emergence, shoot height and plant leaf number). Completely Randomized Block Design (CRBD) 2 factor factorial was employed for bd and mc while, CRBD 3 factor factorial, split - split plot design was employed for maize emergence results, shoot height and number of leaves. The Duncan's Multiple Range Test was used for comparison of the means and test for differences among the parameters of rain, seed vigour, seedbed condition, emergence scores, shoot height and number of leaves.

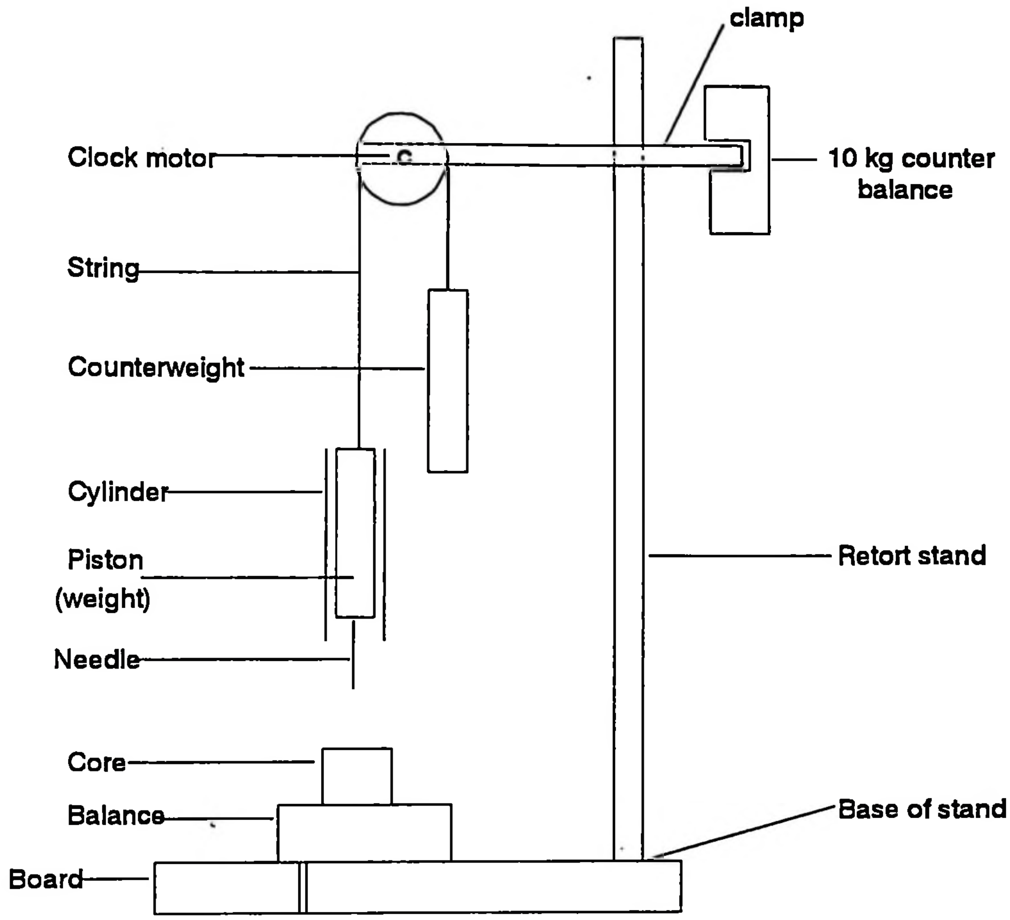


Figure 3.2 Schematic diagram of the needle penetrometer assembly

CHAPTER FOUR

RESULTS

4.1 Matric suction (Ψ_m) and moisture content at ploughing

Soil matric suction increased with an increase in the number of days ploughing was undertaken after the application of 50 mm equivalent of rain (Table 4.1). Gravimetric soil moisture content varied from 51% on day one to 17 % on day five.

There was no significant (P<0.05) difference in Ψ_m between the 1st and 2nd day of ploughing after application of water (DAW). Between the 3rd, 4th and 5th ploughing days Ψ_m, differed significantly and also differed significantly from Ψ_m of the first two days.

4.2 Effect of soil moisture content at ploughing and amount of planting rain on seedbed condition

Three soil parameters, bulk density, aggregate size distribution and soil penetration resistance, were employed to evaluate the effect of soil moisture content at ploughing and the amount of planting rain on the resulting seedbed conditions.

4.2.1 Bulk density (φ_b)

Average values of bulk density after ploughing followed by an application of variable amounts of planting rains are presented in Table 4.2. In plots that received water equivalent to 40 mm of planting rain, φ_b differed significantly (P<0.05) with φ_b in the virgin land (Table 4.3). However, application of water equivalent to 15 mm of planting rain did not significantly (P<0.05) affect φ_b (Table 4.3) compared to φ_b of the virgin land. Within planting rains, φ_b values between seedbed condition (SBC) 1 and 5 differed significantly in the 15 mm planting rain plots. Between planting rains φ_b did not differ significantly (P<0.05)

4.2.2 Aggregate size distribution

Cumulative aggregate percentages of different sizes were plotted against their corresponding aggregate size classes. Aggregate size distribution as was affected by the treatments is shown in Fig. 4.1. The trend of aggregate size distribution is described basing on aggregates of size 6 3 mm as a general cut-off point for large (>6.3mm) and small (≤ 6.3 mm), aggregates respectively. 50% of the aggregates in plots given 15 mm equivalent of rain, were in ≤ 6.3 mm size for all the plots except SBC 3 which had almost 50% of its aggregates falling within a size range of ≤ 2 mm and about 75% of its aggregates ≤ 6.3 mm. Aggregates of size > 6.3 mm in the 15 mm planting rain treatment were about 60% in SBC 1 and 4, ≥ 50% in SBC 2 and 5, and about 25% in SBC 3. The percentage of aggregates of size ≤ 0.6 mm were ≥ 35% in SBC 3 and higher than in other SBC in this level of planting rain.

Fifty percent of aggregates in plots given 40 mm equivalent of rain, were in the size range of ≤ 6.3 mm for plots ploughed 3 and 4 DAW, and within 6.3 mm to 11 mm size range for other plots. Distribution of aggregate sizes > 6.3 mm in this planting rain treatment was ≥ 50% in SBC 1, 2 and 5, ≥ 40% in SBC 4 and <40 in SBC 3. Small aggregates (≤ 0.6 mm) were about 30% in SBC 3 and were higher in this plot than in all other SBC.

4.2.3 Soil penetration resistance (PR)

PR characteristics of the top soil for different treatments are shown on Fig. 4.2. PR showed an increasing trend with passage of days after planting (DAP). In all treatments, average PR values were <1 MPa a day or two after planting except for SBC 1 and 2 in plots given 40 mm equivalent of rain. PR increased 3 DAP and was generally > 1 MPa in all the planting rain treatments except in SBC 1 and 4 in plots given 15 mm equivalent of planting rain and SBC 1, 2 and 3 respectively in plots given 40 mm equivalent of planting rain which had values of 2 MPa. PR 4 DAP was generally 〉 2 MPa for both planting rain plots, and on average 〉 3 MPa in SBC 1 plots given 15 mm equivalent of rain. In both planting rain treatments, SBC 3 showed lower (slightly > 1 MPa) values of PR.

Table 4.1. Soil matric suction at cultivation

Ploughing day following an application of 50 mm equivalent of rain (seedbed condition)	Gravimetric soil moisture content at cultivation (%)	Matric suction (kPa)
1	51.24	1.45 (± 0.024) d
2	29.07	3.28 (± 0.078) d
3	22.77	14.34 (± 0.39)c
4	20.38	30.25 (± 1 23) b
5	17.27	47.03 (± 0.62) a

Means carrying the same letter are not significantly different at $P<0.05$.

Table 4.2. Average soil bulk density (φ_b) g/cm^3 after ploughing at different soil moisture conditions followed by an application of equivalent either 15 or 40 mm planting rain

Ploughing day after application of 50 mm equivalent of rain (seedbed condition)	Gravimetric soil moisture content at cultivation (%)	15 mm planting rain plots	40 mm planting rain plots
1	51.24	1.25±0.066a	1.22 ± 0.034 a
2	29.07	1.05±0.068ab	1.24 ± 0.072 a
3	22.77	1.15±0.120ab	1.17 ± 0.037 a
4	20.38	1.44±0.098ab	1.14 ± 0.043 a
5	17.27	0.97±0.041 b	1.14 ± 0.106 a
LSD (P<0.05)		0.2695	0.2045

Within each column means carrying the same letter are not significantly different

Table 4.3. The overall effect of variable planting rain on bulk density

Plot	Bulk density (g/cm^3)
Virgin land	1.011 (± 0.063) a
Ploughed, 15 mm planting rain	1.110 (± 0.041) ab
Ploughed, 40 mm planting rain	1.182 (± 0.027) b
LSD (P<0.05)	0.1359

Means denoted by the same letter are not significantly different.

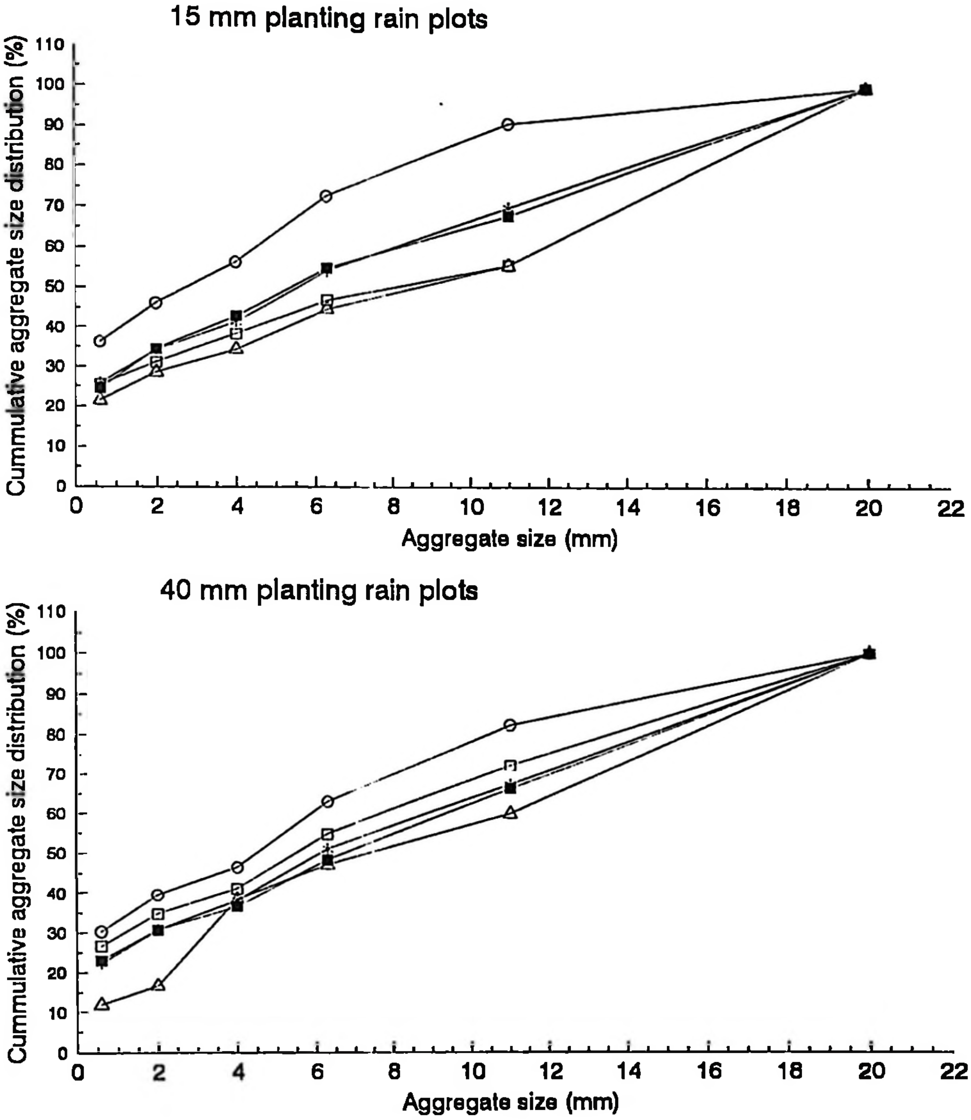


Figure 4.1. Effect of soil moisture content at ploughing and planting rain on aggregate size distribution. Each curve represents a seedbed condition. (Seedbed refers to number of days passed before ploughing following an application of 50 mm equivalent of rain; markers are, seedbeds 1 (△), 2 (∗), 3 (○), 4 (□), and 5 (■))

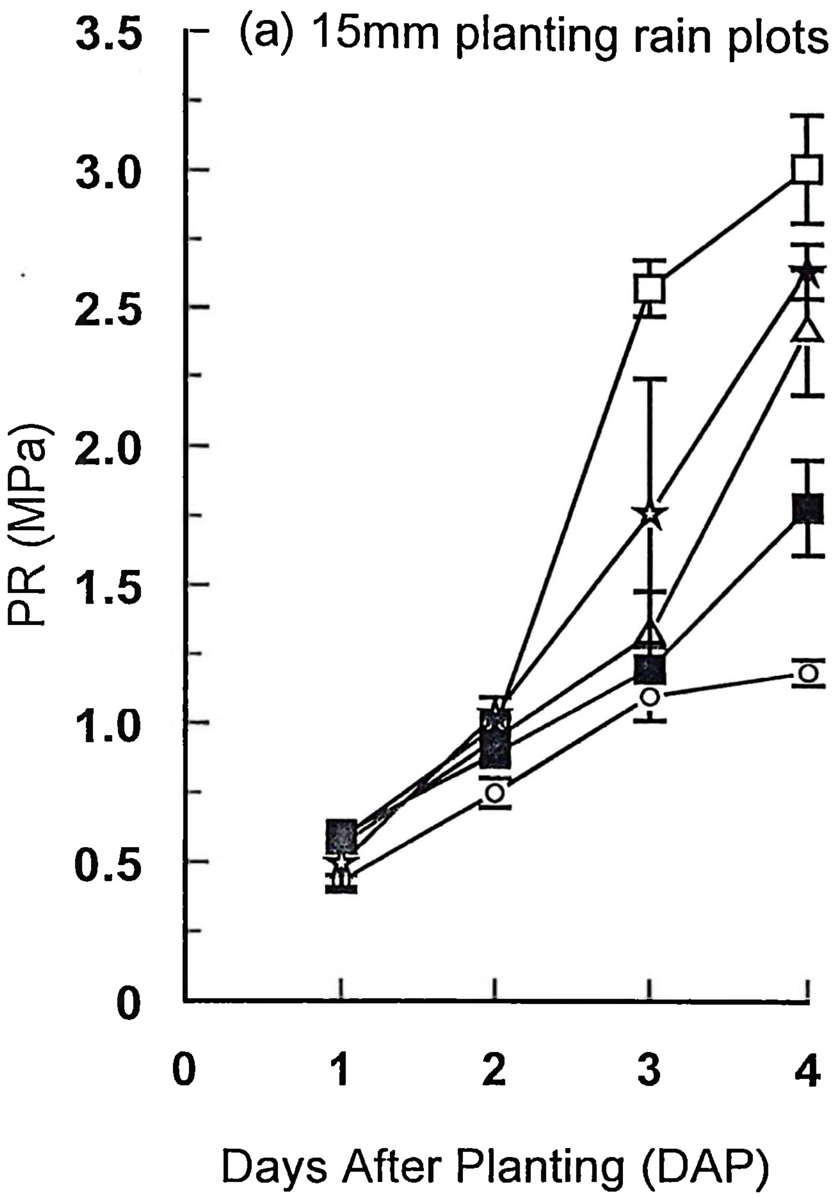
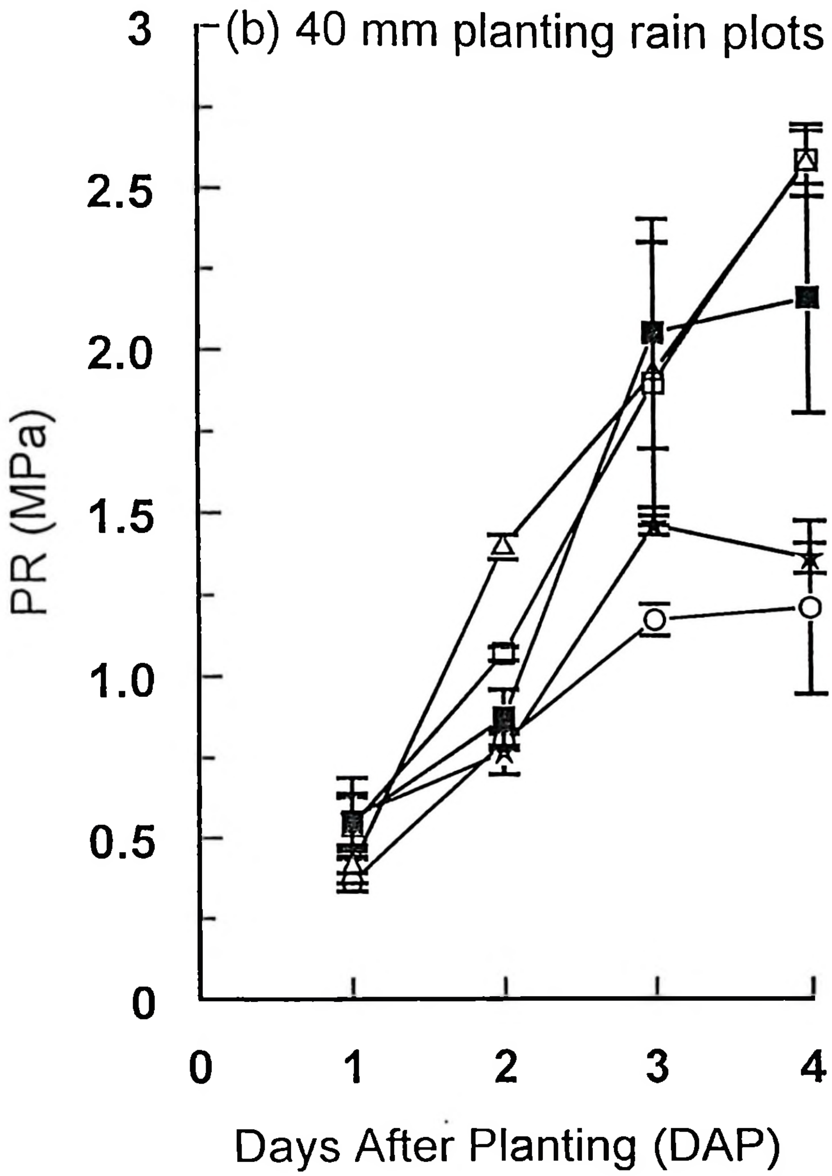


Figure 4.2. Effect of soil moisture content at ploughing and planting rain on soil penetration resistance estimated in four consecutive days after planting Markers are, SBC 1 (□), SBC 2 (△), SBC 3 (○) SBC 4 (*) and SBC 5 (■). Seedbed condition (SBC) refers to the number of days passed before ploughing, following an application of 50 mm equivalent of rain.

Figure 4.2 continue.



4.3 Seedling emergence

The results for seedling emergence as was affected by the treatments are presented in Fig. 4.3 and summarized in table 4.4.

4.3.1 Emergence in plots given 40 mm equivalent of planting rain

Seedlings started to emerge 4 days after planting (DAP). More seedlings emerged in plots planted with high than those planted with low vigour seeds in all the five seedbed conditions (Table 4.4; Fig. 4.3). In both vigour categories, emergence was lower when compared to the standard germination test results.

Averaged over vigour, seedling emergence was not significantly different between SBC 1 and 2. In SBC 3, there was significantly more emergence ($P<0.05$) than other SBC for all the vigour categories except in SBC 4 (Table 4.5). Despite the general decline there was no significant difference ($P<0.05$) between SBC 4 and 3. Seedling emergence declined further in a SBC 5 differing significantly ($P<0.05$) with SBC 3.

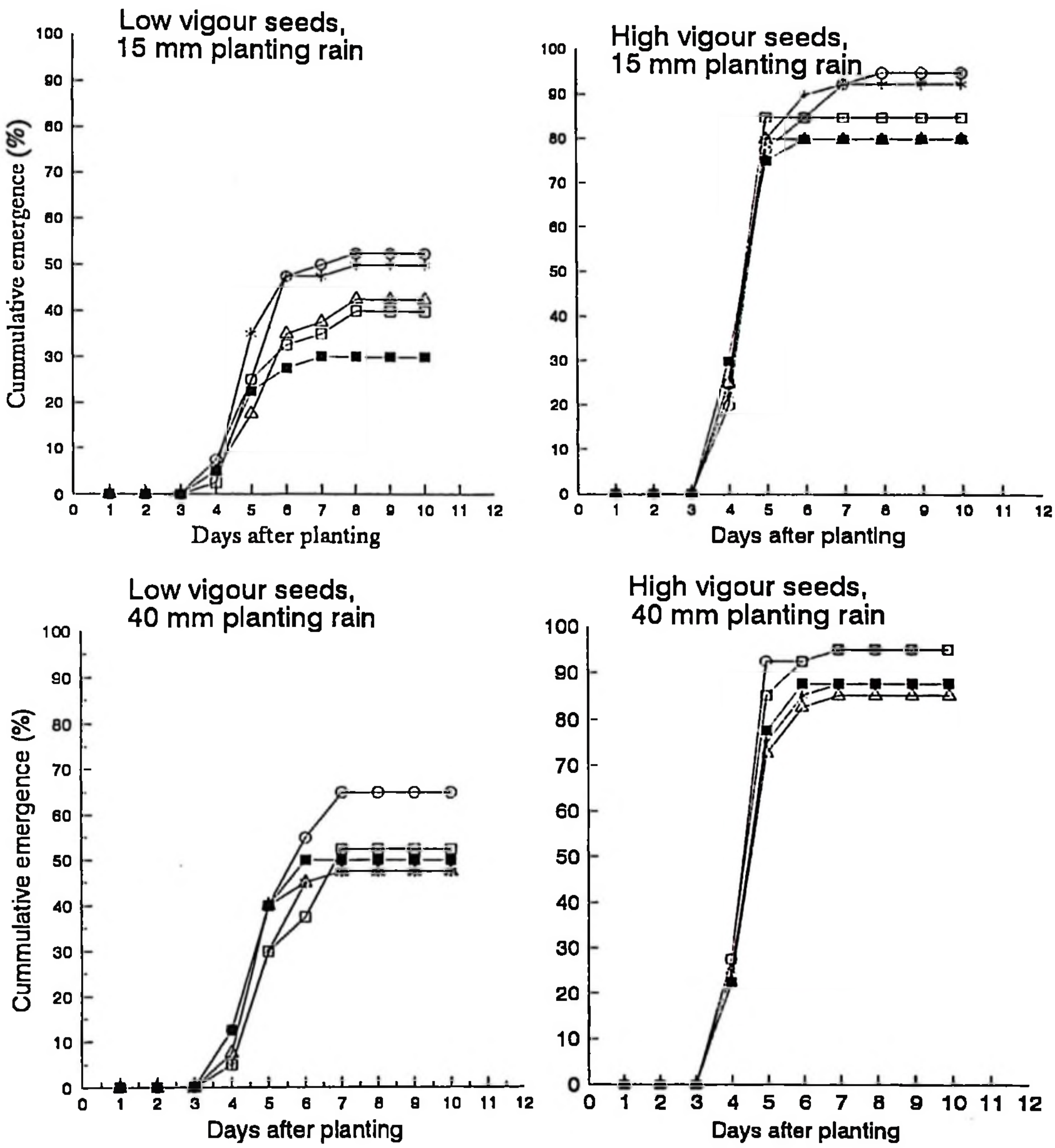


Figure 4.3. Cummulative emergence curves for maize as affected by soil moisture content at ploughing, seed vigour and planting rain (Seedbed condition refers to the number of days passed before ploughing, following an application of 50 mm equivalent of rain). Markers are , day 1 (△), day 2 (*), day 3 (○), day 4 (□), and day 5 (■).

Table 4.4. Percentage of planted seeds which emerged, germinated but not emerged and those which did not germinate as was affected by the imposed treatments

Ploughing day after application of 50 mm equivalent of rain (seedbed condition)	Seed germination and emergence % scores			
	vigour	emerged	germinate not emerged	did not germinate
40 mm Planting rain				
1	Low	47.5	20	32.5
2	Low	47.5	15	37.5
3	Low	65	10	25
4	Low	52.5	10	37.5
5	Low	50	15	35
1	High	85	5	10
2	High	87.5	7.5	5
3	High	95	0	5
4	High	95	0	5
5	High	87.5	7.5	5
15 mm Planting rain				
1	Low	42.5	20	37.5
2	Low	50	22.5	27.5
3	Low	52.5	12.5	35
4	Low	40	17.5	42.5
5	Low	30	32.5	37.5
1	High	80	15	5
2	High	92.5	5	2.5
3	High	95	0	5
4	High	85	7.5	7.5
5	High	80	12.5	7.5

Table 4.5. Mean separation for maize emergence scores as affected by planting rain and moisture condition at ploughing (seedbed condition)

Ploughing day after application of 50 mm equivalent of rain (seedbed condition)	15 mm planting rain emergence means	40 mm planting rain emergence means
1	61.3 (± 0.83) bc	66.3 (± 0.73) b
2	71.3 (± 0.875) ab	67.5 (± 0.88) b
3	73.8 (± 0.843) a	80.5 (± 0.59) a
4	62.5 (± 0.901) abc	73.8 (± 0.92) ab
5	55.05 (± 0.88) c	68.8 (± 0.74) b
LSD ($P<0.05$)	10.04	8.1

Means carrying the same letters within each column are not significantly different at $P<0.05$.

4.3.2 Emergence in plots given 15 mm equivalent of planting rain

As was the case in 40 mm planting rain plots, high vigour seeds performed better than low vigour seeds in all the 5 seedbed conditions (Table 4.4). The trend of emergence increased with increasing number of ploughing days form SBC 1 upto 3 and thereafter declined (Table 4.5).

Emergence results in SBC 1 did not differed significantly from results in SBC 2, 4 and 5 and was only significantly lower (P<0.05) than SBC 3. Emergence results from SBC 2 was significantly higher than emergence results from SBC 5 (Table 4.5).

Averaged over seed vigour, emergence percentage in SBC 3 was higher than in other SBC in this level of planting rain, and was only significantly higher when compared to SBC 1 and 5 (Table 4.5). SBC 3 showed more emergence than other seedbed conditions as was the case under 40 mm planting rain plots.

Emergence was lowest in SBC 5 when averaged over seed vigour but significantly lower (P<0.05) only than in SBC 2 and 3 (Table 4.5). Emergence of low vigour seeds in SBC 5, was dramatically reduced to 30% (Table 4.4).

4.4 Shoot height

Data on shoot height 21 DAP, are shown on Fig. 4.4. Averaged over SBC and seed vigour, shoots were longer in plots which received low amount of planting rain than the plots which received high amount of planting rain. The differences in shoot height were however not significantly different (Table 4.6). Vigour difference interms of shoot height, as averaged over SBC and planting rain, was evident ($P<0.05$) in this study (Table 4.7). There was no difference in shoot height between SBC 1 upto 4. Averaged over planting rain and seed vigour shoot height in SBC 5 was significantly ($P<0.05$) greater than other seedbed conditions (Table 4.8). The above was more clearer with seedlings of low vigour seeds (Appendix 4.1).

Shoot height in 15 mm planting rain plots increased with increasing number of ploughing days. This trend was more evident with seedlings of high vigour seeds (Fig. 4.4). The difference in height between vigour categories was significant only between SBC 5 for high vigour and SBC 1-4 for low vigour seeds (Appendix 4.1). The plot ploughed 5 days after watering, had longer shoots for all vigour categories than in other plots.

There was a general increasing trend in shoot height as ploughing days increased for both vigour categories in 40 mm planting rain plots (Fig. 4.4). Shoot height was significantly different when vigour categories were compared in the 40 mm planting rain plots (Appendix 4.2).

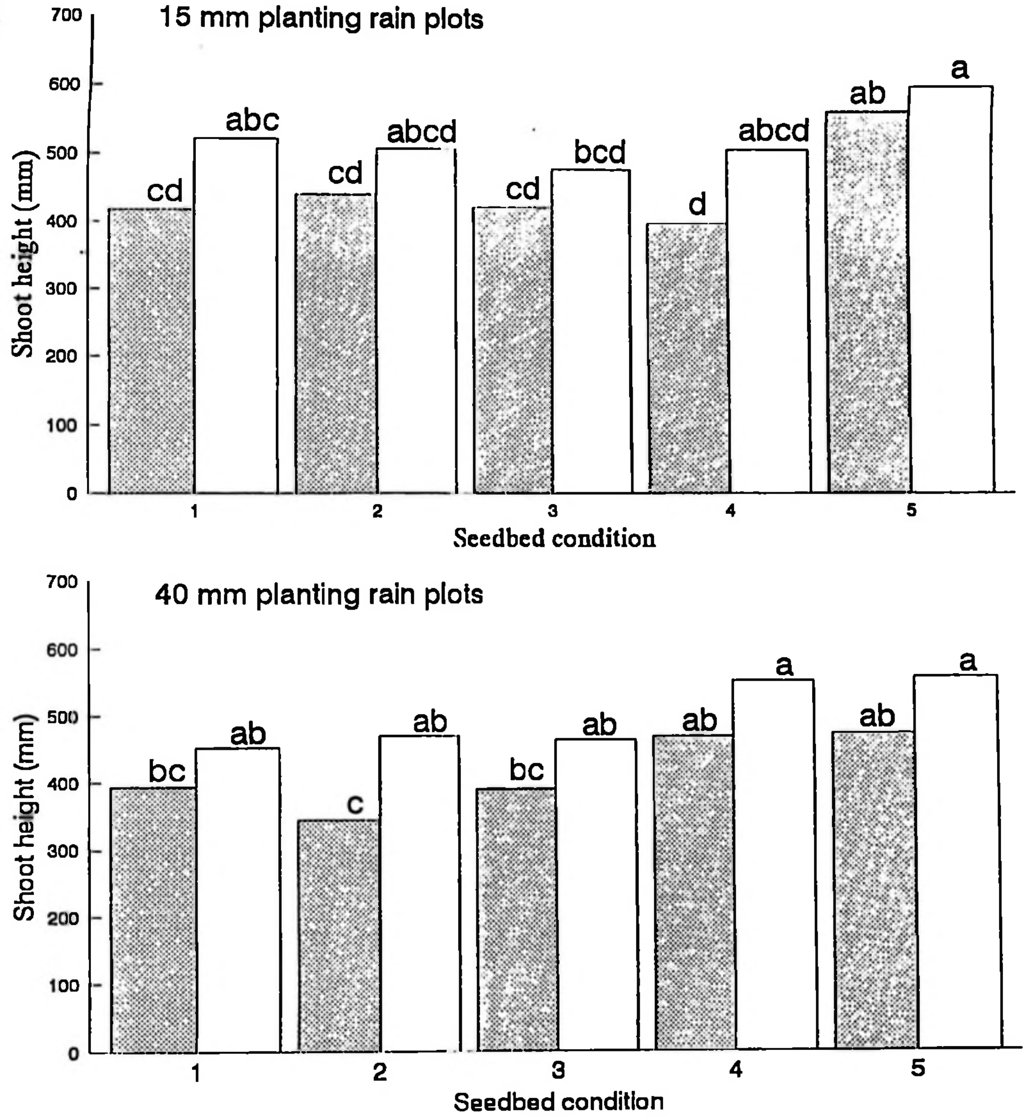


Figure 4.4. Effect of the amount of planting rain, seedbed condition and seed vigour on maize shoot height at harvest. (Shaded bars (low vigour), unshaded bars (high vigour), seedbed condition refers to number of days passed before ploughing, following an application of 50 mm equivalent of rain)

Note: Within and between vigour categories, bars sharing the same letter are not significantly different at $P<0.05$

Table 4.6. Effect of the amount of planting rain on maize shoot height

Equivalent amount of planting rain (mm)	Mean
15	485.468 (± 14.45) a
40	456.885 (± 13.88) a
LSD (P<0.05)	39.883

Means denoted by the same letter are not significantly different at P<0.05.

Table 4.7. Effect of seed vigour on maize shoot height

Vigour category	Mean
Low vigour	430.674 (± 12.318) b
High vigour	511.68 (± 13.266) a
LSD (P<0.05)	31.71

Means denoted by the same letter are not significantly different at P<0.05.

Table 4.8. Mean comparison to separate the effect of seedbed conditions on shoot height

Ploughing after application of 50 mm equivalent of rain (seedbed condition)	Means
1	446.38 (± 19.06) b
2	442.67 (± 20.30) b
3	438.82 (± 16.96) b
4	477.81 (± 25.02) b
5	550.19 (± 20.08) a
LSD (P<0.05)	57.64

Means denoted by the same letter are not significantly different at P<0.05

4.5 Number of leaves per plant

The number of leaves per plant at harvest is presented in Table 4.9 and 4.10. In the 15 mm planting rain treatments, SBC 1 upto 4 had produced the same number of leaves per plant (7 leaves) for low vigour, while the number increased significantly (P<0.05) to 8.80 in SBC 5 (Table 4.9). However, the number of leaves produced at this level of planting rain (15 mm) did not differ significantly (P<0.05) between seedbed conditions for high vigour seeds.

In the 40 mm planting rain treatments, ploughing at different DAW did not generally affect leaf production for low vigour seeds. The number of leaves increased significantly in SBC 4 for high vigour seeds (Table 4.10). Number of leaves per plant did not differ between planting rain treatments (Table 4.11). Seed vigour had a significant ($P<0.05$) effect on number of leaves per plant (Table 4.12). The interaction between seed vigour and seedbed conditions was significant ($P<0.05$) (Appendix 4.3)

Table 4.9. Mean values for the number of leaves in 15 mm planting rain plots

Ploughing day after application of 50 mm equivalent of rain (seedbed conditions)	Low vigour seeds	High vigour seeds
1	6.23 (± 0.62) f	7.94 (± 0.22) abcd
2	6.92 (± 0.29) def	8.25 (± 0.31) abc
3	6.62 (± 0.30) ef	7.69 (± 0.34) bcd
4	7.32 (± 0.24) cde	8.29 (± 0.25) abc
5	8.80 (± 0.41) a	8.58 (± 0.31) ab

Means carrying the same letter are not significantly different at $P<0.05$, LSD = 0.876.

Table 4.10. Mean values for the number of maize leaves in 40 mm planting rain plots

Ploughing day after application of 50 mm equivalent of rain (seedbed conditions)	Low vigour seeds	High vigour seeds
1	6.69 (± 0.45) cd	7.35 (± 0.41) bc
2	6.25 (± 0.176) d	7.38 (± 0.07) bc
3	6.47 (± 0.226) cd	7.30 (± 0.28) bc
4	7.22 (± 0.21) bcd	8.46 (± 0.28) a
5	7.38 (± 0.56) bc	7.98 (± 0.21) ab

Means carrying the same letter are not significantly ($P<0.05$) different (LSD = 0.9)

Table 4.11. Mean values for the number of leaves in terms of planting rains

Amount of equivalent planting rain	Means
40 mm	7.28 (± 0.14) a
15 mm	7.69 (± 0.16) a
LSD ($P < 0.05$)	0.42

Means carrying the same letter are not significantly different

Table 4.12. Mean values for the number of leaves in terms of seed vigour

Seed vigour category	Means
Low	7.04 (0.16) b
High	7.93 (0.11) a
LSD ($P < 0.05$)	0.38

Means carrying the same letter are not significantly different.

CHAPTER FIVE

DISCUSSION

5.1 Effect of soil moisture content at ploughing and amount of planting rain on seedbed conditions and on seedling establishment

5.1.1 Bulk density

Bulk density of the soil can increase with long cultivation (Lyon *et al.* 1952). There was no significant difference between the bulk density of the virgin land and all ploughing treatments given an equivalent of 15 mm of planting rain. Ploughing at different moisture content followed by light showers (15 mm of planting rain), has no effect on bulk density. However, ploughing at different soil moisture content, followed by high planting rain (40 mm) can increase the bulk density of the soil significantly. Bulk density of the soil is determined by the quantity of pore spaces and soil solids. Soils that are loose and porous will have low values, while compact soils will have high values of bulk density (Brady, 1984). Several findings have been reported on increase in bulk density due to increase in soil compactness (Veihmeyer, 1948; Brady, 1984). Soil slumping, as was observed in this study, could have resulted in a decrease in pore spaces. Application of high amount of planting rain resulted into washing of fine soil particles into the pore spaces to decrease further the amount of pores. This decrease in pore spaces caused an increase in weight per unit volume of the soil and hence an increase in bulk density. The increase in bulk density due to slumping which also caused a decrease in pore spaces probably caused a decrease in oxygen supply to affect crop growth. Poor growth in compacted zones has been attributed to inadequate aeration in the soil (Gill and Miller, 1956). Poor establishment in a seedbed condition resulting from ploughing a day after application of water, followed by high planting rain, among other factors, can be explained by soil slumping.

5.1.2 Aggregate size distribution

According to Bresson and Moran (1995) structural changes occur upon wetting rather than drying. Soil slumping due to rapid wetting and coalescence as enhanced by microcracking of coarse aggregates has been observed (Bresson and Moran, 1995). The effect of soil moisture condition at ploughing and planting rain on the resulting seedbed conditions is clearer when aggregate size distribution was evaluated. Higher percentages of aggregates of size >6.3 mm (diameter) in seedbed conditions 1 and 2 in 40 mm planting rain treatments (about 70% and 60%) respectively, (as compared to < 40% of the same size group in SBC 3), is an indication of soil slumping and collapsing of aggregates following working the soil at high soil moisture contents. With high planting rains, fine soil particles were probably washed into the interaggregate spaces, thus coalescence of small aggregates might have occurred to result into large soil aggregates on drying. According to Barley *et al.* (1965) roots penetrate horizons that lack wide pores by deforming the soil. When soil strength is sufficiently high and it can not be deformed, plant growth may be prevented. There was an increase in bulk density and probably as well as a decrease in pore spaces in high planting rain treatments. Soil PR also increased to > 3 MPa in SBC1 and

> 2 MPa in SBC 2. Young and weak shoots of maize seedlings probably experienced difficulty in lifting the large aggregates. There could have been also few interaggregates joints mechanically weak enough for seedlings to negotiate through and emerge. Soil PR was also sufficiently high to cause the soil to resist deformation by young seedlings and hence negatively influenced seedling emergence. This effect was more pronounced for low vigour seeds. PR values between 3 and 2 MPa have been reported to affect emergence through reduced root penetration (Taylor and Gardner, 1963). Reduced seedling emergence observed in the above plots can be attributed to the presence of large aggregates.

Experience indicates that the secondary aggregate sizes must be small enough around the seed and seedling roots to prevent undue drying of the soil, to provide sufficient soil solution-seed or soil solution-root contact and to provide adequate aeration (Larson, 1964) Emergence of maize seedlings has been found to be most rapid at any given matric suction and soil temperature for soils with aggregate size distribution ranging between 1.0-6.8 mm (Schneider and Gupta, 1985). There was high percentage of aggregates of size ≤ 6.3 mm in SBC 3 for both planting rain treatments (that is, >75% and > 65% in 15 and 40 mm planting rain treatments respectively). This suggests an association of these aggregate sizes to provide good seed-soil water contact. Soil strength in SBC 3 was also minimal. More emergence in these plots, that is, 65 and 95% (in plots given 40 mm equivalent of planting rain) and 52.5 and 95% (in plots given 15 mm equivalent of planting rain) emergence for low and high vigour seeds respectively, can be attributed to these effects. High percentage of aggregates sizes ⟩ 6.3 mm diameter which were ≥ 50% in SBC 4 and 5 in low and high planting rains respectively lead to poor seed-soil water contact. The effect of soil strength could also have contributed to reduced emergence in these plots. Such an effect of soil strength on emergence has been reported by Taylor and Gardner (1963) The effect of poor seed-soil water contact was more pronounced interms of seedling emergence in 15 mm planting rain plots, probably due to the low amount of soil moisture conditions as a result of low amount of planting rain. The effect was less pronounced in the high planting rain plots due to the masking effect of high amount of soil moisture. Similar results as those reported above have been observed by Grable and Siemer (1968), Schneider and Gupta (1985), Larson (1964) and Collis-George (1987).

5.1.3 Soil penetration resistance (PR)

PR has been reported by various workers to have a negative effect on crop establishment. Such studies include those by Bengough and Mullins (1990) where PR values ranging from 3 - 6 MPa were shown to greatly reduce or completely halt root growth; Weaich *et al.* (1992), and Weaich (1993) observed no emergence in maize planted on hardsetting soils as PR reached 2 MPa; Ball and O'Sullivan (1982) observed a reduced emergence in barley with PR >2.5 MPa. In the current study, PR resistance increased to values of > 2.5 MPa in a plots ploughed 1 and 2 DAW in both levels of planting rain. Furthermore, in SBC 1 in plots given 15 mm equivalent of planting rain, PR increased to the tune of > 3 MPa 4 DAP. PR also has been shown to reduce penetration of soil by seedlings roots. A decrease of 30% in root penetration at a soil strength of 1 MPa, and a decrease of 70% in root penetration at a soil strength of 2 MPa has been reported by Taylor and Gardner (1963). PR values observed in the current study are similar to those quoted above. Thus, reduced emergence in these plots can be attributed to the effect of increased soil PR. PR did not increase substantially in SBC 3. It was apparent from this study that, ploughing at relatively low soil moisture content (as low as 22.77% in plots ploughed 3 DAW), does not influence PR to the tune of affecting crop establishment at least at the early stages of vegetative growth as emergence.

5.2 Seedling establishment

Overall emergence was low in both vigour categories as compared to the standard germination test results, thus agreeing with the observation by Perry (1972).

Performance of seedlings in this aspects is discussed with respect to seedbed treatments under the respective planting rain plots.

5.2.1 Performance in 40 mm planting rain plots

In seedbed ploughed 1 DAW, and hence at high soil moisture content, soil slumping and collapsing of aggregates occurred. There was probably an alteration of soil pore volume owing to soil slumping and hence a small number of macropores. On applying high amount of water (40 mm equivalent of planting rain), most pores might have been filled with water to deplete oxygen in the seed zone. Under field conditions oxygen diffusion is determined largely by the moisture content of the soil if bulk density is not a limiting factor (Tisdale and Nelson, 1971). Reduced oxygen diffusion as a result of thick water films around the seed resulting from high amount of water may result into poor emergence (Schneider and Gupta, 1985). Hence low emergence in this plot can be due to low or poor supply of oxygen. As the time went by, aeration improved due to evapotranspiration and percolation of water to the lower soil horizons from the seed zone facilitating germination and subsequently emergence. High vigour seeds had higher germination and emergence percentages than low vigour seeds. In conjunction with decrease in moisture content over time, PR in this plot (SBC 1) increased upto $>$ 2.5 MPa 4 DAP. a value reported to reduce emergence of barley (Ball and O'Sullivan, 1982). In this study, soil strength might have also contributed to reduced emergence in SBC 1. Seedling emergence results in SBC 1 and 2 were almost similar. The above implies that, ploughing at 2 DAW created a more or less the same seedbed conditions as ploughing 1 DAW.

When the soil was worked 3 DAW, soil moisture had already decreased (from 29.07 on day 2 to 22.77%) through evapotranspiration as well as percolation to allow ploughing at a friable moisture condition, which is the right moisture condition for working the soil (Brady, 1984). This also allowed for production of small aggregates to provide good seed-soil water contact (Hadas and Russo, 1974). As the planting rain was applied it appears that, infiltration, percolation and evapotranspiration (although aboveground environment was not monitored) were at a rate that allowed a reasonable combination of air and moisture supply, and with small aggregates to provide a good seed-soil water contact. The conditions provided a good environment for germination and subsequently for emergence of maize seedlings. The above agrees with observation by Grable and Siemer (1968) and Schneider and Gupta (1985). The reason that makes the performance in SBC 3 to be regarded as having been better than in the other seedbed conditions is the closeness of the emergence scores to the germination test results. Field emergence was 65% and 95% for low and high vigour seeds respectively, while total score from laboratory germination test results was 69% and above 95% for low and high vigour seeds respectively. Results from this seedbed condition are an indication that, under non-stress conditions, the difference between laboratory germination tests and field germination results may not be so obvious.

Results in SBC 4 were the same as in SBC 3 for high vigour seeds but were lower than in SBC 3 for low vigour seeds though not significantly different. The reduced emergence for low vigour seeds in this plot can be attributed to the effect of large aggregates sizes and soil PR. The effect of these factors did not caused significant effect due to the masking effects of high amounts of planting rain. It appears that almost the same conditions prevailed in SBC 5 as emergence was not significantly different to SBC 4.

5.2.2 Performance in the 15 mm planting rain plots

In SBC 1, the soil was worked at high moisture condition to probably cause soil slumping and collapsing of soil aggregates. As soil moisture decreased, the soil developed a high strength. With light showers (15 mm planting rain), the soil was softened to allow some seeds which germinated early to emerge through. According to Bengough and Mullins (1990), root growth is greatly reduced or halted in a soil at a PR ranging from 3 to 6 MPa. Weaich (1993) working on a hardsetting soil, observed no maize emergence as PR reached 2 MPa. In this study PR increased to > 3 MPa in 4 days after planting, thus seeds which germinated later, might have failed to push through the hardened layer surface of the soil due to drying. Development of high soil strength 4 DAP in SBC 1, might have contributed to reduced emergence in this plot. Seedbed condition 2 gave better emergence than SBC 1. The difference in emergence in the two plots can be explained by the influence of PR which was lower in SBC 2 and higher in SBC 1 on the 4th DAP.

Total emergence percentage in SBC 4 was lower than on other seedbed conditions except the 5th for low vigour seeds, and higher than in SBC 1 and 5 for high vigour seeds. The number of seeds which did not germinate in this plot was also higher than other plots except in plot ploughed 5 DAW. Reduced emergence in this plot can be explained by the effect of several factors including soil strength, which increased to > 2.5 on the 4th DAP, a value which is reported to cause reduced or halted seedling emergence (Bengough and Mullins, 1990; Weaich, 1993). Additionally, large soil aggregates > 11 mm in diameter dominated (50%) in this SBC to the extent of causing poor seed-soil water contact (Schneider and Gupta, 1985). Similarly, due to low amount of planting rain, soil moisture decreased relatively faster with time to a level that was inadequate for imbibition, germination and emergence. The effect of low amount of soil moisture content is also substantiated by the large number of seeds which did not germinate in this SBC.

In SBC 5, aggregates produced were too large to provide good seed-soil water contact. With light showers (15 mm planting rain) some seeds imbibed and germinate. About one-third of the sown low vigour seeds germinated but did not emerge, and about the same proportion did not germinate (Table 4.4). The above can also serve as an evidence of early drying of the soil,'that some seeds on germinating could not pierce through or lift the dry large soil aggregates. Large number of seeds which did not germinate is an indication that, the soil in this plot ran out of water before completion of the imbibition process for some seeds.

5.3 Performance of maize seedlings in terms of shoot height

Acquisition of greater plant height in low planting rain plots, is an indication that, there was higher growth rate in these plots as compared to those in high planting rain. Bulk density was not affected in the plots given low amounts of planting rain. Tisdale and Nelson (1971) reported that, under field conditions oxygen diffusion into the soil is determined largely by moisture level of the soil if bulk density is not a limiting factor. As the φ_h did not differ significantly with φ_h in the virgin land and the fact that these plots were given low amount of planting rain, it appears that oxygen diffusion was not affected to the extent of adversely influencing seedling growth. Due to small amount of planting rain in 15 mm planting rain treatments, air filled pores seems to have been available in an amount not to negatively affect aeration, resulting into a more better growth condition as compared to the plots in 40 mm planting rain treatments. The observed differences in shoot heights in the two levels of planting rain, was probably due to better growth conditions in terms of air and moisture in low planting rain plots, compared to those in high planting rain. Letey *et al.* (1961) observed an increase in shoot height with an increase in oxygen supply. The increase in plant shoot height with increasing number of ploughing days suggests an association of this character with soil moisture content at ploughing (SBC) at least during early vegetative growth. It appears that, this association becomes more prominent when ploughing is followed by low planting rain.

5.4 Number of leaves per plant

The factors which determine leaf production in plants are genetic of the plant as well as growth media condition like air and moisture in the soil. There was no clear trend for the number of leaves to vary with seedbed condition and planting rain treatments. The observed differences in the number of leaves produced when considering the above treatments were statistically insignificant. The results reported here where number of leaves per plant are not affected by crop establishment problems have been reported by Rwehumbiza (1994). Slow growth of seedlings has been associated with low vigour seeds (Gurmu and Naylor, 1991). The observed lower number of leaves in low vigour seeds may be explained by slower emergence as evidenced by longer time to T_{50} in this vigour category as compared to high vigour seeds. This implies that seedlings from low vigour seeds were at a relatively younger growth stage and therefore had fewer number of leaves per plant than those from high vigour seeds.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the current study:

Moisture content at cultivation has been found to influence the resulting seedbed condition. When a seedbed was prepared 3 days after the first high rains (50 mm), the resulting seedbed condition was found to have a high percentage of aggregates of size ≤ 6.3 mm which have been reported to provide good seed-soil water contact, to enhance germination and to have lower PR values as compared to other seedbeds.

Seedbed condition has been shown to affect crop establishment and more so to low vigour seeds. SBC 3 had more emergence in both planting rain treatments followed by SBC 4 for both vigour categories. SBC caused a reduced emergence in SBC 1, 2, 4 and 5. Low vigour seeds were more affected compared to high vigour seeds. The implication of the above is that, farmers can lose upto about 50% and above of the cultivated maize crops from planting low vigour seeds, and upto about ≥ 10% when ploughing is undertaken 1, 2 and 5 days after the rains (50 mm). Crop loss on this soil can be minimized if seedbed is prepared at a gravimetric soil moisture content ranging from 20 - 23% after the first rains. In view of the above, it is hereby concluded that, when ploughing is undertaken 3 days after high rains amounting to 50 mm in the study area, the resulting SBC favours crop establishment.

The increase in bulk density is believed to have probably interfered with aeration to reduce emergence especially for low vigour seeds. The effect of low planting rain on establishment is associated with early drying of the soil as substantiated by high soil strength in this rainfall treatments and low emergence as compared to high rainfall treatments. High planting rains can give better crop establishment if seedbeds had been prepared at a gravimetric soil moisture content of 20.4 - 22.8% (3-4 days) after the rains.

The interaction between seedbed conditions, amount of planting rain and seed vigour had no significant effect on establishment on this particular experimental site probably because the land had been under fallow for a very long period.

Following the above conclusions it is recommended that, whenever there is rainfall as high as 50 mm in the study area, farmers should be advised to undertake ploughing 3 and no more than 4 days after the rains or when gravimetric soil moisture content is as low as 22.8% to 20.4%. The responsible organs in agriculture should set bylaws whereby planting seeds from both farmers and commercial seed companies will be tested for vigour to reduce crop loss due to planting of low vigour seeds. With a history of having planting rains succeeded by a dry spell of a fortnight or so in the study area, it is advised that planting should not be effected when planting rain is as low as ≤15 mm. Further research is suggested in other areas to enrich the knowledge on maize establishment problems to create a firm base for intervention measures that crop loss due to the effect of these factors can be reduced.

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APPENDICES

Appendix 4.1. ANOVA Table for seedling emergence as was affected by seedbed condition (A), planting rain (B) , and seed vigour (C)

Source of variation	Df	Sum of squares(SS)	Mean SS	F-ratio	Test of significance
Rep	3	6.10	2.033	2.05	
A	4	21.80	5.450	5.50	**
Error	12	11.90	0.992		
B	1	8.45	8.450	8.31	**
AB	4	7.30	1.825	1.80	ns
Error	15	15.25	1.017		
C	1	328.05	328.050	342.31	**
AC	4	1.95	0.487	0.51	ns
BC	1	1.80	1.800	1.88	ns
ABC	4	1.45	0.363	0.38	ns
Error	30	28.75	0.958		

Appendix 4.2. ANOVA Table for shoot height as was affected by seedbed condition (A), planting rain (B) , and seed vigour (C)

Source of variation	Df	Sum of squares(SS)	Mean SS	F-ratio	Test of significance
Rep	3	1437.64	479.213	0.05	
A	4	143194.50	35798.626	3.79	*
Error	12	113209.32	9434.110		
B	1	17561.41	17561.408	3.16	ns
AB	4	43043.81	10760.953	1.93	ns
Error	15	83489.53	5565.969		
C	1	127821.66	127821.659	45.36	**
AC	4	4473.15	1118.289	0.40	ns
BC	1	558.57	558.572	0.20	ns
ABC	4	8114.52	2028.630	0.72	ns
Error	30	8114.52	2817.729		

Appendix 4.3. Mean separation for vigour differences in shoot height in the 15 mm equivalent of planting rain plots

Ploughing day after application of 50 mm equivalent of rain (seedbed condition)	Seedlings of Low vigour seeds	Seedlings of high vigour seeds
1	417.99 (±35.49)cd	521.50 (±39.00)abc
2	441.07 (±26.86)cd	507.92(±30.80)abcd
3	422.10 (± 38.52) cd	478.40 (±28 38)bcd
4	399.05 (±36.74)d	508.55 (±59.86)abcd
5	565.72 (±19.42)ab	602.86 (±25.61)a

Means denoted by the same letter are not significantly different at P<0.05 (LSD = 105.82)

Appendix 4.4. Mean separation for vigour differences in shoot height in the 40 mm equivalent of planting rain plots

Ploughing day after application of 50 mm equivalent of rain (seedbed condition)	Seedlings of Low vigour seeds	Seedlings of high vigour seeds
1	393.14 (±26.15) bc	452.89 (±26.39) ab
2	344.25 (±31.89) c	469.95 (±25.47) ab
3	390.86 (±12.10) bc	463.95 (±41.57) ab
4	469.52 (±34.28) ab	552.13 (±34.03) a
5	473.59 (±54.52) ab	558.58 (±32.78) a

Means denoted by the same letter are not significantly different at P<0.05 (LSD = 99.49)

Appendix 4.5. ANOVA Table for number of leaves per plant as was affected by seedbed condition (A), planting rain (B) , and seed vigour (C)

Source of variation	Df	Sum of squares(SS)	Mean SS	F-ratio	Test of significance
Rep	3	3.11	1.037	1.73	
A	4	16.30	4.094	6.81	**
Error	12	7.21	0.601		
B	1	3.96	3.960	7.45	*
AB	4	3.18	0.794	1.49	ns
Error	15	7.97	0.531		
C	1	16.31	16.300	58.70	**
AC	4	3.01	0.753	2.71	*
BC	1	0.003	0.003	0.01	ns
ABC	4	1.91	0.478	1.72	ns
Error	30	0.33	0.278		