SOKOINE UNIVERSITY OF AGRICULTURE

SOIL-WATER MANAGEMENT IN SEMI-ARID TANZANIA RESEARCH PROJECT

FINAL TECHNICAL REPORT

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RECOMMENDATIONS

11. The semi-arid areas should be provided with an extension service which among other things is equipped to train farmers in the use of soil-water management techniques which help to conserve and efficiently utilize rain water.

12. Adequate application of farm yard manure (FYM) should be strongly emphasized in the agricultural extension programme in the semi-arid areas. Further to this and in-order to break the vicious circle of poverty and land degradation in the study area, assistance to the farmers in the study area should first and foremost be directed towards adequate application of FYM on their fields. However,further on-farm trials are required to establish the optimum rate of farm yard manure application.

13. Further research should be conducted to adapt a system of no-till tied-ridging that will involve the use of deep tillage with tractor and installation of tied-ridges once every three or four years. In subsequent years the farmer can use the current system of 'kuberega' (on the ridges instead of flat land) in-order to save labour and power requirement. More emphasis should be put on analysing the response of economic factors.

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CA:	Catchment area
CAN:	Calcium ammonium nitrate
CB:	Cropped basin
CBAR:	Catchment:Basin area ratio
DAE:	Days after emergence
FAO:	Food and Agriculture Organisation
FC:	Flat cultivation
FCM:	Flat cultivation with mulch
FYM:	Farm yard manure
HARC:	Hombolo Agricultural Research Centre
ICRISAT	International Centre for Research in Semiarid Tropics
IDRC:	International Development Recearch Centre
ISRIC:	International Soil Resources Investigation Centre
RRA:	Rapid rural appraisal
RWH:	Rain water harvesting
SCL:	Sandy clay loam
SCT:	Strip catchment tillage
SL:	Sandy loam
SUA:	Sokoine University of Agriculture
TSP:	Triple superphosphate
TT:	Tractor tillage
TTM:	Tractor tillage with mulch
UNESCO:	United Nations Education and Scientific Organization
ZT:	Zero tillage, "*kuberega*"

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1. INTRODUCTION

1.1 Background

Tanzania is a large country having a land area of 886,000 km^2 with complex climate, soils and topography. Tanzania also has within its borders 55,000 km^2 of lakes. On the basis of the current population estimates there are about 40 ha of land per person. It is estimated that only 5% (2 ha per person) of the total land area is under cultivation.

Several methods have been used to classify Tanzania into agro-ecological zones. The classification shown in Figure 1.1 gives six (6) major zones according to soil type, altitude, mean annual rainfall and duration of the growing season (LRDC, 1987). The zones are (1) Coast, (2) Arid Lands, (3) Semi-Arid Lands, (4) Plateaux, (5) Southern and Western Highlands, and (6) Northern Highlands and isolated granitic mountains.

The agricultural potential of the country is limited over large areas o[illegible]e country by a combination of:

- Low soil fertility, where truly fertile soils are confined to:
  - the volcanic soils of the northern highlands,
  - soils of southern highlands, and
  - the alluvial soils in large river basins.
- Low and erratic rainfall, where only 22% of the land receives 570 mm or more of rainfall in 9 years out of 10.
- High evaporation rates, where nearly throughout the country, potential evapotranspiration exceeds rainfall during more than nine months of the year
- Tsetse infestation.

In general, land with a combination of adequate soil fertility, adequate rainfall and free of tsetse infestation is limited to less than 10% of the total area of Tanzania. Consequently, more than 65% of the population live in the 10% of the land. The potential for lateral agricultural expansion, to meet the food security needs of a population growing at 3% annually, is therefore, very constrained.

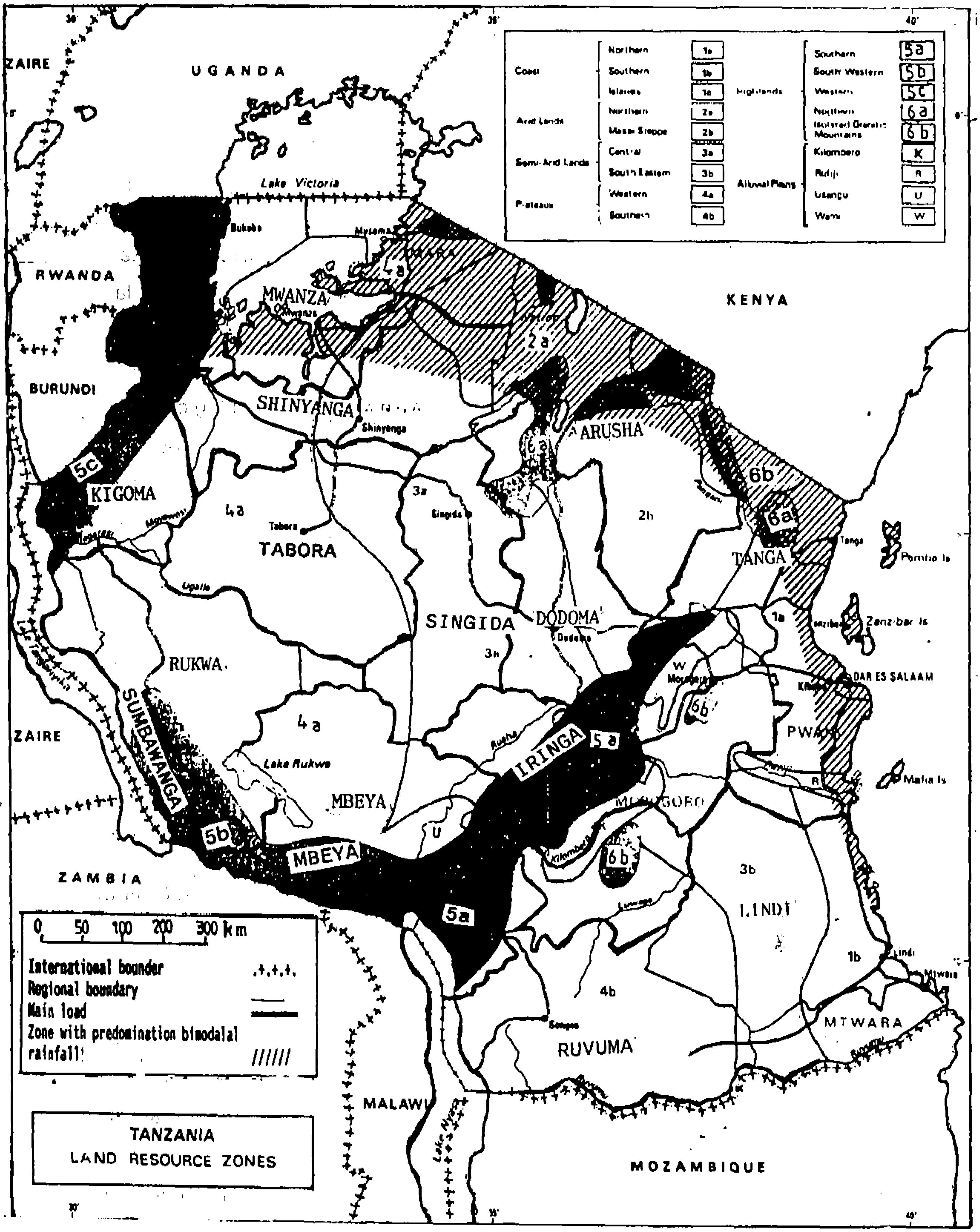


Figure 1.1: Tanzania, classification of agro-ecological zones

While a number of large estate farms and irrigated farms exist, small-holder rainfed subsistence agriculture is the most important component of Tanzania's economy (FAO, 1993). For example, 80% of the marketed cereal production comes from the small-holder farmers. Because of its subsistence nature, the small-holder sector is the main livelihood for a large percentage of the population. The rainfall is the major factor influencing crop and livestock production, but apart of being low in amount rain also falls at high intensity causing substantial runoff losses.

Therefore, soil-water is a critically vital resource needing effective development, efficient utilization and management. This requires not only the improvement of soil-water management techniques to hold more water in the soil, but also improved cultural practices and more optimal use of inputs, to ensure efficient utilization of soil-water by plants.

In view of this, Sokoine University of Agriculture (SUA) initiated a research programme on soil-and-water management in semi-arid areas of Tanzania in 1991. The International Development Research Centre (IDRC) of Canada through its Environmental Policy Programme provided funds to implement the first research project in Dodoma. This report gives a summary description of the implementation and main findings of the 3-year project.

1.2 The Problem and Research Objectives

The semi-arid zone occupies about one third (295,000 km^2) of the total area of Tanzania and extends NE/SW across the central part of the country. The main PROBLEM in this zone is Low and Unreliable Crop and Livestock Production. The main EFFECT of this problem is Low Food Supply, Sufficiency and Security. The main contributing CAUSE of the problem is Low Availability of Soil Moisture. This is, in turn, caused by low rainfall, erratic distribution of rainfall, high run-off losses (Plate 1a) and high evaporation losses. The problem is conceptualized in Figure 1.2.

Therefore, the overall objective of the Soil and Water Management (Tanzania) Research Project is to develop, test and introduce appropriate and socially acceptable management interventions for improving the capture of rainfall by soils and soil-water availability to plants, in the semi-arid areas.

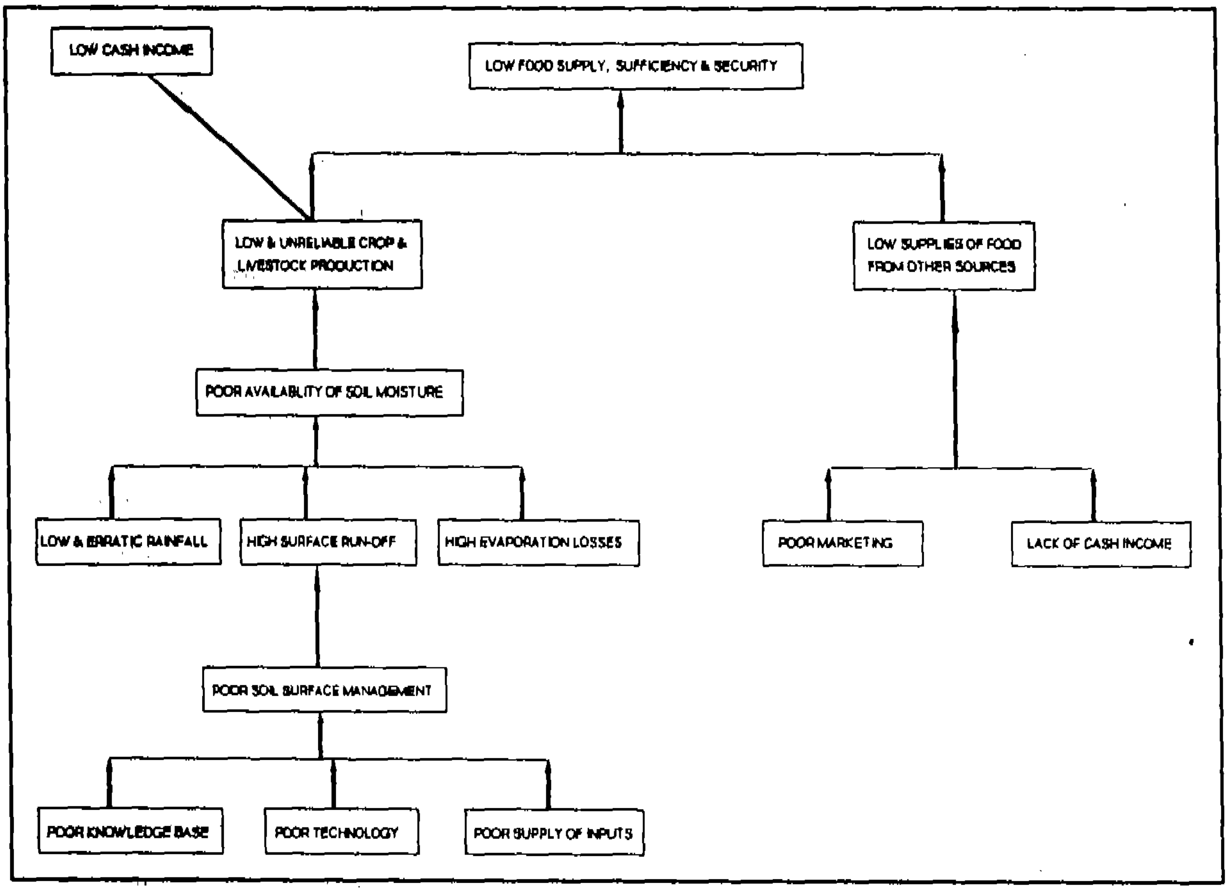


Figure 1.2: Problems, causes and effects of subsistence farming in semi-arid Tanzania

The following are the specific objectives of the research:

i) To analyze historical rainfall records from various sites within the study area, and provide probabilistic description of the rainfall regime;

ii) To characterize the soils of the research sites within the study area;

iii) To investigate the means for improving the infiltration of water into the soil profile, reducing runoff and improving the efficiency of utilization of soil moisture by crops;

iv) To determine the effects of rainfall and other weather parameters, slope, soil characteristics, soil fertility (farm yard manure, organic matter and inorganic fertilizers), crop genotype and agronomic practices on runoff, soil moisture balance, soil moisture uptake by crops and crop development;

v) To assess water harvesting techniques for increasing soil water supply in the cropped area;

vi) To conduct socio-economic studies aimed at generating information that will direct research activities to the most important constraints; and

vii) To initiate farmer-managed on-farm trials and to train farmers in promising techniques.

1.3 Review of Literature

1.3.1 Agrometeorology

The climatic factor of greatest economic and social significance in semi-arid areas of Tanzania is rainfall (Griffiths, 1972). The coming or not of rain may mean life or death to human and livestock. The amount and intensity of rain is of decisive importance for crop yield.

Rainfall recording in the semi-arid zones of Tanzania dates back to 1898 when a recording station at Mpwapwa was opened. There are about 26 rainfall recording stations in the immediate study area more of Dodoma District. At Dodoma airport meteorological records have been kept since 1911.

The use of the long-term mean calculated over any length of time has serious disadvantages particularly when estimating future rainfall. As seen from Figure 1.3, negative departures from the average/mean are more numerous than the positive ones. This results in positive skewness of the frequency distribution of rainfall total for individual years. As a consequence, the annual mean rainfall of any particular site is inflated by a few very high values and indicates higher rainfall figures than can be expected (Nieuwolt, 1977). It is therefore very important to analyze the variability and reliability of different amounts of rainfall in order to describe the rainfall of any particular site.

In central Dodoma it has been shown that an annual rainfall of less than 500 mm may be expected in at least 1 out of 5 years (Riise, 1971; Griffith, 1972; Nieuwolt, 1973). The fluctuation of the monthly rainfall from the mean is shown on Table 1.1. It can be seen that rainfall at the beginning and end of the season have the highest variability.

Table 1.1: Monthly rainfall variability in Dodoma (After Ngana, 1983)

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
X	0.0	0.0	23.1	108.5	132.4	109.1	111.7	52.1	3.8	0.0	0.0	0.0
s.d	-	-	41.5	65.2	79.7	65.1	62.5	51.4	7.2	-	-	-
C.V	-	-	180.0	60.0	60.0	60.0	56.0	99.0	189.0	-	-	-

X = Mean; s.d = Standard Deviation, C.V = Coefficient of variation

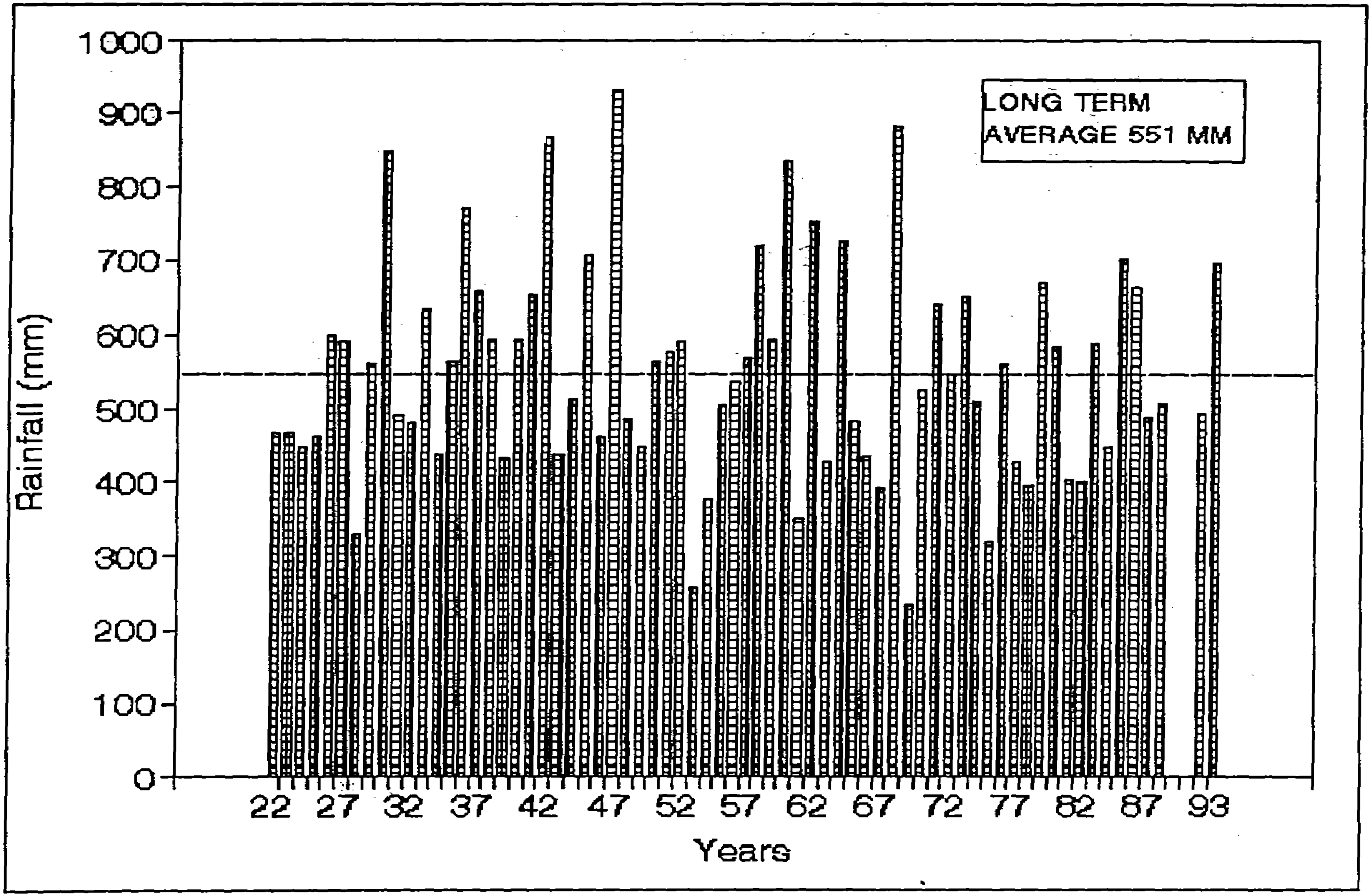
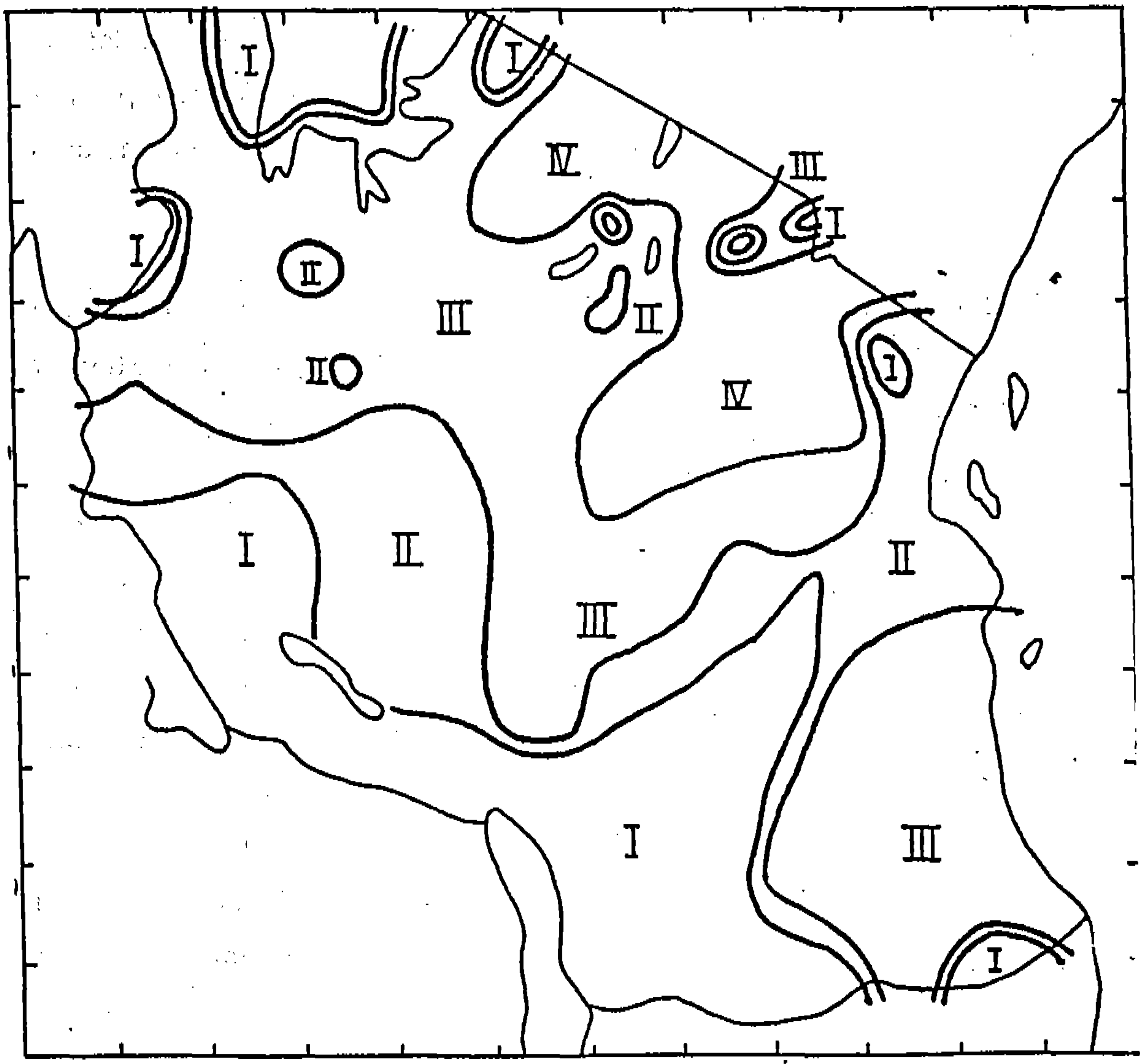


Figure 1.3: Seasonal rainfall at Dodoma Airport Meteorological station (1921-1993)

Spatial variability is also very important in Dodoma. Within the same rainy season one area may receive normal rains and adequate harvests while an adjacent area may experience severe drought and total crop failure. For example, during the 1970/71 season Dodoma Meteorological station recorded 689.1 mm of rain while Matumbulu, 12 km to the south, recorded only 151.2 mm.

Statistical analyses of rainfall data to assess reliability and variability have been carried out by several researchers. Manning (1950) established the asymmetry of frequency distributions for monthly rainfall totals and developed a procedure for evaluating confidence limits for expected rainfall during a given period using a logarithmic transformation of skew data. Glover and Robinson (1953) calculated means, standard deviations and probabilities of exceeding certain minimum amounts of rainfall, for Kibaya in Arusha region. They showed that maize can grow and yield well at this area if planted so that its peak water demand coincides with the month of March. Similar analysis was carried out by Evans (1955) for Nachingwea, in southern Tanzania. He illustrated that only a narrow margin of the rainfall can be successfully used by plants and emphasized the importance of calculating the long term mean of this margin rather than the annual or seasonal mean.

Kenworthy and Glover (1958) used monthly mean rainfall to define seasonal distribution of rainfall. They mapped the reliability of different amounts of rainfall for the main rain seasons in different areas. The marginal nature of rainfall was shown by the rapid decrease in areas with reliable rainfall as the expected levels of rainfall amounts and their reliability were increased. Braum (1975) examined the reliability of seasonal rainfall by a ranking procedure. The seasonal data to individual years were ranked and the probability of exceeding 50, 100, 150 mm etc seasonal was rainfall calculated. He used simulated soil water holding capacities to relate the rainfall ability to satisfy crop water requirements in a given season. Both Hyera (1983) and Mhita (1984) assessed dry spells at Dodoma and defined onset, cessation and duration of the rainfall season and the optimum length of growing period. Gommes and Houssiau (1982) assessed the rainfall pattern in Tanzania in terms of reliability for maize and sorghum and arrived at reliability classifications shown in Figure 1.4.



Zone I: There is a chance of obtaining 80% of the local maximum yields of maize in eight out of ten years

Zone IV: There is a chance of obtaining only 50% of the local maximum yields of sorghum in five out of ten years

Figure 1.4: Tanzania, rainfall reliability classification

Ngana (1990) in a study to examine the stochastic characteristics of the seasonal rainfall of seven stations in semi-arid Tanzania concluded that there is a 5-year cyclic phenomenon in the seasonal rainfall series. In some localities there is an additional 2.5 year cycle superimposed in the 5 year cycle. He further concluded that the basic pattern of the seasonal rainfall can, to some extent, be predicted by a periodic function or model although the model does not adequately predict the peaks or lows of the seasonal rainfall series. However, the information is important in giving general awareness/warning to farmers and water resources planners on an oncoming wet or dry year.

Another interesting analysis of rainfall data is the correlation of seasonal rainfall amount and length of the rainy season with the onset of the rain season. Stewart (1987) found that the 1954 - 1983 precipitation data of Niamey, Niger, can be divided into two groups: early and late onset of rains. He characterized three features in each group. In the early season, median rainfall amounted to 602 mm compared to 400 mm in the late onset seasons. The median duration of the rainy season was 113 days versus 83 days for the early and late seasons, respectively. Average rainfall in the early season was 5.3 mm compared to a late onset season average of 4.7 mm. A similar analysis has been carried out for selected stations in Tanzania by Matari (1992). Decadal statistics of daily rainfall data were used in determining the start, end and length of the growing season. Using frequency distribution, spatial distribution and regression analysis the results showed that it is possible to estimate with reasonable accuracy the average onset date, the length of growing season and the seasonal rainfall.

This type of analysis provides a means by which historical data can be used to reduce the risk of farming in highly variable climate. The farmer can determine fairly early in the growing season the probable conditions for that year's crop. This is the concept of response farming (Stewart, 1985).

Identification or development of improved soil-water management strategies will only be possible through a better understanding of the agro-climatic potential and limitations of the region. Therefore, the main objective of the agro-meteorological component of the soil-water management research project was to analyze the rainfall data from Hombolo in order to:

- Compile mean monthly and yearly rainfalls and the probabilities of the frequency of occurrence of particular rainfall amounts;
- Correlate the amount of seasonal rainfall, rainfall duration and intensity with the onset of the first rainfall; and
- Identify the distribution and frequency probabilities of dry spells of different durations during the rainy season.

1.3.2 Hydrology and soil-water balance

In Tanzania, hydrological data is limited to gauging of large rivers. Measurement of run-off from agricultural size catchments is very limited. Fawley (1956) calculated the runoff from the Msalatu reservoir catchment in percentage of rainfall for the years 1945-1953. He concluded that for five years out of nine the runoff as a percentage of rainfall in December is above 20%, and two years out of nine it is above 26%. Rapp et al (1972) concluded that runoff, from semi-arid pediment areas of East Africa with poor vegetation cover, can reach 30-40% of the rainy seasons precipitation for catchment areas of a few square kilometres in size.

Surface runoff from small erosion plots in some parts of central Tanzania have been reported (Staples, 1938; Purvis, 1945; Van Rensburg, 1955; Shindo, 1989). Temple (1972) compiled and analyzed existing run-off data and demonstrated that in the semi-arid areas severe losses of soil and water are associated with land clearance, cultivation and overgrazing (Table 1.2).

Table 1.2: Run-off, soil erosion and sediment concentration at Mpwapwa (After Temple, 1972)

	BARE			VEGETATED		
	UC	FC	RC	C	G	T
R/O (% of Rain)	50.4	31.5	23.0	26.0	1.9	0.4
Erosion (m^3 ha^{-1})	97.8	85.2	43.3	52.0	0.0	0.0
Sediment in R/O (kg m^{-3})	49.2	70.0	63.6	44.9	-	-

UC = uncultivated; FC = flat cultivation, RC = ridge cultivation, C = crop, G = grass, T = thicket; R/O = runoff

Infiltration in the study area was assessed using data from infiltration experiments and soil moisture tests carried out in nearby catchment (i.e. Ikowa) by the Dodoma Water Master Plan Team in 1973 (TMWD, 1974). The infiltration results showed that high rates of infiltration (100-300 mm/h) were recorded in areas with homogeneous deep profiles of loamy sand. The lowest rates (30-80 mm/h) were recorded in areas with rather compact profiles. Work done at another nearby catchment of Makutupora showed similar trends (Shindo, 1991). For example, in a series of measurements, the infiltration rates were 169.0, 81.5 and 65.7 mm/h for upland, middle terrace, and flood plain, respectively.

The soil moisture tests showed that the average soil moisture contents were low throughout the profile, varying from 3-9%, and the field capacity (around 20%) was never reached. Such low soil moisture contents prevailing during the rainy season provide clear evidence of a permanent soil moisture deficit. At valley bottoms the soil moisture varied from 2-22% in the upper 50-60 cm and from 7-15% in the lower layers down to 150 cm. Uplands showed similar patterns. Thus, variations were largest in the upper layers, while in the deeper part of the profiles variations were rather small (TMWD, 1974).

Due to the general low soil moisture and the high evapotranspiration even in the rainy season, moisture does not move gravitationally to the deeper layers, and consequently, there is virtually no recharge of ground water in these areas except where water courses cross fracture zones. It is clear that there is a shortage of soil moisture during the rainy season in the study area. The limited information reviewed above also show that the main reason for this shortage is high run-off losses. Therefore, further investigations and development of means to reduce surface run-off are important.

1.3.3 Interventions

1.3.3.1 Purpose of interventions

Interventions are required to impart stability to crop production during sub-normal rainfall years and maximize yields in normal rainfall years. The intervention techniques should in general aim at maximizing soil-water available to crops as a result of each rainfall event and optimize crop yield per unit of this available soil-water. The objective of intervention strategies are given in Box 1.

Box 1: Main objectives of interventions in soil-water management

> There are two main objectives of soil-water management interventions; these are:
>
> i) To maintain the soil moisture status at optimum conditions for crop growth for the greater part of the growing season. This can be achieved in two ways:
>
> - If the rainfall is deemed to be enough for crop growth then the interventions will aim to capture the maximum possible rain where it falls, by maximizing the soil water holding capacity, maintaining high infiltration rates, reducing surface run-off and reducing deep drainage of water below the root zone.
> - If the direct rainfall is not enough then, rain water run-off can be encouraged in certain areas in order to concentrate and use this water to improve soil moisture in the area of interest.
>
> ii) To ensure high crop water use efficiency (i.e high crop yield per unit of water transpired by the crop).

Farmers and researchers in the semi-arid regions have developed seven categories of intervention techniques to meet these objectives (Mann and Singh, 1977). These are:

i) Selection of crops and varieties having growth patterns which match tho soil-water availability patterns of the given locality;

ii) Adoption of tillage practices conducive to soil, water and nutrient conservation;

iii) The adjustment of sowing time so as to ensure that the periods of critical water requirement coincide with the periods of adequate available soil-water;

iv) A judicious fertilizer use commensurate with the status of soil, nutrients needs of crops, plant population and available soil moisture;

v) The conservation of moisture through the use of partial or complete sub-surface barriers and organic or inorganic mulches to cut down losses owning to deep percolation and evaporation, respectively;

vi) Timely control of weeds and the adoption of effective plant-protection measures; and

vii) Adoption of appropriate rain water harvesting techniques so as to ensure higher amounts of moisture for longer periods.

1.3.3.2 Tillage Interventions

Tillage methods are broadly separated into conventional and conservation methods (Soil Science Society of America, 1982). Tillage affects soil-moisture status through soil physical properties, in various ways as discussed below.

a) **Bulk density, porosity and mechanical strength** have a major impact on soil water relationships and crop root development and consequently crop yield. For example, work done in Botswana has shown that the elongation of roots in a sandy loam soil can be reduced by fifty percent by an increase in the soil bulk density from 1.6 Mg m^{-3} to 1.8 Mg m^{-3} (DLFRS, 1985).

Most tillage operations are performed to decrease soil density within the disturbed zone. However, bulk density often varies widely both spatially and temporally because of undisturbed zones within the soil and solidification due to subsequent tillage and slumping of unstable soil aggregates as a result of precipitation. This variation is illustrated in Table 1.3.

Table 1.3: Change of soil bulk density (Mg m^{-3}) of the top 50 mm with time after different tillage treatments (after Hatibu et al, 1991)

Tillage Treatment	Days after Tillage		
	10	32	55
No-till (bare)	1.20	1.21	1.22
No-till (with mulch)	1.20	1.21	1.22
Hand hoeing	0.96	1.06	1.13
Mouldboard ploughing only	1.10	1.20	1.25
Disk ploughing only	1.01	1.18	1.23
Mouldboard ploughing with disk harrowing once	1.10	1.21	1.25
Disk ploughing with disk harrowing once	1.10	1.19	1.21
Mouldboard ploughing with disk	0.97	1.24	1.29
Disk ploughing with disk harrowing thrice	0.93	1.10	1.25

b) **Surface micro-relief or roughness** provides surface depressions for temporary storage of water on the surface, thus providing more time for water infiltration and reducing the flow of water across the surface. Work by Makungu et al. (1993) in Morogoro indicated that treatments with higher values of depression storage tend to have higher soil moisture content.

c) **Soil hydraulic** properties include saturated and unsaturated conductivity, water content, water retention characteristics. These properties in turn affect hydraulic processes such as water flow through the soil, drainage, infiltration and evaporation.

d) **Infiltration and run-off** are two important processes which affect soil-water balance as discussed in section 1.3.2 above. Generally tillage reduces runoff yields as shown in Table 1.4.

Table 1.4: Effect of tillage on runoff from land cropped to maize in Nigeria (After Rockwood and Lal, 1974)

Slope %	Run-off (%)		
	Bare fallow	Ploughed	No-tillage
1	18.8	8.3	1.2
5	20.2	8.8	1.8
10	17.5	9.2	2.1
15	21.5	13.3	2.2

Previous research has shown that the depth of tillage is one of the most important aspect in conventional tillage. Deep tillage helps to overcome the low porosity and hardening of the soil after rains and permits root proliferation and exploitation of soil water and nutrients at deep horizons of the soil profile. Experiments carried out at ICRISAT (Laryea et al., 1991) have shown that there is an increase in crop yield and reduction of runoff and soil loss with depth of tillage as shown in Table 1.5.

Another aspect which has raised interest in the Semi-Arid Tropics (SAT) is the timing of the primary tillage operations. Untilled soil can be too hard to plough before the onset of rainy season. Therefore, ploughing will only be possible after rains have moistened the soil to sufficient depth which delays planting. It has therefore been proposed that primary tillage in semi-arid zones with hard setting soils should be done as soon as possible after harvesting (Willcocks, 1984). It is argued that this tillage method controls weed growth and therefore reduces profile moisture loss during the dry season, and that it opens the land to infiltration of early rains. At ICRISAT in India, this off-season tillage has been found to be helpful in increasing the amount of rain water infiltration and in decreasing weed problems. In most years, off-season tillage alone can increase crop yields by 7-9% over the control. Furthermore, off-season tillage has been found to minimize the evaporation of stored water by a "mulching" effect and thus allowing the acceleration of planting operations and extension of the growing season (Pathak et al., 1987).

Table 1.5: Effect of different depth of tillage systems on sorghum grain yield, runoff and seasonal soil loss of Luvisol [After Laryea et al., 1991]

Tillage treatment	Grain yield (t ha^{-1})	Runoff (mm)	Soil loss (t ha^{-1})
Hand hoeing 10 cm	2.52	128	1.66
Chisel 15 cm	2.83	102	1.62
Mouldboard 15 cm	2.76	106	1.70
Mouldboard 25 cm	3.22	85	1.41

Most tillage research related to semi-arid parts of Sub-Saharan Africa has been reported mainly in West Africa and Botswana. Tillage research in Botswana has been undertaken since early 1970s on sandy loam soils under two broad themes (DLFRS, 1985):

i) Evaluation of the effect of tillage methods, implements and depth on yields.

ii) Evaluation of the effect of these tillage systems on moisture conservation.

The research has shown that rooting is impeded by the natural compactness of the sandy loam soils. Related to this is readiness of any surface tilth to slake, slump and dry to a hard crust restricting seedling emergence and water infiltration. Consequently, it was proposed that the "best" method of tillage would be to supplement shallow mouldboard ploughing with occasional deep ploughing (mouldboard or chisel).

Work in semi-arid areas of West Africa has led to the following recommendations on tillage requirements (Aina et al., 1991):

i) For sandy loam and loamy sand soils chisel ploughing, tie ridges, ploughing at the end of rains and rough seed bed are recommended;

ii) For clayey, sandy clay and sealing soils ridge and furrow and broad bed systems are recommended.

Limited tillage research has been reported from Tanzania. Prentice (1946) reported higher yields from tie ridges than from flat seedbed in years of partial drought. Dagg and Macartney (1968) observed that tie-ridged land produced significantly more maize yield only on red soils but not on black (Vertisol) or on ash (Andosol) soils (Table 1.6).

Macartney et al., (1971) reports on work which was done to examine the effectiveness of tillage in semi-arid central Tanzania over two seasons. Although two seasons is too short, the research indicated that conventional disc ploughing and harrowing combined with flat planting, resulted in good germination and establishment, but was inefficient in terms of water and soil conservation. Ripping prior to the commencement of the rains was found to be good in conserving early rainfall. Also tie ridging was shown to give good results in two season which were deemed to be widely contrasting. It was proposed that the development of strip tillage system would probably result in greater advantages. Work by Huxley (1979) indicated that no-till techniques gave 47% lower yield than the conventional tillage methods in the semi-arid loamy soils of Morogoro.

Table 1.6: Maize grain yield (kgha^{-1}) under different tillage systems in Tanzania (after Dagg & Macartney, 1968)

Soil	Yields (kgha^{-1})			
	Tie-ridged	Ridge & furrow	Flat	Means
Vertsol	3274	3251	3085	3204
Red soil	3433	3029	2628	3030
Andosol	2824	2465	2509	2599

1.3.3.3 Surface mulching

Crop residue mulch is an important ingredient in soil surface management. The benefits of mulching are attributed to physical effects that principally improve rainfall acceptance, reduce runoff and surface crusting and improve moisture conditions and aeration in the topsoil. In addition, there are also improvements in soil chemical and nutritional properties. Lal (1976) reported an annual increase of 32% of rain water capture as a result of applying 6 tons ha^{-1} of crop residue mulch. Work by Khatibu et al (1984) demonstrated the effectiveness of mulch in reducing runoff and erosion in Zanzibar and Tanga. In unmulched plots, 10.2% of the total rainfall was lost as runoff compared to only 0.01% in the mulched treatment. The total soil loss from the mulched treatment was only 3.63% of that from the unmulched plots. At Tanga, Ngatunga et al. (1984) evaluated the effects of straw mulch applied at, 6 t ha^{-1}, on runoff and erosion in comparison with bare, unmulched treatment. Results showed that mulching provided an effective erosion control even on steep slopes of up to 22%.

The use of mulching is, however, constrained by the inadequate supply of mulch material in the semi-arid regions due to prolonged periods of drought and the fact that crop residues have alternative uses such as animal feed.

1.3.3.4 Weed control

Weeds affect crop yields by competing for moisture, nutrients, light and space, as well as by increasing insect and disease problems. It has been shown that millet, sorghum, maize and groundnuts could tolerate weed competition for only 21 days after germination. When soil surface is dry or when there is full plant canopy most of the water lost is by transpiration. This means that complete weed control is a paramount consideration in water-limiting areas. Control of the weeds releases the nutrients and moisture for increased crop growth and yield.

Weed control means any procedure that reduces the infestation or vigour of weeds to a level that will enable production of crops. Three methods are mainly used, namely cultural, mechanical and chemical. Cultural control methods involve sound agricultural practices which include using weed-free crop seed, crop competition and crop rotation. These methods prevent weeds from being established. Mechanical weed control include methods which utilize physical methods for weed removal. Tillage and cultivation are the main methods of mechanical weed control. In semi-arid tropics where weed control is done manually, up to 75% of the farmers' time could be spent on weeding activities (Holm, 1975). Chemical control involves the use of herbicides. Introduction of herbicides into appropriate cropping system can be an important input.

1.3.3.5 Rain water harvesting

Rain-water harvesting is the collection of surface runoff from one area (normally uncropped) for use to increase soil-water content in a cropped area. Rain-water harvesting is beneficial when used together with the techniques of soil water conservation where total seasonal rainfall is not sufficient for crop production.

In many semi-arid areas of Tanzania farmers practice some kind of rain water harvesting through valley farming, which involves intensive cultivation of valley floors, where runoff from slopes is concentrated. In Tabora and Shinyanga regions farmers have developed a system of rain-water harvesting which involves diversion of water from ephemeral streams to valley fields sub-divided by bunds of 25 - 100cm height to form cultivated reservoirs (paddies). The collected run-off is stored in these reservoirs for use by transplanted rice crop (Mwakalila, 1992).

The system of rain-water harvesting has been shown to work under varying environmental conditions and for different purposes around the world (Reij et al, 1988). Very limited research on rain water harvesting agriculture has been done in Tanzania to develop management strategies for its implementation. Furthermore, available rainwater harvesting research data has been collected under conditions of low intensity rainfall, whereas rainfall in the semi-arid areas of Tanzania is of high intensity with high risk of erosive storms.

1.3.4 Socio-economic status

The agricultural potential of land in Tanzania is divided into three broad categories: high potential areas, intermediate potential areas and low potential areas. Most high potential areas are the highlands and plateaux while the intermediate potential areas constitute the coastal and semi-arid lands in the central and north-eastern part of Tanzania. It is generally expected that high and intermediate potential areas are likely to have the greater response to economic and technical interventions.

In the low potential semi-arid lands, crop and livestock production can be carried out but at greater human effort and capital investment than in high potential areas (ADIS,1992). The farming system of the semi-arid lands of central Tanzania, is agro-pastoralism in which there is an interaction of arable cropping and cattle keeping. However, increasing population pressure and inappropriate agricultural practices has led to increased migration by agro-pastoralists from the semi-arid lands of Dodoma, Singida and Mara into Tabora, Mbeya and Morogoro regions (ADIS, 1992). Thus households in the semi-arid lands therefore are becoming increasingly dependent on crop production as a source of cash income. Sorghum and millet are the main staple grains in these areas. Field survey data show that annual crops are grown on an average of 3.6 plots per holding with an average area of 0.44 ha each (ADIS, 1992). The average household size is 4.8 persons and the dependency ratio is 1:3 (ADIS, 1992). Therefore, for many households labour shortage is a serious problem.

Most households in semi-arid lands cannot produce enough to satisfy food energy requirements. Apart from the rainfall constraint, Acker and Lev, 1986 point out that low soil fertility, poor use of available manure, soil erosion and poor crop husbandry are the factors contributing to low production. The role of pests and diseases on sorghum production has also been reported by Saadan, (1990). In semi-arid areas such as Dodoma low food productivity keeps the population in famine in most years (Box 2).

The mean value of the wealth index is 19.7 (ADIS, 1992). About 80 percent of households have an index of less than 25. This implies that for them to acquire other necessities, they have to sell a part of their produce (Table 1.7).

The second source of income is self employment. Mainly these are petty businesses conducted in the area and the major business is sale of locally brewed beer which uses staple food grains as raw materials, thus competing with demand for food uses.

Table 1.7: Percentage distribution of households by their main source of income

Source	Sale of Food crops	Sale of other crops	Petty trading	Employment	Other	Total
First	51	5	27	9	9	100
Second	32	8	37	8	15	100

Source: ADIS, 1992.

Box 2: The vicious cycle of poverty in semi-arid areas

Low productivity <-------------- Low consumption

Low investment <-------------- Low savings

The population is not evenly distributed on the available land. People are concentrated in more accessible areas along the major road network and within villages. This settlement pattern has led to intensive use of land close to settlements while more distant land is relatively under-used because of the difficulties of transport or of guarding crops against animals and pests. Until recently land accumulation was limited and this was attributed to the lack of a formal land market (Collier, et.al., 1986). The government's recent land tenure policy and law reviews propose individual rights to buy, lease and pledge for land.

This land use pattern has led to land degradation mainly due to deforestation, overstocking, burning, and inappropriate agricultural practices (Mbegu and Mlenge, 1983). In most farming systems soils have traditionally been cultivated on the basis of shifting cultivation. These systems have changed as people have concentrated in villages, with fallow periods shortening to the point where soils are being continuously cultivated (Table 1.8). In the case of Dodoma, overgrazing and reduced fallow appear to be the major causes of land degradation (Table 1.9).

Table 1.8: Distribution of holders by ease of access to new land for agricultural activities (% of holders in each zone). (After ADIS, 1992)

Zone	No problem	Quite difficult	Very difficult	No need for land
Newala *	71	26	2	1
Mbozi **	29	52	19	1
Urambo *	81	8	2	9
Kwimba *	29	31	34	6
Dodoma *	55	34	7	4
Hai **	3	55	41	0

Notes: * = Intermediate potential; ** = High potential

Table 1.9: Percentage distribution of holders by local agricultural practices identified as leading to degradation (After ADIS, 1992)

Overgrazing	Deforestation	Ploughing slopes	Bush burning	Reduced Fallow	Others
31	17	3	4	22	23

As discussed above there are a number of techniques which can be used to circumvent the constraints to crop production inherent to the semi-arid lands. The above mentioned techniques can only be useful and effective if they are identified, improved and adapted to farming systems and are in turn adopted and used by small farmers.

In Tanzania, as like elsewhere in the semi-arid tropics, shifting cultivation was the main way of soil-water conservation. Population pressure led to reduced fallow periods and farmers in these areas adapted by developing traditional soil-water management techniques. In the Uluguru mountains of Eastern Tanzania, for example, ladder terraces (trash contour ridges) have been used (Temple, 1972). In the Southwest of Tanzania, Matengo pits are used (Allan, 1965; Baschart, 1973). In the Ukara Island, Northern Tanzania, earth and stone terraces, tied ridging, stone barriers in gullies and mound cropping have been used (Allan, 1965; Ludwig, 1968). In the rice fields of Shinyanga region, farmers have developed effective soil-water management techniques to grow rice.

These indigenous techniques were developed within the constraints and preferences of small-holder farmers. In view of the inadequacy of the current indigenous techniques as exemplified by the low productivity of these farming systems more interventions need to be developed in order to increase the currently poor productivity levels. A number of interventions from research and extension, as outlined above, have been tried in various parts of the semi-arid tropics but the indigenous production system has not been changed to desirable levels.

The ADIS study (1992) identified the following constraints to adoption:

- Inability to transfer appropriate technology to farmers
- Lack of inputs and transport
- Lack of credit or its poor delivery system
- Lack of an efficient extension system for transferring new technology.

In most of soil and water management research work in Tanzania and elsewhere, land users have either been ignored or instructed rather than being consulted or trained. They usually responded with indifference, incomprehension or hostility, like in the Uluguru Land Use scheme of 1950 (Crichley et al., 1992).

There is a large body of literature on technology adoption by farmers, most of which pays little attention to the technology itself; but, the interaction between the characteristics of the technologies. The characteristics of the farmers and the farming systems have recently been emphasized (CIMMYT, 1993). Thus socio-economic characteristics such as wealth, land tenure and education are used to explain differences in technology adoption (De Vries, 1976; Fajardo, 1987).

2. METHODOLOGY

2.1 Location

The study was carried out in four villages namely Ipala, Hombolo Bwawani, Msanga and Chamwino (Figure 2.1). These are located between latitudes 5°55'to 6°05' S and longitude 35°50' to 36°05'E at an average altitude of 1,100 m a.s.l. Hombolo Bwawani and Ipala villages are within the Dodoma municipality while Chamwino and Msanga are located in Dodoma rural district. For the purpose of this research the two districts (urban and rural) will be referred as Dodoma District.

Ipala and Hombolo villages have flat to undulating plains with occasional inselbergs and seasonal streams. The topography of these two villages is dominated by the Hombolo reservoir across the Kinyasungwe river. The reservoir extends for about 9 km upstream. Msanga and Chamwino villages also have flat undulating plains with ephemeral streams which drain into bottom valleys. Large stones and boulders are common in all the four villages although they are dominant in Msanga and Chamwino.

Most of the soils are characterised by a low nutrient status, particularly with regards to phosphorus and exchangeable base content. Organic matter levels in the soils are low and the soils are susceptible to erosion. Only dark, sticky cracking clays and friable and calcareous clays found in poorly drained parts (lowland plains), which are very limited in extent have satisfactory amounts of exchangeable bases (Christianson, 1981; Morberg, 1990).

The climate in the four villages is dry savanna type characterised by a long dry season between April to late November and a short wet season (500 - 600 mm) from end of November to early April. The rainfall amount and frequency in the four villages is highly variable between and within seasons. Evaporation is always higher than rainfall throughout the year and it ranges from 2100 to 2200 mm per year.

The mean monthly temperature is 22.5°C and the highest 33°C (EAMD, 1975). The mean maximum and minimum temperatures are 29.9°C and 17.5°C, respectively. However, temperature extremes do occur with the lowest recorded being 8°C and the highest 33°C.

The natural vegetation consists of scattered baobab (*Adansonia digitata*) trees and acacia (*Hyporrhenia* spp.) bushes with grassland (Plate 1 b).

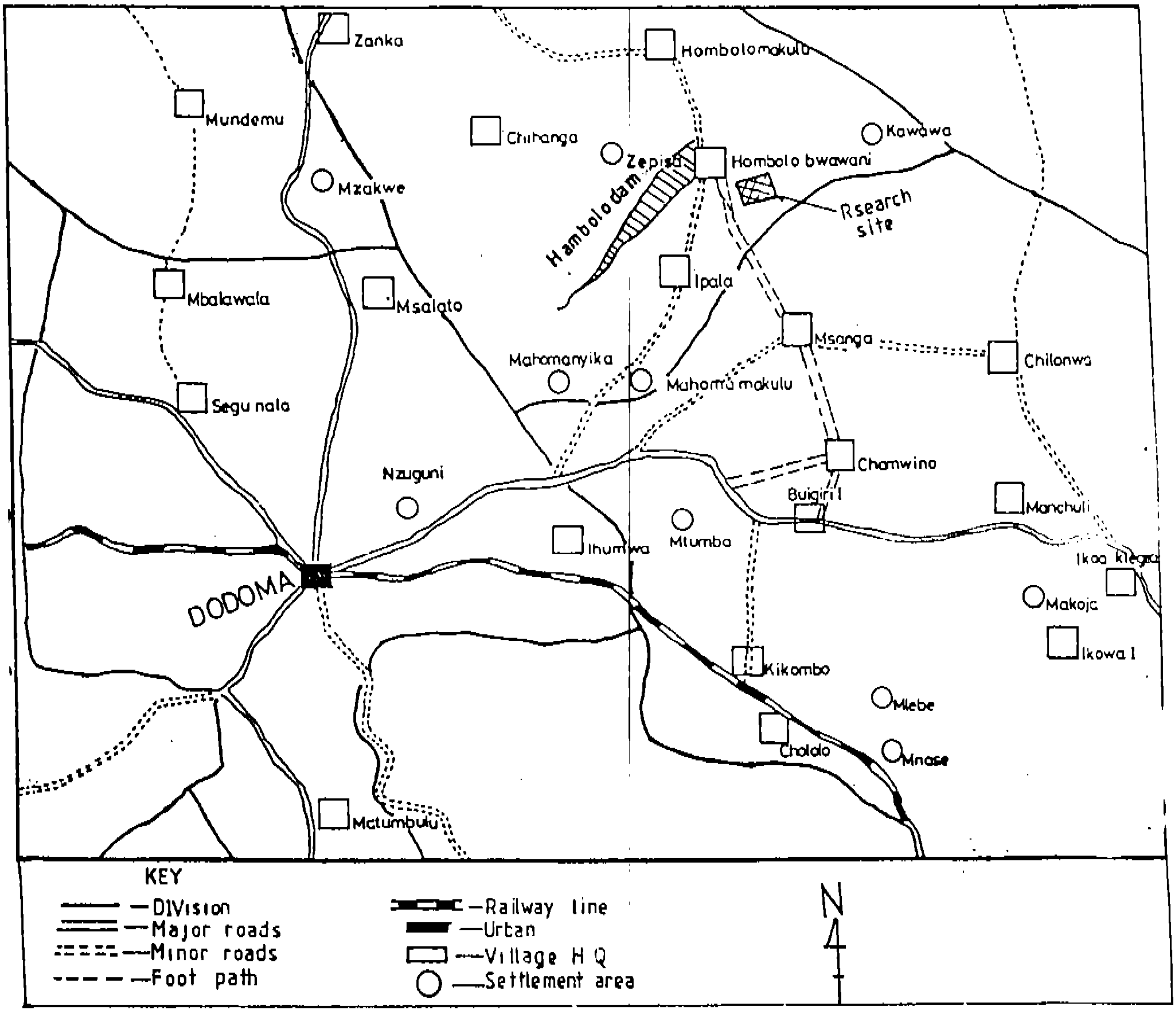


Figure 2.1: Location of the research area in Dodoma

2.2 Rainfall Analysis

2.2.1 Start and end of rainfall season

The method outlined by Ilesanmi (1972) and Alusa & Mushi (1974) was modified and used to determine the earliest possible onset and cessation dates of rainfall in Dodoma and Hombolo. Cumulative rainfall was derived from the mean daily rainfall and was plotted against day number with 1st January as day 1. The earliest possible dates on maxima and minima curvature points were then used as guides to derive the start and end dates of the growing season.

The start of the effective growing season was defined as the first occasion after an earliest possible date obtained (using rainfall record data) on which a running total of at least 20 mm of rain was reached in 4 days. This definition has been used by other workers, eg. Davy et al. (1976) in semi-arid areas of Niger, Ilesanmi (1972), Stern et al. (1982) in Nigeria, and Kassase et al. (1992) in Tanzania.

The end of the effective growing season was taken as the first occasion after an earliest possible ending date derived on which 15 consecutive dry days occurred following the first occasion. A day was considered dry if it has less than 3.0 mm of recorded rainfall. Such an amount is often insignificant in terms of its contribution to crops as it is usually lost through evaporation in a matter of few hours (Buishand, 1977; Stern et al., 1982 and Nieuwolt, 1989). INSTAT statistical package was used to determine the frequency distributions of start and end of rain season for each year. Frequency distributions of these events were plotted and percentage points at 20%, 50% and 80% were determined.

2.2.2 Dry spells

Mid-season dry spells are the most important rainfall parameter affecting crop growth and yield. Longest dry spells for each month were recorded by considering a wet day with 3 mm or more of rain and counting the number of days backwards to the last wet day. A dry spell was considered to belong in the month where it ended. Therefore, sometimes dry spells of more than 30 days were recorded for a particular month.

2.2.3 Seasonal rainfall analysis

Long term rainfall was analyzed for minimum, mean, amount exceeded at 70% probability of and maximum for both monthly and season. The methodology described by Unganai & Kabanda (1994) was used.

2.3 Soils

The on-station field experiments were located at Hombolo Bwawani village in an area of gently sloping (0 - 2%) terrain (Figure 2.2). The soils were fairly uniform based on the colour and texture. One representative soil profile was therefore dug to a depth of 1.84m. The morphology of the profile was studied and described using standard procedures (FAO, 1977, Soil Survey Staff, 1951, 1990).

The site (1.2 ha) was divided into four fairly homogeneous parts from which 8 sub-samples were collected from the top soil (0 - 20 cm). These were thoroughly mixed and sub-sampled to obtain one representative composite sample. A total of four composite samples were made. These samples were analyzed in the laboratory according to Page (1982) and Klute (1986) for the following physical and chemical properties:

- texture (Bouyoucos hydrometer method)
- bulk density (core sample method)
- pH potentiometrically in 1:2.5 soil/water and in KCl
- Organic Carbon - wet oxidation method of Walkley-Black
- Organic matter - estimated by multiplying the % organic C by Van Bemmelen factor of 1.724
- Total Nitrogen - Kjeldahl method
- Available P - Bray and Kurtz No.1 method
- Exchangeable bases and the CEC-Neutral Ammonium Acetate saturation method. The exchangeable bases were determined by atomic absorption spectrophotometry.

The field and laboratory data were used to classify the experimental soils to sub-group level of the US Soil Taxonomy (Soil Survey Staff, 1990) and to sub-unit level of the FAO - UNESCO/ISRIC (1989) system.

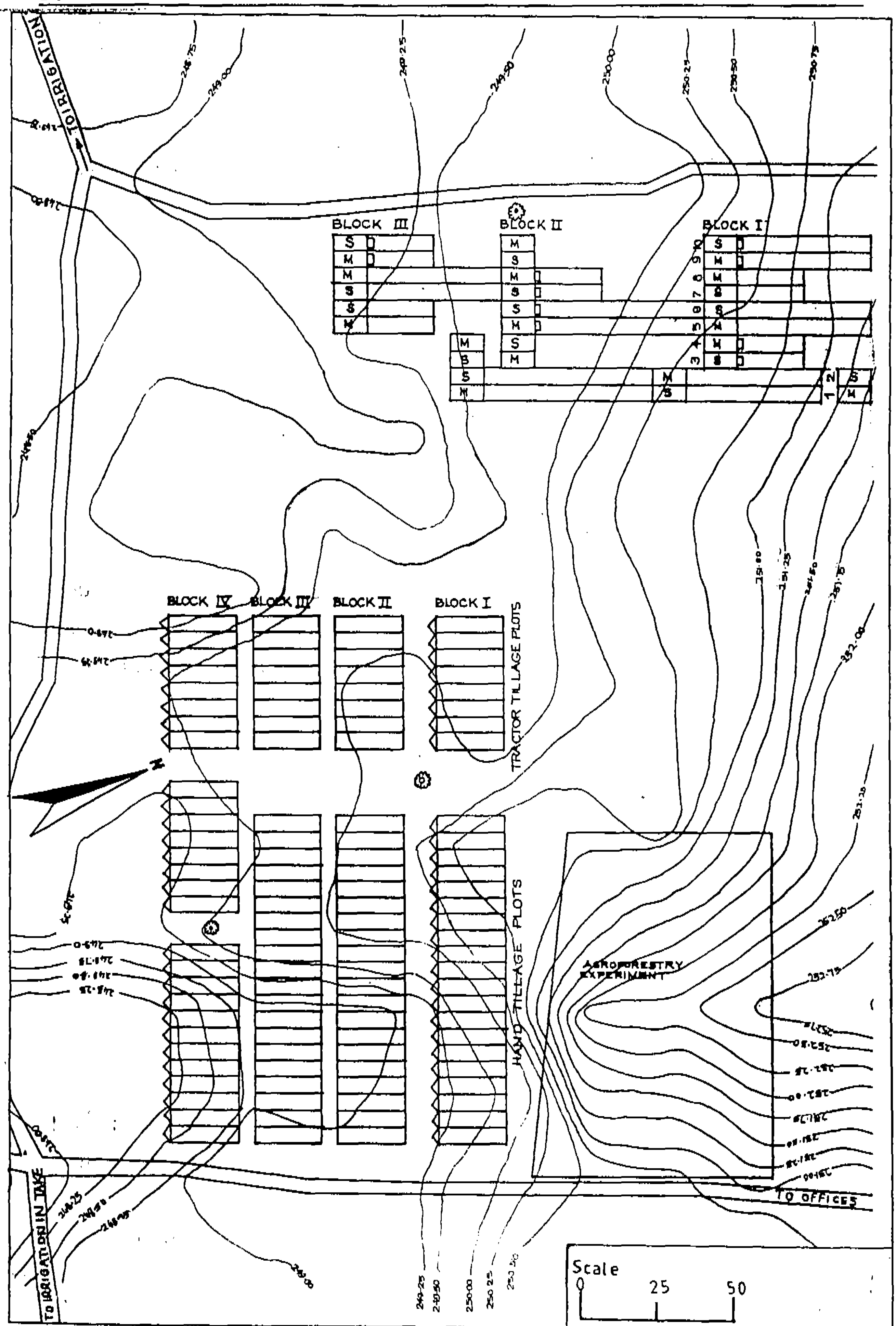


Figure 2.2: Contour map of the experimental site

The soil fertility status was determined by rating the soil properties which are used to indicate the fertility status against the general rating as adopted and modified from Landon (1984) (Table 2.1)

Table 2.1: General rating of organic matter, exchangeable bases and available P (Landon, 1984)

Soil property		Very low	Low	Medium	High	Very high
Organic matter (%)		< 1.0	1.0-2.0	2.0-4.0	4.0-6.0	> 6.0
Total N (%)		< 0.05	0.05-0.1	0.1-0.2	0.2-0.3	> 0.3
Exchangeable Cations (cmol (+)kg^{-1}	Ca^{2+}	< 2.0	2.0-5.0	5.0-10.0	10.0-20.0	> 20.0
	Mg^{2+}	< 0.5	0.5-1.5	1.5-3.0	3.0-8.0	> 8.0
	K^{+}	< 0.1	0.1-0.3	0.3-0.6	0.6-1.2	> 1.2
Bray & Kurtz 1 Available P(mgkg^{-1})			< 7.0	7.0-20.0	> 20.0	

Saturated hydraulic conductivity (K_{sat}) was determined by the disc permeameter method (CSIRO 1988). It was determined under three field conditions namely cultivated, undisturbed and compacted.

2.4 Field Experiments

In-order to derive quantitative data, develop and test different interventions, experiments were run through three growing seasons from 1991/92 to 1993/94. In addition, on-farm trials were initiated with farmers in all the four villages and run only for 1993/94 season.

2.4.1 Treatments

2.4.1.1 Tillage cum fertilizer experiment

The experiment consisted of 28 treatments with four replications. The treatments were a factorial combination of seven tillage methods and four fertilizer regimes. Each plot was 5x20 m^2 laid lengthwise up a slope of 1-2% and were arranged in a completely randomized block design (Figure 2.3). The tillage treatments were:

- Zero tillage (*'Kuberega'*), which is the technique commonly used by local farmers (SWMRP, 1991). It involved manual slashing of standing vegetation before making holes for planting into the bare ground .

- Flat cultivation, which involved digging across the slope with a hand hoe to a depth of 10 cm before planting.
- Flat cultivation with mulch, which involved the addition of mulch (1 t ha^{-1}) to a plot after the first weeding operation had been done .
- Strip catchment tillage, which involved digging to 10 cm depth a strip which is 20 cm wide before planting in the middle of the strip.
- Tie-ridging, which involved making parallel ridges across the slope, laid at 0.75 m apart and then the furrows were tied at 1.5 m intervals.
- Tractor tillage, which involved a three furrow disc plough, pulled by a 50 HP tractor ploughing at a depth of 15 cm.
- Tractor tillage with mulch, which involved the addition of a layer of mulch (1 t ha^{-1}) to a plot after the first weeding operation had been done.

The fertilizer treatments were:

- Control: No application of Farm Yard Manure (FYM) and / or Triple Super Phosphate (TSP);
- TSP alone applied at a rate of 100 Kg ha^{-1};
- FYM alone applied at a rate of 10 t ha^{-1}; and
- FYM plus TSP each applied at their respective half rates.

All plots were grown with sorghum (Sorghum bicolor var. Tegemeo) and 40 kg N ha^{-1} in the form of calcium ammonium nitrate (CAN) was top dressing to all plots at the 6th leaf stage.

2.4.1.2 Rain water harvesting (RWH) experiment

The experiment had five treatments with three replicates. The treatments were five levels of rain water harvesting where a bare slightly compacted area located above the cropped plot was allowed to generate and add run-off to the cropped plot (Figure 2.4). The two parts are Catchment Area (CA) and Cropped Basin (CB), respectively. The levels of RWH regime were determined by the Catchment: Basin Area Ratio (CBAR) with or without storage. Therefore, the RWH treatment were:

- CBAR of 0:1, i.e the cropped field was receiving no run-off
- CBAR of 2:1 without storage of run-off
- CBAR of 2:1 with storage of run-off
- CBAR of 4:1 without storage of run-off
- CBAR of 4:1 with storage of run-off

Each cropped field was ploughed with a tractor operated disc plough to a depth of 15 cm, and was 10 m x 10 m in size. The sides were demarcated with metal sheets buried to a depth of 15 cm. The upper side was left open to receive run-off, except for the 0:1 treatment. The catchments were cleared bare and slightly compacted with a hand pulled roller, to allow collection of run-off at about 20 - 30%, thus increasing the rainfall on the cropped field by 40 - 60% (2:1) or 80 - 90% (4:1). Storage was intended to improve distribution, by allowing the run-off to collect in a pond located between the catchment area and the cropped field. The collected run-off was applied to the cropped field every ten days unless another rainfall event occurred in between. Maize and sorghum were used as test crops on split plots.

2.4.2 Measurements

2.4.2.1 Soil and hydrological characteristics

Soil dry bulk density was determined for the site prior to the initiation of the experiment for the site. There after it was done after harvest for all seasons (and for 1993/94 season after tillage and after harvest). The bulk density was determined using the oven-dry weight of 98.2 cm^3 cores extracted from depths of 0-5, 5-10, 10-15 and 15-20 cm.

Cumulative infiltration was determined for each plot prior to the initiation of the experiment, and thereafter immediately after harvest for each season. The double ring infiltrometer method described by Klute (1986) was used.

One aluminium access tube (2.0 m long and internal diameter of 49 mm) was installed in each plot of blocks I & IV of the tillage cum fertilizer experiment (Fig. 2.3). Access tubes were installed in the RWH plots as shown in Figure 2.4. A neutron probe CPN 503 DR was employed to measure counts at depths of 10, 30, 50, 80, and 150 cm from the ground surface. Measurements were taken after a rainfall event or weekly in the absence of rainfall. However, due to logistical and supply problems this system of measuring moisture content was not ready until early 1993. Therefore, full data was obtained only in the 1993/94 season. The neutron probe had been calibrated under wet and dry conditions. The calibration curve was used to convert the counts into wet basis moisture content.

2.4.2.2 Runoff

Each plot in block I and IV was surrounded with metal sheets driven to a depth of 15 cm on the sides and the up-slope edge (Plate 1 c). Runoff was measured using the system shown in Figure 2.5 and Plate 1 d. This consisted of a divider drum with 15 outlet pipes of diameter 1.91 cm. The central outlet pipe was connected to the collector drum. The overflow pipes of the divider drum were adjusted such that the overflow volume draining into the collector drum was between 1/12 and 1/18 of the total overflow. Calibration of the runoff collection system was done in order to obtain the actual ratio of the overflow that drained into the collector drum. This ratio was used to calculate the total runoff from the plot. After each rainfall event the depth of runoff collected into each drum was measured, and then the volume of run-off was determined with the help of a depth to volume calibration curve which had been established for each drum . Again due to logistical, supply and construction delays, full data collection was only possible in the 1993/94 season.

2.4.2.3 Crop growth and yield

Sorghum (*Sorghum bicolor* var. Tegemeo) was planted at a spacing 0.75 m between rows and 0.3 m within each row. The target was to maintain 2 plants per hill and a plant population of 89,000 plants per ha (Plate 1 e). However, this was seldom achieved due to poor germination and establishment. Germination percentage was determined by counting the number of emerged plants seven days after first emergence (DAE).

Plant growth was monitored by measuring plant height and number of leaves from four randomly selected 1 m^2 areas in each plot. The measurements were taken at 22, 42 and 130 DAE.

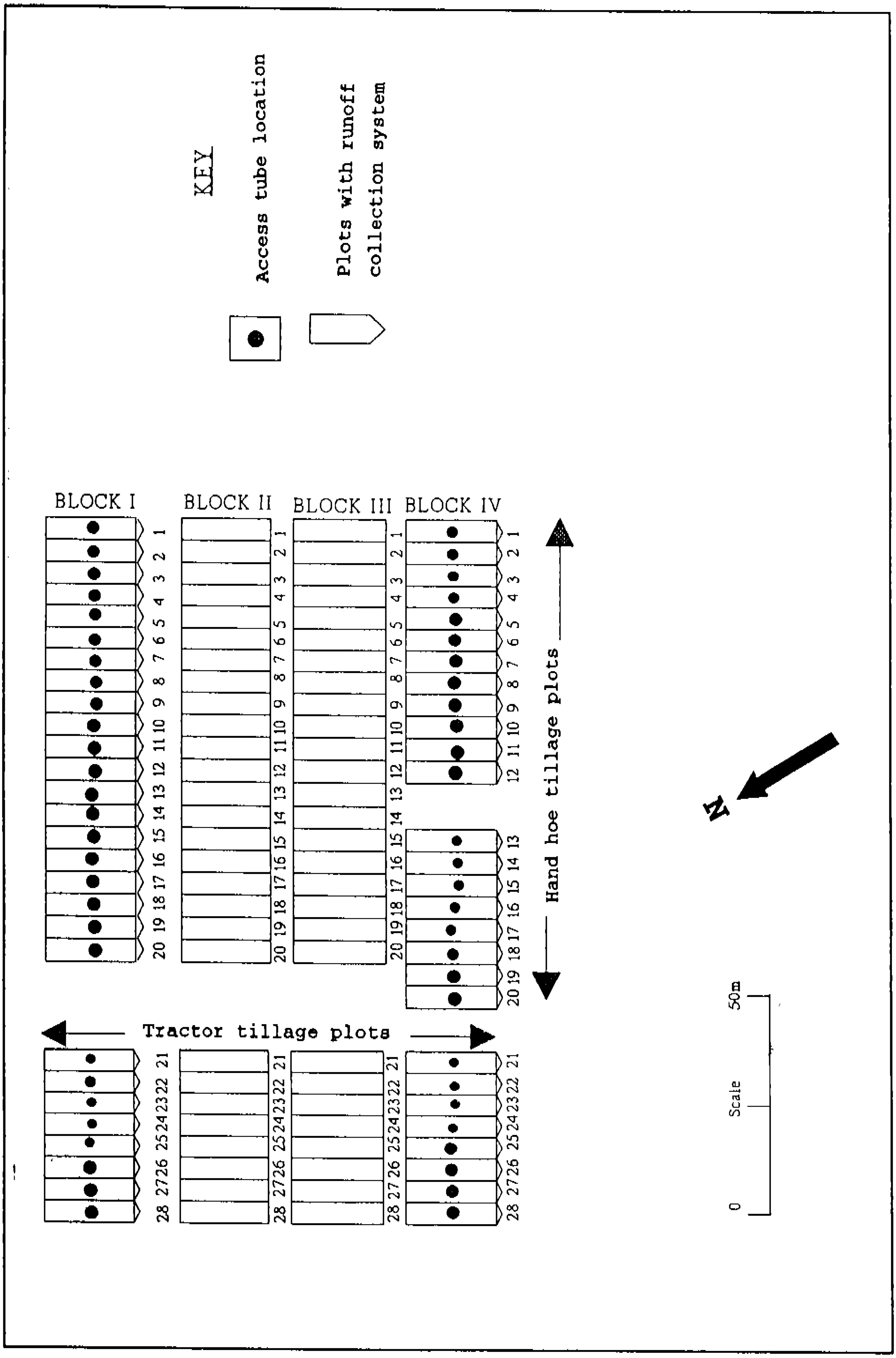


Figure 2.3 Layout of Hombolo tillage experiment

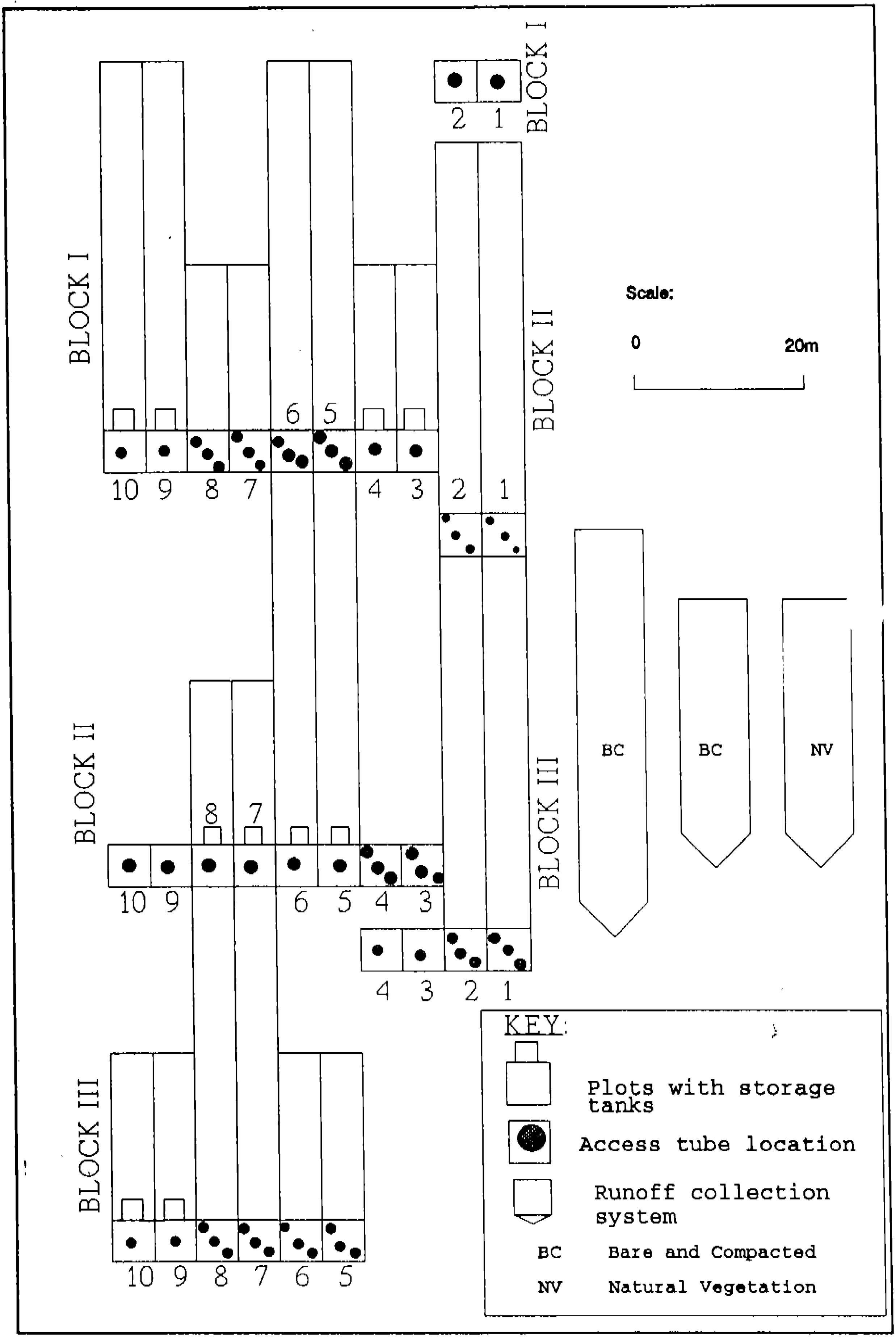


Figure 2.4: Layout of the Rain Water Harvesting Experiment at Hombolo

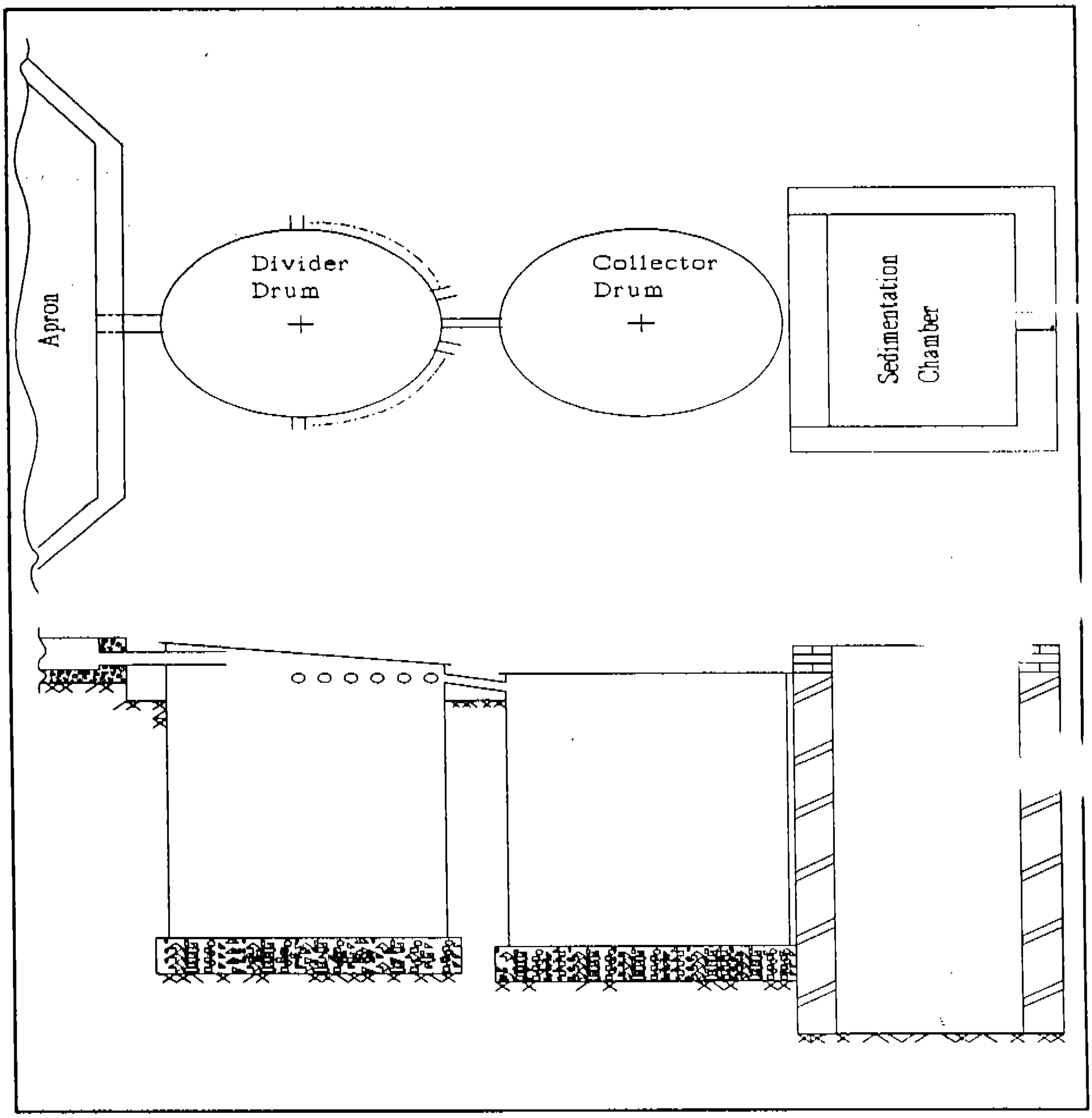


Figure 2.5: Runoff measuring system

2.5 Social-Economic Studies

2.5.1 Rapid rural appraisal

The aim of the Rapid Rural Appraisal (RRA) was to assess quickly the most important constraints to soil-water management for plant growth in the study area. The appraisal was conducted during the first week of September, 1991 by a multidisciplinary research team and the regional agricultural and livestock development office in Dodoma (SWMRP, 1991). The information was collected through direct observations as well as discussions with the local people in four villages namely Msanga, Chamwino, Hombolo Bwawani and Ipala. These were:

- Villagers (Plate 1 f)
- Farmers as individuals
- The village agricultural extension staff
- School teachers as a group
- Personnel in other institutions
- Researchers at Hombolo research station.

2.5.2 Single visit socio-economic survey

A systematic sampling technique was used to choose respondents in each village using a list of farmers. Farmers were stratified according to the land size and number of livestock owned. A single visit formal survey using a designed questionnaire was used to collect the data (SWMRP, 1993). The questionnaire was administered to a sample of 90 households per village. Therefore the total sample was 360 respondents from four villages. Cross tabulations and percentages were used in data analysis.

2.5.3 Farmer monitoring

Following the results of the RRA and the socio-economic survey a detailed farmer monitoring exercise was found to be necessary. This was carried out in Hombolo, Ipala, Msanga and Chamwino villages. The main purpose was to collect full season socio-economic data from the target villages and relate this information to soil-water management practices in the target villages. The information was collected through administering of a continuous questionnaire throughout the season. Data was entered on questionnaires weekly from the start of the cropping season.

The target farmers were also requested to set aside a plot of land on which to implement a selected soil-water management practice as agreed upon during the farmers' seminar. Farmers had full responsibility to manage the plot using their own resources. Only a few farmers were involved in the monitoring exercise (Table 2.2).

Table 2.2: Number of farmers involved in the monitoring

Village	Number of farmers monitored			Total
	Large	Medium	Small	
Hombolo	2	3	0	
Ipala	1	2	3	6
Msanga	1	2	2	5
Chamwino	2	3	1	6

Two schemes of questionnaire (SWMRP, 1993) were used to collect data in the 1993/94 season. All the two schemes were administered by village extension officers in the study area. The first scheme was administered at the beginning and end of the season. Data was collected on household characteristics, farm size and assets owned by the farmer (at the beginning and end of the season).

The second scheme was administered weekly with the aim of collecting information on a number of aspects including daily farming activities, labour allocation to activities on the farm, expenditure patterns and sources of income. Data from the study were analyzed mainly using cross tabulations and gross margins.

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PLATE 1:
a) The problem of run-off and erosion in the study area
b) Natural vegetation of the study area
c) Lay out of tillage trial plots
d) Run-off collection system
e) Plant spacing and density
f) Discussion with farmers during the RRA

3. RESULTS

3.1 Historical Rainfall Analysis

3.1.1 Rainfall characteristics

Rainfall is the most important climatic element in the semi-arid zone. The amount, intensity, and distribution of the rain are of decisive importance for soil erosion as well as for crop yields. In Dodoma district the year may be divided into two distinct seasons, a dry season lasting from May to October and a rainy season lasting from November to April (Table 3.1). Most of the rains fall between December and March.

3.1.1.1 Number of wet days and risk of dry spells

Dry spells occurring between December and April have significant influence on crop growth and yield. There is a 30% risk (i.e. 3 years out of 10) of dry spells of 11, 17, 20 and 15 days, for January, February, March, and April, respectively Table 3.1). Maximum observed dry spells for these months vary between 17 and 34 days.

3.1.1.2 Start, end and length of rainy season

Rains may start from as early as October to as late as December (Table 3.2). The end of rain is more certain and occur in May (Figure 3.1). Therefore, the main rainy season occurs from December to April. The length of the season mainly depends on the starting date. The effective length of the rainy season at Hombolo was found to vary between 124 days at 80% probability to 151 days at 20% probability. A linear correlation was found to exist between the starting day number and the length of the rainy season, such that

$$L = 216 - 0.84S \quad (r^2 = 0.71) \qquad (1)$$

Where: L = Length of growing season (days) and S = Start of rain season day number (where September 1st = day 1)

Table 3.1: Summary of long term rainfall characteristics for Hombolo

Month		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	season total
Rainfall (mm)	Minimum	0.0	0.0	0.0	0.0	35.7	39.7	7.0	0.8	0.0	0.0	0.0	0.0	326.3
	Mean	0.0	3.8	33.9	113.5	133.7	121.7	111.4	61.6	5.9	0.0	0.0	0.0	591.9
	70%[1]	0.0	0.0	9.6	60.8	83.8	81.8	82.0	20.8	2.8	0.0	0.0	0.0	518.0
	Maximum	0.3	43.6	88.5	290.5	293.7	253.1	180.0	212.2	24	0.7	0.5	0.0	881.6
Wet days	3 mm +	0	2	2	6	8	7	7	5	0	0	0	0	37
	5 mm +	0	1	1	5	6	6	5	3	0	0	0	0	22
	10 mm +	0	1	1	3	4	4	2	2.2	0	0	0	0	18
Longest dry spell (days)	Minimum	30	21	5	5	4	3	4	1	8	22	31	31	
	30%[2]	30	31	27	19	11	17	20	15	31	30	31	31	
	Mean	30.1	30.5	19	17	8	12	14	13	29	34	31	31	
	Maximum	31	31	30	41	17	25	27	34	48	58	31	31	

1 = Probability of exceeding; 2 = Risk

Table 3.2: Earliest possible dates for onset and cessation of rains in Dodoma and Hombolo

Station	Onset date at different probabilities					Cessation date at different probabilities				
	Earliest	20%	50%	80%	s.d	earliest	20%	50%	80%	s.d
Dodoma Airport	14 Oct	25 Nov	6 Dec	21 Dec	14 days	5 Apr	10 Apr	15 Apr	23 Apr	9 Days
Hombolo	11 Oct	18 Nov	3 Dec	19 Dec	14 Days	8 Apr	15 Apr	19 Apr	27 Apr	10 Days

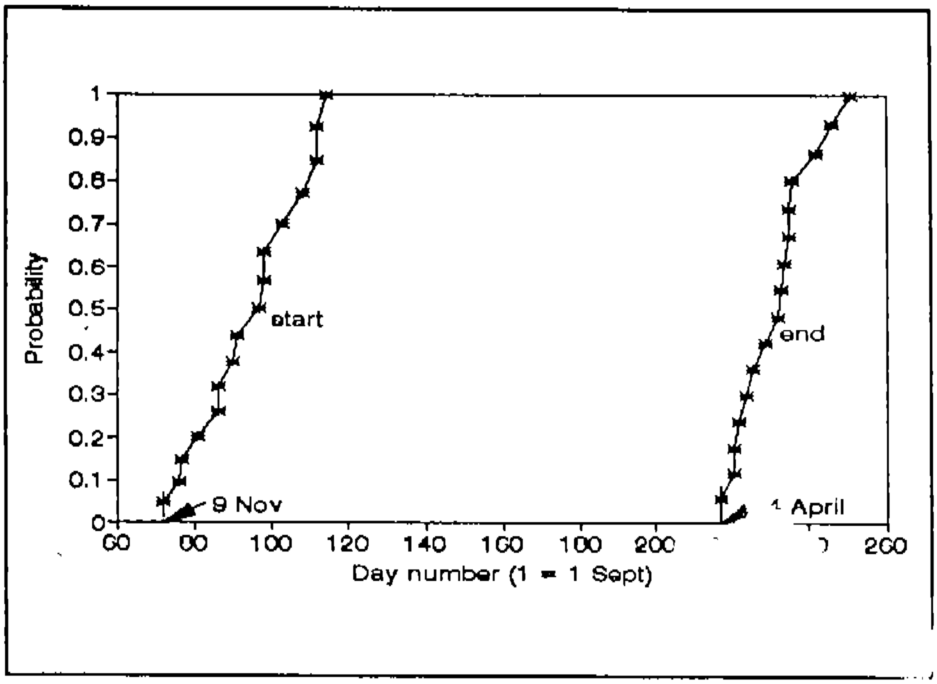

Figure 3.1: Cumulative probability of start and end of rains

3.1.1.3 Daily rainfall and intensities

Rainfall intensities for ten years (1968 - 1977) at Dodoma Airport are presented in Figures 3.2 and 3.3. At the onset and end of the rainy season lower rainfall intensities were observed, ranging from 0-15 $mmhr^{-1}$. Five minutes intensities higher than 100 $mmhr^{-1}$ were observed in March and April, (Figure 3.1) while 30 minutes intensities higher than 50 $mmhr^{-1}$ were observed in January, March and April (Figure 3.3).

3.1.1.4 Monthly and seasonal rainfall

The results of long term analysis of rainfall show that only the months of January and February receive a minimum rainfall of between 35 and 40 mm [Table 3.1]. All the other months within the rainy season (October to May) may experience total drought. The probabilities of having significant amounts of rainfall in these months was found to be 10% (October); 70% (November) 95% (December); 95% (March); 90% (April); 30% (May) (Table 3.3).

The minimum seasonal total rainfall is 326.3 mm and the long term average (592 mm) is exceeded in only 3 out of every ten years. The amount of rainfall that is exceeded in 7 out of ten years is 518 mm and the maximum observed seasonal rainfall is 881.6 mm.

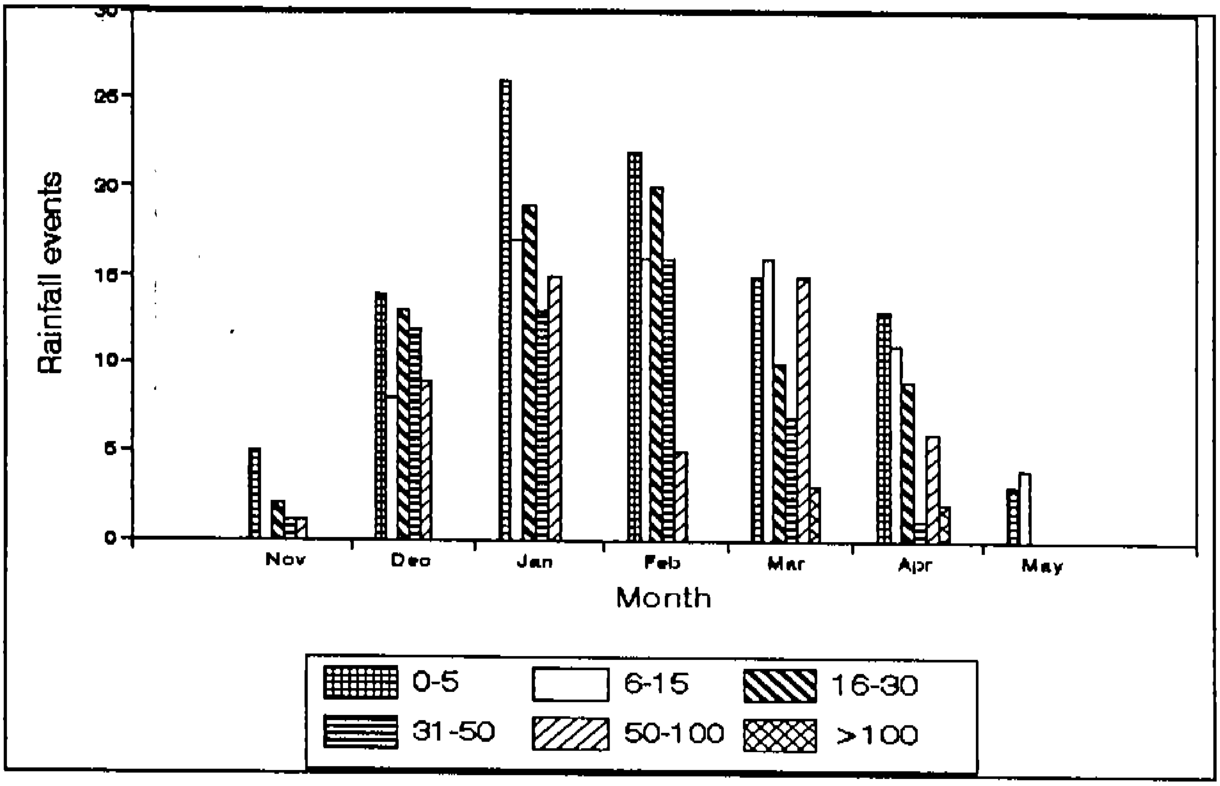

Figure 3.2: Distribution of 5 minutes rainfall intensities (mm hr^{-1}) for 10 years (1968 - 1977) Dodoma airport

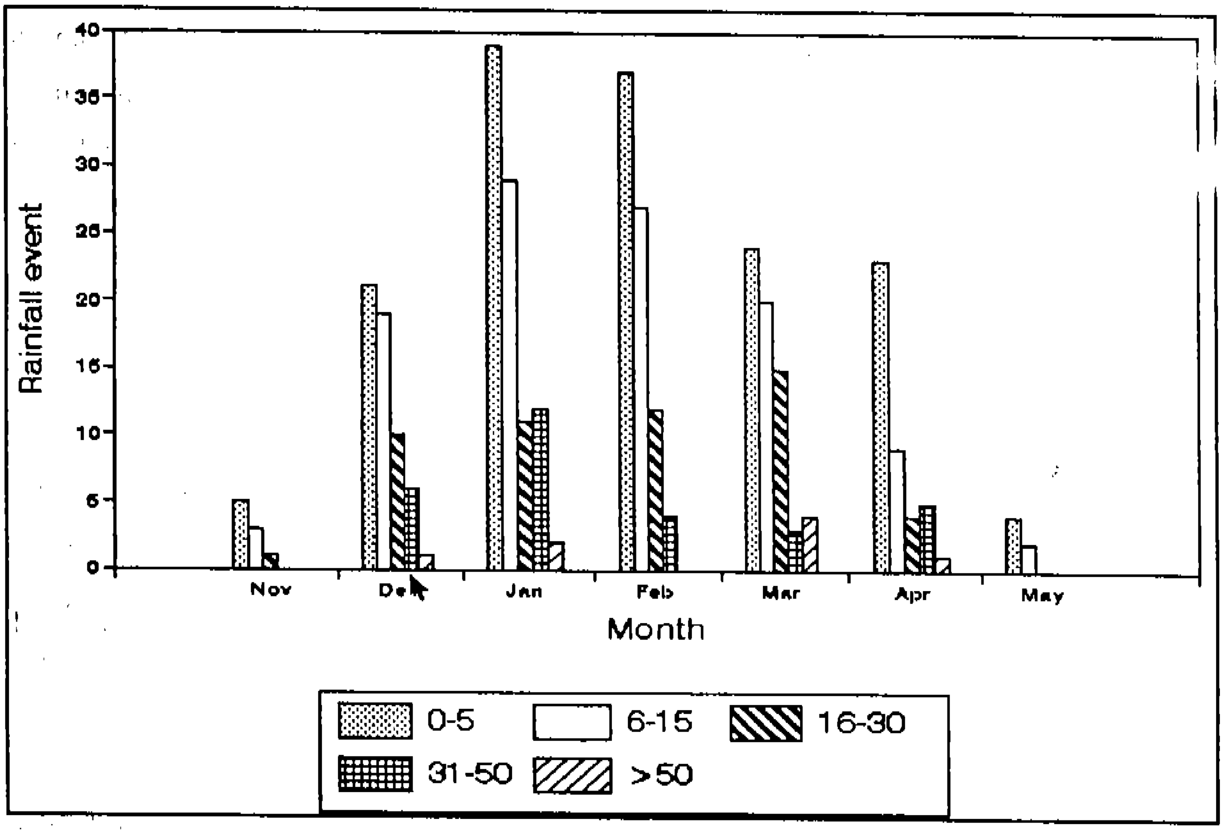

Figure 3.3: Distribution of 30 minutes rainfall intensities (mm hr^{-1}) for 10 years (1968 - 1977) Dodoma airport

Table 3.3: Hombolo: Ranked annual Rainfall (mm) (Over 20 years)

Year	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total(mm)
1976/77	0.0	0.0	1.2	54.4	137.6	68.5	7.0	39.6	18.0	0.0	0.0	0.0	326.3
1985/86	0.0	0.0	53.4	61.9	128.6	82.8	82.0	21.7	12.7	0.0	0.0	0.0	443.1
1974/75	0.0	0.0	0.0	60.8	135.1	81.8	177.4	10.4	4.1	0.0	0.0	0.0	469.6
1975/76	0.0	0.0	0.0	172.1	35.7	110.5	136.5	26	3.1	0.0	0.0	0.0	483.9
1983/84	0.0	0.0	5.3	139.8	111.9	95.7	65.6	94.6	0	0.7	0.0	0.0	513.6
1987/88	0.0	0.3	88.5	12.7	196.0	39.7	180.0	0.8	0.0	0.0	0.0	0.0	518.0
1981/82	0.3	0.7	20.3	113.5	131.7	63.1	107.7	85	3.1	0.0	0.0	0.0	525.4
1984/85	0.0	0.0	25.9	70.4	96.7	177.4	145.1	20.4	8.8	0.0	0.5	0.0	545.2
1992/93	0.0	0.0	87.8	17	250.3	101.6	82.8	11.3	2.3	0.0	0.0	0.0	553.1
1977/78	0.0	0.4	31.7	190.6	74.7	128.7	103.9	38.0	0.0	0.0	0.0	0.0	568.0
1982/83	0.0	43.6	88.5	146.3	83.8	82.8	112.2	5.4	7.3	0.0	0.0	0.0	569.9
1979/80	0.0	0.0	9.6	107.2	137.1	79.7	70	166.1	1.7	0.0	0.0	0.0	571.4
1991/92	0.0	0.0	0.2	77.5	55.6	195.4	178.9	77.5	3.1	0.0	0.0	0.0	588.2
1990/91	0.0	0.4	34.6	42.4	181.8	99.8	204.6	16.2	12.7	0.0	0.0	0.0	592.5
1993/94	0.0	23.1	6.2	2.9	293.7	135.9	126.1	20.8	4.3	0.0	0.0	0.0	616.0
1980/81	0.0	0.0	84.4	132.4	57.5	206.3	135.7	37.5	8.1	0.6	0.0	0.0	662.5
1986/87	0.0	0.9	23.2	121.6	223.6	139.7	66.8	58	12.3	0.0	0.0	0.0	746.1
1988/89	0.0	0.0	10.0	138.2	194.2	108.8	155.5	212.2	2.5	0.0	0.0	0.0	821.4
1978/79	0.0	0.0	29.4	181.7	148.4	253.1	118.9	109.1	2.8	0.0	0.0	0.0	843.4
1989/90	0.0	2.3	43.5	290.5	77.7	235.7	138.0	92.3	1.6	0.0	0.0	0.0	881.6

3.1.2 Rainfall patterns during the Research Period

There was marked variability in the seasonal rainfall during the trial period (Table 3.4, Fig. 3.4). During the first season (1991/92) the rains started in December which obtained 8 wet days (with 3 mm of rain or more). However, it was followed by a dry period in January where 55.6 mm were received but with only 1 wet day and a dry spell of 18 days. A long dry spell of 12 days was also observed in March. The total seasonal rainfall was 589.6 mm which was close to the long term average.

Of the three trial seasons, the second season (1992/93) received the worst distribution of rainfall. The rainfall started very early in November which received 87.8 mm with six wet days. However, a dry period was observed in December which received only 17 mm and a dry spell of 12 days. Highest rainfall was received in January (249.8 mm) but still a dry spell of 12 days was observed. The total seasonal rainfall was 552.6 mm which is below the long term average.

The third season (1993/94) was the best in terms of distribution and amount. The rains did not start effectively until January when 293.7 mm were received. The longest dry spells observed in January, February and March were only 7, 5 and 6 days, respectively. The total seasonal rainfall received was 647.4 mm which was significantly above the long term average.

The coincidental variation in rainfall patterns during the project period provided a good opportunity to assess the effect of rainfall pattern on crop growth and yield since one year was below average, another above average, and the third was average. Similarly, it will be interesting to assess the impact of the different interventions under the three different rainfall patterns.

3.1.3 Other weather parameters

Open pan evaporation data also showed interesting patterns during the research period (Table 3.5). The relationship between monthly evaporation and rainfall show that evaporation exceeded rainfall in all months except January and February (1991/92), January (1992/93) and January, February & March (1993/94). This also gives an indication of the relative quality of the three seasons, and again 1993/94 is shown to be a good year.

Table 3.4: Summary of rainfall characteristics at Hombolo during the research period

Parameter	Year	Month											
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Rainfall (mm)	1991-92	0	0	0	78	56	195	179	78	3	0	0	0
	1992-93	0	0	88	17	250	102	83	11	2	0	0	0
	1993-94	0	23	6	3	294	136	129	21	4	0	0	0
Wet days (3 mm +)	1991-92	0	0	0	8	1	11	5	7	0	0	0	0
	1992-93	0	0	6	2	9	5	4	0	0	0	0	0
	1993-94	0	2	0	0	11	10	5	1	0	0	0	0
Longest dry spell (days)	1991-92	30	31	30	14	17	17	21	9	37	30	31	31
	1992-93	30	31	15	25	12	8	12	34	31	30	31	31
	1993-94	30	31	30	31	7	11	6	12	48	30	31	31

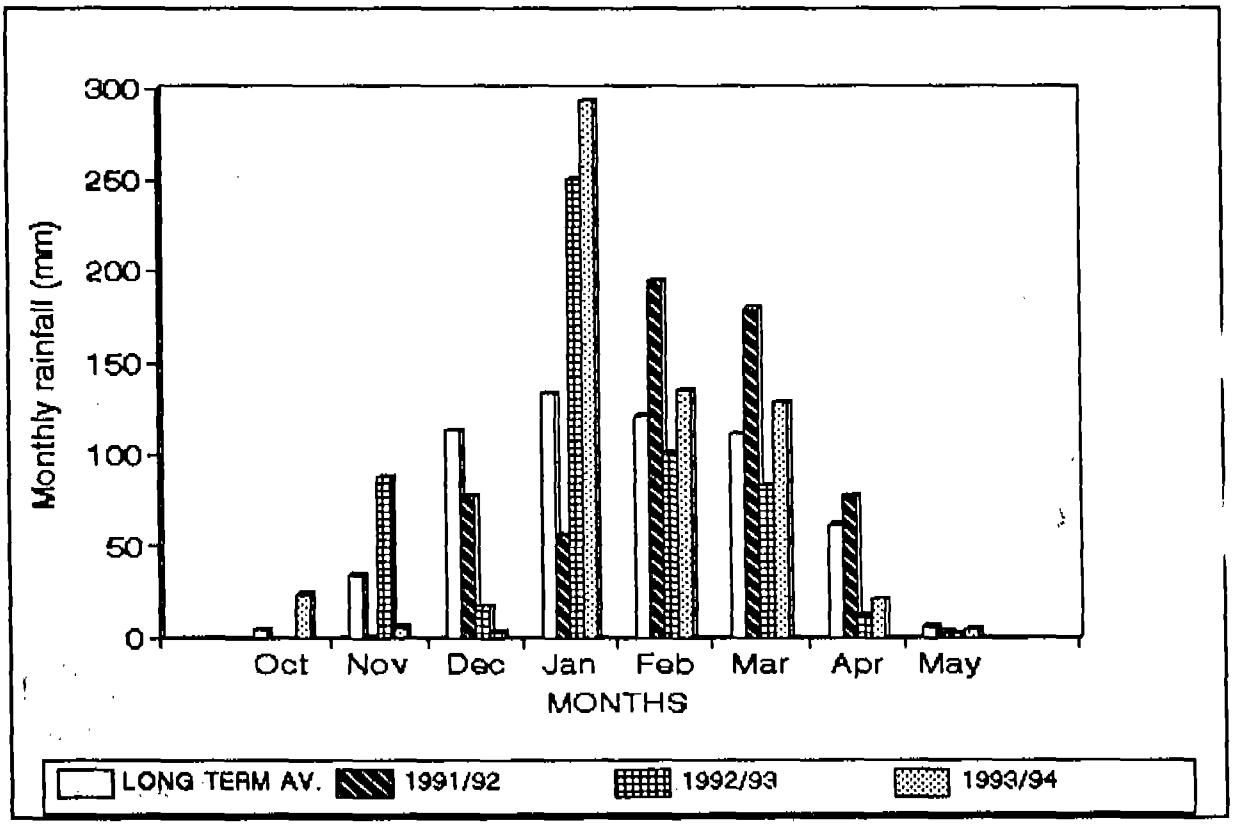

Figure 3.4: Rainfall Pattern during the project years

Table 3.5: Other important weather parameters

Month	Total Pan Evaporation (mm)				Mean Maximum Temperature °C				Mean Minimum Temperature °C			
	91/92	92/93	93/94	Aver	91/92	92/93	93/94	Aver	91/92	92/93	93/94	Aver
Sept		264.0	272.6	267.8		29.9	29.4	30.5		18.4	16.2	17.1
Oct		330.5	326.7	328.6		31.9	31.2	31.6		18.4	18.2	18.5
Nov		244.8	310.6	286.7	32.7	30.9	33.2	32.0	19.1	19.2	19.8	19.2
Dec		215.1	365.4	249.5	30.7	29.9	34.1	30.7	19.7	19.8	20.3	19.4
Jan	172.7	199.3	206.7	192.9	32.4	28.2	30.3	29.9	20.0	19.0	19.9	19.0
Feb	146.5	143.1	126.1	133.7	29.7	29.3	29.0	29.8	19.3	18.5	19.0	18.5
Mar	164.6	162.8	114.1	129.8	28.8	29.6	29.1	29.6	19.3	19.0	18.6	18.6
Apr	142.4	159.6	152.9	158.6	29.1	29.8	29.4	29.2	18.2	19.0	17.5	18.3
May	148.1	180.8	152.7	126.2	28.6	29.7	28.4	28.7	16.9	17.6	16.9	16.4
Jun	165.0	199.0	185.5	182.6	27.9	28.2	28.4	29.2	15.5	16.0	14.3	14.4
Jul	163.5	196.0	176.0	191.3	27.3	27.0	27.7	27.4	13.7	13.0	14.1	13.9
Aug	239.5	229.2	219.0	228.9	27.7	27.9	28.5	28.2	14.5	15.3	15.7	15.3

3.2 Soils and Hydrological Properties

3.2.1 Soil morphological characteristics and classification

The soil at the experimental site is classified as Typic Ustorthent in the US Soil Taxonomy and as Dystric Regosol in the FAO-UNESCO system. The soil profile is fairly deep (> 100 cm) with texture ranging from sandy to sandy clay on the surface to sand clay loam in the subsoil (Plate 2). The structure of the surface horizon is weakly developed. The profile is characterized by an ochric epipedon and no other diagnostic horizon is recognized. The sand fraction in the profile is dominated by quartz minerals. The moisture and temperature regimes of the soil are ustic and thermic, respectively.

The soil reaction of the profile range from strongly acidic (pH 5.1) to medium acidic (pH 6.0) and it varies irregularly with depth with surface horizon having pH of 5.4 and the deepest horizon pH of 5.3. The exchangeable Aluminium is fairly low in the Ap horizon (i.e. 0.8 cmol (+) kg^{-1}) and it increases with depth to 3.0 cmol (+)kg^{-1} at 102 cm depth, after which there is a gradual decrease in the levels of exchangeable Al to 1.0 cmol(+)kg^{-1} at the bottom of the profile. The high levels of exchangeable Al in the subsurface horizons may adversely affect deep rooted crops. Phosphorus availability may also be reduced in the subsurface horizons because of the high levels of exchangeable Al. The low levels of organic carbon, total N, total exchangeable bases and a base saturation of less than 50% in the Ap horizon indicate that the soils are generally poor in fertility (Table 3.6).

Therefore, the soil of the experimental site are characterized by sandy to sandy clay surface soils and sandy clay loams in the subsoil. The structure of the surface and subsurface horizons (0-30 and 30-150 cm depths, is weakly developed whereas that of the deep soil is strongly developed with coarse sub-angular blocky quartz gravel, (at 150-184 cm depth). The bulk density of surface soils is 1.43-1.53 gcm^{-3}, increasing with depth. Total porosity of surface soils is 42%, that of subsoils is 35% and 30% deep for soils. The surface soils are also characterized by hard setting and crusting phenomena, rendering them relatively impermeable to water. The cumulative infiltration over a period of three hours was 55.9 mm and the saturated hydraulic conductivity was 71.5 cm day^{-1}. The chemical properties of the soils are characterized by soil reaction of pH 5.1-6.0, low levels of organic carbon (C), total nitrogen (N), and exchangeable bases (Ca^{2+}, Na^{+}, K), and therefore, generally of poor fertility (Table 3.7).

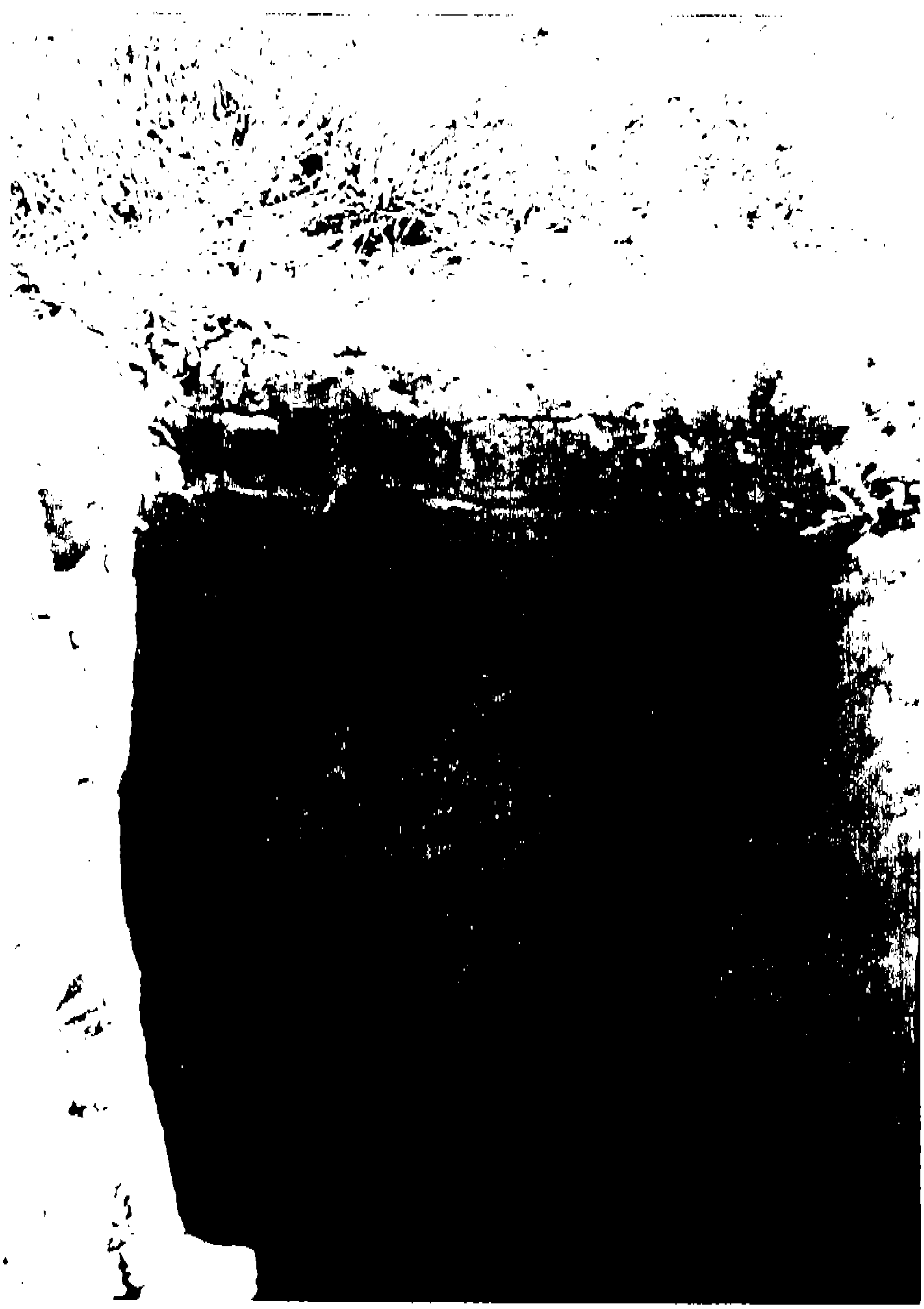

PLATE 2: Profile pit at Hombolo experimental site

Table 3.7: Initial characteristics of the top soil (0-20 cm) of the experimental area

Soil property		Sample number				Mean ± s.d
		1	2	3	4	
Texture:	clay (%)	20.0	16.0	27.0	21.0	21.0 + 4.5
	silt (%)	2.0	5.0	4.0	2.0	3.3 ± 1.5
	sand (5)	78.0	79.0	69.0	77.0	75.8 ± 4.6
	Textural Class	SCL*	SL**	CSL*	SCL*	SCL*
Bulk Density (Mg m^{-3})		1.46	1.43	1.53	1.52	1.49
pH	(in 1:2.5 water)	6.0	5.3	6.0	6.2	5.9 ± 0.4
	(in 1:2.5 KCl)	4.1	4.1	4.7	4.5	4.4 ± 0.3
Organic Carbon (%)		0.54	0.47	0.45	0.65	0.53 ± 0.09
Organic matter (%)		0.93	0.81	0.78	1.12	0.91 ± 0.15
Total Nitrogen (%)		0.05	0.05	0.06	0.05	0.05 ± 0.01
Available P (mg/kg)		5.6	6.0	5.6	5.6	5.7 ± 0.2
Exchangeable cations (cmol(+)kg^{-1})	Ca^{2+}	4.0	2.4	4.8	10.4	5.4 ± 3.5
	Mg^{2+}	0.8	0.3	1.4	0.9	0.9 ± 0.5
	Na^{+}	1.2	1.0	0.9	1.1	1.1 ± 0.1
	K^{+}	0.6	0.7	1.1	0.7	0.8 ± 0.2
Exchangeable bases (cmol(+)kg^{-1})		6.6	4.4	8.2	13.1	8.1 ± 3.7
Exchangeable Al (cmol(+)kg^{-1})		0.5	1.2	0.0	0.1	0.5 ± 0.5
Cations Exch. capacity (cmol(+)kg^{-1})		11.0	16.0	15.0	14.8	14.2 ± 2.[illegible]
Bases saturation (%)		60.0	27.5	54.7	88.5	57.7 ± 25.0

* SCL = Sandy clay loam ** SL = Sandy loam

3.2.2 Effects of tillage on bulk density over the research period

There was a decrease in soil bulky density of the top (0-15 cm) soil (Table 3.8). The decrease was much higher at depths 5-10 cm and 10-15 cm. However, at depths 15-20 cm, there was no reduction in bulk density for all the treatments except tractor tillage plus mulch where there was a 1.4% reduction. For example, for flat cultivation there was an increase of 13.8% in bulk density at harvest compared to the pre-planting period.

The highest and lowest bulk density at planting and harvesting (1.65 and 1.62 Mg m^{-3}, respectively) of the top 0 - 5cm soil depth was observed under flat cultivation. However, down the profile, there was a gradual decrease, reaching 1.38 Mg m^{-3} during planting at 15 - 20 cm depth during planting. In the zero tillage, the variation down the profile (0 - 20 cm) was very small. Bulk density ranged between 1.49 to 1.55 Mg m^{-3}.

There was an increase in bulk density in all the three cropping seasons when compared to the bulk density prior to the experiment. For the top 0 - 5 cm soil depth, the highest increase (10.9%) was observed under flat cultivation plus mulch and flat cultivation (10.9%) followed by zero tillage (10.2%). Across the seasons, there was a general increase in bulk density of the top 0 - 5cm soil depth. Bulk density in 1993/94 season increased by 4.6%, 5.8%, 3.8% for tied-ridging, flat cultivation and flat cultivation plus mulch, respectively. For tractor tillage and tractor tillage plus mulch there was also a gradual increase in bulk density in the three seasons.

3.2.3 Effects of tillage on cumulative infiltration

In all three seasons, FCM gave relatively higher cumulative infiltration at harvest followed by SCT and FC (Table 3.9). Tractor tillage and tractor tillage with mulch showed low cumulative infiltration compared to flat cultivation with hand hoe. This is opposite to what would be expected in relation to the bulk density patterns (Table 3.8), which indicates that cumulative infiltration should have been higher in all the three seasons. Tied-ridging gave the lowest cumulative infiltration in all the three seasons. This is because the infiltration was carried out on the furrows where soil was scooped to make the ridges. Across season comparison shows that there was in general increase in cumulative infiltration except for tied-ridging. This was again an unexpected trend which could have been due to the cumulative effect of farm yard manure.

Table 3.10: Effects of tillage on generated run-off during the 1993/94 season

	Rainfall			Generated Runoff, mm (% of rainfall)[1]						
Growth stage	Date	Ranked Amount (mm)	Intensity I_6 (mm/hr)	ZT	FC	FC+M	SCT	TR	TT	TT+M
Sowing to Tillering	4/1/94	6.2	7.67	0.3 (4.4)	0.07 (1.1)	0.03 (0.5)	0.13 (2.1)	0.00 (0.0)	0.01 (0.2)	0.00 (0.0)
	14/1/94	12.2	9.61	1.5 (12.2)	0.45 (3.7)	0.40 (3.3)	1.21 (9.9)	0.04 (0.3)	0.02 (0.2)	0.02 (0.2)
	15/1/94	10.1	77.36	0.9 (8.4)	0.63 (8.4)	0.67 (6.2)	0.78 (0.7)	0.10 (7.7)	0.12 (1.0)	0.08 (1.8)
	3/1/94	35.1	92.25	3.3 (9.2)	17.68 (50.4)	11.0 (31.3)	16.0 (45.5)	0.01 (0.1)	4.87 (13.9)	0.97 (2.8)
	25/1/94	62.4	152.13	**	**	**	**	7.47 (12.0)	**	**
	7/1/94	63.0	50.01	**	**	14.3 (22.7)	31.9 (50.6)	0.76 (1.2)	17.20 (27.3)	12.83 (20.4)
Tillering to Flowering	6/2/94	7.0	16.61	0.0 (0.0)	0.02	0.01	0.01	0.00	0.00	0.00
	25/2/94	7.1	18.81	0.0 (0.0)	0.04	0.01	0.01	0.00	0.00	0.00
	17/2/94	11.4	5.42	0.2 (1.2)	0.11 (1.0)	0.12 (1.1)	0.13 (1.1)	0.11 (1.0)	0.17 (1.5)	0.16 (1.4)
	12/2/94	15.5	21.33	1.2 (7.5)	0.45 (2.9)	0.74 (4.8)	0.60 (3.9)	0.11 (0.8)	0.32 (2.1)	0.04 (0.3)
	11/2/94	21.6	27.62	0.8 (3.7)	0.51 (2.4)	0.30 (1.7)	0.48 (2.2)	0.01 (0.8)	0.27 (1.3)	0.02 (0.1)
	21/2/94	26.7	65.38	5.2 (19.6)	7.47 (28.5)	6.43 (24.5)	9.23 (35.2)	0.92 (3.5)	14.05 (53.6)	9.35 (35.7)
	7/2/94	29.0	143.81	3.7 (12.8)	1.35 (4.7)	0.19 (0.7)	1.10 (3.8)	0.35 (1.2)	2.07 (7.1)	2.33 (8.0)
Flowering to Harvest	29/3/94	4.0	7.73	0.0 (0.0)	0.00	0.00	0.00	0.00	0.00	0.00
	11/4/94	5.9	27.40	0.0 (0.0)	0.01 (0.2)	0.01 (0.2)	0.00 (0.0)	0.00 (0.0)	0.01 (0.2)	0.01 (0.2)
	13/3/94	9.0	25.41	0.2 (2.4)	0.06 (0.7)	0.08 (0.9)	0.19 (2.1)	0.01 (0.1)	0.32 (3.6)	0.05 (0.6)
	18/3/94	11.0	52.88	1.0 (9.2)	0.59 (5.4)	0.52 (4.7)	0.68 (6.2)	0.01 (0.1)	0.74 (6.7)	0.20 (0.2)
	26/3/94	15.8	23.05	2.9 (18.4)	1.50 (9.4)	0.24 (1.5)	2.64 (16.6)	0[illegible] [illegible].5)	1.07 (6.7)	0.53 (3.3)
	14/4/94	11.1	37.30	0.7 (4.1)	0.66 (3.9)	0.04 (0.2)	0.86 (5.1)	[illegible] (0.9)	0.53 (3.1)	0.02 (0.1)
	6/3/94	18.7	27.76	2.6 (13.7)	3.24 (17.3)	2.12 (11.3)	4.07 (21.8)	[illegible]9 (1.6)	5.09 (27.2)	3.70 (20.3)
	2/3/94	22.6	44.94	0.6 (2.6)	0.04 (0.2)	0.25 (1.1)	0.36 (1.[illegible]	0.00 [illegible].0)	0.00 (0.0)	0.00 (0.0)
	3/3/94	28.6	18.65	4.5 (15.7)	3.51 (12.3)	1.93 (6.8)	4.16 ([illegible])	0 4[illegible] [illegible]1.5)	4.00 (13.9)	3.34 (11.7)
	17/3/9	5.3	56.06	1.7 (4.7)	1.5 [illegible].5)	1.40 (3.9)	2.32 (6.6)	0.26 (0.7)	2.63 (7.5)	2.36 (6.7)

Note: [1] SCT = strip catchment tillage, TR = Tied ridging, FC = flat cultiva[illegible] FCM = Flat cultivation with mulch, ZT = zero tillage, TT = Tractor tillage and TTM = Tractor tillage with mulch.

** runoff was in excess of the capacity of the measuring system

3.2.5 Soil moisture content temporal changes

Changes in soil profile water content within the rooting depth (0-60 cm) for the 1993/94 season, as affected by different tillage treatments are as shown in Table 3.11. Marked treatment differences occurred during tillering to booting stage of growth, with the FCM treatment showing a net increase in profile water by 19 mm while there was a net decrease of 22 mm under the FC treatment.

Table 3.11: Effect of treatments on profile water (mm) changes (1993/94)

Parameter		Change in profile water (mm)				
Growth stage		EDS[2] to 6th leaf	6th leaf to tillering	Tillering to booting	Booting to maturity	Maturity to harvesting
Cummulative rainfall (mm)		293	97	62	32	0
Treatments[1]	ZT	16	4	-22	-15	-2
	FC	28	2	-1	-44	-4
	FCM	25	2	19	-58	-4
	SCT	15	5	-14	-18	-9
	TR	35	-4	-5	-34	-4
	TT	15	8	1	-34	-4
	TTM	21	5	-4	-34	-3

Notes: [1] SCT= strip catchment tillage, TR= Tied ridging, FC= flat cultivation, FCM= Flat cultivation with mulch, ZT= zero tillage, TT= Tractor tillage and TTM= Tractor tillage with mulch.
[2] End of Dry Season

3.3 Tillage and Fertilizer Treatment Effects on sorghum growth and yield

3.3.1 Treatment effects on germination and crop establishment

Percentage emergence of sorghum for the three consecutive cropping years is shown in Table 3.12. With the exception of 1991/92 cropping year, percentage emergence was very poor. Results show that emergence and establishment is correlated to the cumulative amount of rainfall received immediately (up to 2 weeks) after sowing. The amount of rainfall received before sowing seems to have very little effect.

In 1991/92, for example, 24.5 mm of rain was received 9 days after sowing followed by 5 wet days giving a cumulative total of 39.3 mm two weeks after sowing. This explains good emergence under 1st sowing. Emergence was poor in the 1st sowing in 1992/93 and both 1st and 2nd sowing in 1993/94 and this was related to low cumulative rainfall received 2 weeks immediately after sowing. However, emergence from 2nd sowing was poor in 1992/93 due to too much rainfall (207.2 mm) received within two weeks after sowing. These results indicate that a threshold rainfall amount of 20-50 mm must be received within two weeks after sowing to obtain good crop emergence and establishment.

Table 3.12: Percentage emergence and Pre-and-Post-rainfall conditions

Cropping year	1991/92	1992/93			1993/94		
Variable	1st sowing	1st sowing	2nd sowing	3rd sowing	1st sowing	2nd sowing	3rd sowing
Sowing Date(s)	3-6 Dec 1991	11-5 Dec 1992	9 Jan 1992	Gap filling	29 Oct - 3 Nov. 1993	10-11 Dec 1993	10-13 Jan 1994
Emergence(%)	80	0	<50	-	0	0	88
Cumulative rain falling within 2 weeks before sowing	0.2 mm	0.0	8.8	-	4.7	0.0	164.0
Cumulative rain falling within 2 weeks after sowing	39.3 mm	17.0	207.2	-	2.4	1.1	132.8

3.3.2 Tillage treatment effects on sorghum grain yield

Sorghum grain yield was significantly affected by tillage treatments throughout the three consecutive cropping years (Table 3.13). In 1991/92 cropping year, hand-hoe cultivation treatments recorded higher grain yields than tractor-tillage plots, with tied ridging registering 2118 kg ha^{-1} (Table 3.13). Tractor-tillage plots were planted late and the yields are, therefore, not comparable to hand-hoe cultivation. In 1992/93 cropping year, the highest yields were obtained from tractor-tillage with- and without mulch followed closely by flat cultivation and tied-ridging (Table 3.13). In 1993/94 cropping year, the highest grain yields were recorded from tied-ridges followed closely by flat cultivation and strip catchment tillage.

The high grain yield under tractor-tillage in 1992/93 was attributed to good crop establishment as exemplified by high plant population (Table 3.13). Conversely, the grain yield under a similar treatment in 1993/94 was not the highest due to not so good crop establishment. In the three consecutive years, tied-ridging has consistently produced overall high sorghum grain yields. This is because tied-ridging facilitates high infiltration into the soil by retaining a high proportion of rainfall received on-site (Table 3.11).

Table 3.13: Sorghum grain yield and plant population as affected by tillage

Tillage Treatments	Growth and yield[1]					
	1991/92	1992/93		1993/94		
	Grain (kg ha^{-1})	Population (plants ha^{-1})	Grain (kg ha^{-1})	Population (plants ha^{-1})	Grain (kg ha^{-1})	Mean Grain (3 yrs)
Zero	1909 b	51409	1442 b	47958	3059 b	2113.7
Flat	1895 bc	51898	1693 b	51389	3471 a	2353.0
Flat with mulch	1760 c	52176	1252 b	47056	3104 b	2038.7
Tied-ridging	2118 a	54989	1641 b	57778	3514 a	2424.3
Strip catchment	1961 b	51991	1961 b	55083	3412 a	2444.7
Tractor	756 e	57257	1689 b	48133	3193 b	1879.3
Tractor with mulch	1048 d	58553	2142 a	48806	3201 b	2130.3
Mean	1635		1688		3279	2201

[1] Means followed by the same letter or none at all are not significantly different at P<0. 0.5 according to the Duncan's Multiple Range Test (DMRT).

3.3.3 Tillage cum fertilizer interactions on sorghum grain yield

The interactions effects of tillage and fertilizer on grain yield are shown in Table 3.14. In 1991/92 cropping year, Strip Catchment Tillage + half (FYM + TSP) combination gave highest significant grain yield followed closely by Tied Ridging-Fertilizer combinations. In 1992/93 cropping year, the Tractor Tillage plus Much-FYM combination gave the highest significant grain yield followed by the Tractor Tillage plus Mulch + half (FYM+TSP). For the (1993/94) cropping year, highest significant yields were obtained from Strip Catchment Tillage + FYM and Tractor Tillage + FYM followed closely by Tied-Ridging + half (FYM + TSP) combination.

The 1993/94 season out-performed significantly the other two seasons for all treatments. This is a good correlation with rainfall pattern discussed in section 3.1.2.

Table 3.15: Fertilizer treatment effect on yield parameters

Fertilizer Treatment	Grain Yield (Kg ha^{-1})		
	1991/92	1992/93	1993/94
Control	1425 b	1351 b	2611 c
Farm Yard Manure	1756 a	2153 a	3944 a
TSP	1573 ab	1363 b	3149 b
1/2 (TSP & FYM)	1816 a	1945 a	3415 b

[1] Means followed by the same letter or none at all are not significantly different at P<0. 0.5 according to the duncan's multiple Range Test (DMRT).

Table 3.16: Percentage emergence and Pre- and Post- rainfall conditions

	1992/93		1993/94		
	1st	2nd	1st	2nd	3rd
Sowing date	12.12.1992	9.1.1993	29.10.1993	11.12.1993	13.1.1994
Emergence (%)	30	85	0	0	88
Rainfall (mm) 2 weeks before sowing	0	9	5	0	165
rainfall (mm) 2 weeks after sowing	17	207	3	1	124

Table 3.17: Effects of RWH treatments on plant height of maize and sorghum

Treatments	Plant height (cm)					
	22 DAE		42 DAE		130 DAE	
	Maize	Sorghum	Maize	Sorghum	Maize	Sorghum
0:1	37.4	43.9	80.8	101.1	150.8	227.[illegible]
2:1	25.1	35.5	63.3	109.3	138.3	[illegible]
4:1	32.8	42.7	74.2	95.3	149.8	230.3
2:1 + Storage	34.4	46.2	87.9	142.7	157.8	249.3
4:1 + Storage	26.9	29.2	26.9	95.2	239.9	208.6

[1] Means followed by the same letter or none at all are not significantly different at P<0. 0.5 according to the duncan's multiple Range Test (DMRT).

Table 3.18: Effects of rain water harvesting treatments on grain yield of maize and sorghum

Catchment size	1992/93		1993/94	
	Sorghum	Maize	Sorghum	Maize
0:1	1800 b	1690 c	2397	3088
2:1	1480 bc	2140 bc	1736	3369
2:1 + storage	2670 a	2180 b	1876	3461
4:1	1770 b	1770 c	2602	3908
4:1 + storage	3220 a	3260 a	1944	3131

[1] Means followed by the same letter or none are not significantly different at P<0. 0.5 according to the duncan's multiple Range Test.

3.5 Social-Economic Studies

3.5.1 Socio-economic setting

3.5.1.1 Population and demographic characteristics

The population density of the study area is about 22 people per square kilometre, which is below the national average of 26. The target villages had an average family size of 7, and when categorized into age group there were no remarkable differences.

The majority of household members are resident to their respective villages (73%). The rest are either not residents (16.3%), temporary residents (9%) or visitors (17%). A comparison of the migration patterns of the population show that generally there has been a net inward migration into the study area 10 and 20 years ago.

The main occupation of the people in the target area is farming in the family's household farm. However, a relatively big proportion of household members (28.2%) is either old or sick making them not available for household work (Table 3.19). About 46% of the household members in the villages studied had no formal education. For those with formal education the majority are between standard 4 and 8 inclusive (36.6%) (Table 3.19).

Table 3.19: Social characteristics of the villagers

Occupation	Type	Family farm	Petty trade	Employed	Casual employment	Sick/old	Children	
	(%)	52.1	2.2	6.2	1.2	28.2	10.1	
Education	Type	No educ.	Adult educ	Std 1-4	Std 4-8	O-level	A-level	College
	(%)	46	5	12.5	32.6	2.7	0.4	0.6

3.5.1.2 Social organization

Administratively, the target villages are governed by village governments, which are headed by respective village chairmen. The apex of the village government organizational structure is the village assembly. Members of this assembly are all adults aged 18 years and above. The village council, is the executive arm of the village government. Members of the village council include the village chairman, village executive officer who is also the secretary of the council and other five members from committees of the village government. The committees are:

- Finance and Planning
- Industries, Works and Transport
- Education, Culture and Social Services.

In addition to the village government officials, there are technical officers working in the villages, including agricultural and livestock extension officers, teachers, health officers etc.

3.5.1.3 Land, labour and capital resources

Villagers retain and inherit land formerly owned and used by the family. Normally all land cultivated by individual household is considered private [illegible]y. Most of the un-cultivated and grazing land is common property. Land in valley bottoms is highly valued and some owners lease pieces to others on an annual basis to grow maize.

Total area under cultivation in the study villages is 4,960 ha out of which 3100 ha are planted with food crops. Cultivated farm sizes vary between households, mainly depending on labour force and capital availability. Farmers in the study area can be categorized into large, with greater than 5 ha, medium, with 2-5 ha and small, with 2 ha or less. The majority of the farmers have 2 ha or less. Of the 2 ha each household cultivates about 1.5 ha are divided into three or more small plots (SWMRP, 1991), these are:

- garden plots within the homestead intensively cultivated with vegetables
- homestead fields where manure application & intercropping are practised
- distant fields located in valley bottoms or middle grounds.

The remaining area is left as fallow.

The main source of labour is derived from the household members and tasks like land clearing and preparation, sowing, weeding, harvesting and processing are undertaken jointly by all members. A relatively high proportion of hired labour is used in harvesting operations (Table 3.20). Most farmers own and use only hand tools to undertake farm operations. Only 3% and 7% use tractors and oxen, respectively, mainly by hiring and only for primary tillage.

Table 3.20: Allocation of responsibility for various tasks in the study areas (percent)

	Land clearing and preparation	Sowing	Weeding	Harvesting	Processing	Marketing	Cattle rearing
Head of H	(28)9.1	(50)15	(18)5.8	(18)5.9	(17)5.5	(135)53.6	(28)31.8
Males	(8)2.6	(9)2.7	(3)1	(2)0.7	(3)1	(3)1.2	(6)6.8
Females	(28)9.1	(16)4.8	(18)5.8	(16)5.2	(28)9.1	(12)4.8	(8)9.1
Children	(5)1.6	(4)1.2	(3)1	(4)1.3	(4)1.3	(5)1.9	(25)28.4
All	(203)66.1	(240)71.9	(234)75.5	(174)56.7	(235)76.5	(93)36.9	(8)9.1
Hired labour	(35)11.5	(15)4.5	(34)11	(93)30.2	(20)6.5	(4)1.6	(16)14.8
Total	(307)100	(334)100	(310)100	(307)100	(307)100	252(100)	(88)100

3.5.1.4 Economic means

The main source of cash income (about 50%) is selling of crops. Petty trading is also an important off-farm source of income. Other sources of income include selling livestock and livestock products, employment and remittances (Table 3.21).

3.5.2 Agricultural production and marketing

3.5.2.1 Farming systems and crop yields

The most important farming system of the study area is livestock-sorghum-millet. This farming system is based on fixed settlements. Sorghum and millet are the most important crops, but there are others like maize, groundnuts, bambaranuts, vegetables, sunflower, cassava and pigeon peas. Generally crop yields per household are low and the average yield for maize, sorghum and millet is well below the expected average yields for Dodoma region (Table 3.22).

Table 3.21: Sources of Cash Income in the study villages

Category	Source	1989/90		1990/91	
		Number	%	Number	%
On-Farm	Sale of crops	152	48.3	166	49.7
	Sale of livestock & milk	8	5.8	20	6.0
	Sub-Total	170	54.4	186	55.7
Off-Farm	Petty trade	88	27.9	90	26.9
	Employment	33	10.5	34	10.2
	Remittances	11	3.5	13	3.9
	Others	13	4.1	11	3.3
	Sub-Total	145	46.0	148	44.3
Total		344	100.0	315	100.0

Table 3.22: Average yields in the study area for major crops

Crop	National average, t ha^{-1}	Dodoma region average yields, t ha^{-1}	Study area average yields, t ha^{-1}		
			1989/90	1990/91	1993/94*
Maize	3.7	1.6	0.5	0.5	0.45
Sorghum	6.0	1.5	0.4	0.5	0.4
Millet	5.0	1.1	0.3	0.4	0.7

3.5.2.2 Livestock production

As mentioned above livestock is an important part of the farming system. Livestock kept include cattle, goats, sheep, pigs and poultry. The livestock serve as symbols of wealth and some sort of banking. Pigs are kept mainly for sale while poultry are kept for home consumption. It was further noted that very few households keep cattle for draft power and for manure (Table 3.23). This indicates the low level of crop-livestock integration. The grazing of livestock is mainly done on communal land (Table 3.24). However, after harvest animals are allowed to graze on the stover left in crop fields.

Table 3.23: Reasons by (%) of respondents for keeping cattle in the study area

Reasons	Ipala	Hombolo	Msanga	Chamwino	Total
For sale	13.0	30.0	11.1	26.3	21.1
For draft power	13.0	0.0	22.2	5.3	8.5
For manure	30.4	10.0	0.0	10.5	14.1
Saving / reserve	30.4	50.0	66.7	47.4	45.1
Total	100	100	100	100	100

Table 3.24: Grazing areas for livestock in the study area (1990/91) season

Method /area	Ipala	Hombolo	Msanga	Chamwino	Total
On household land	17.9	32.3	40.0	34.6	30.5
Communal land	78.6	61.3	60.0	60.0	66.7
Stall fed	3.6	6.5	6.5	0.0	2.9
Total	100	100	100	100	100

3.5.2.3 Agricultural inputs

The use of inputs such as chemical fertilizers and pesticides is limited in the study area. The most commonly used fertilizer is Farm Yard Manure (FYM) and is restricted to plots which are near the homestead. Non availability, financial problems and high prices are the major reasons explaining low rates of using chemical inputs.

5.3.2.4 Marketing

Farmers sold on average 60% of total ground nuts produced, 51% of the total maize produced and 46% of the total sorghum produced during 1989/90 season. The corresponding figures for 1990/91 season are 60%, 35% and 31% respectively. Considering the low levels of crop yields, the marketed proportions are very high, indicating that farmers are forced to sell their crop output to meet their cash needs even though food consumption in the household is not satisfied. The main problem in marketing of agricultural crops is insufficient production and low prices offered especially for maize (Table 3.27).

Table 3.25: Marketing problems identified by respondents (%) for major crops

Problem	Maize		Sorghum/Millet	
	%	Number	%	Number
Crop not produced	28.2	70	7.2	17
Low production	49.2	122	71.3	169
Too Low Price	12.5	31	5.9	14
Transport cost too high	2.0	5	1.3	3
Delays in Payment	2.8	7	6.7	16
Poor Crop Quality	2.8	7	2.1	5
Others	2.4	6	5.5	13
Total	100	248	100	237

3.5.2.5 Constraints on crop and livestock production

The major constraint to agricultural production is non-reliability of rainfall. Other constraints are lack of credit, lack of farm power, low soil fertility, crop pests especially birds and poor marketing arrangements. Diseases were the major constraint in livestock production (Table 3.26).

Table 3.26: Percentage ranking of constraints on crop and livestock production

Constraint	Food crops		Export crops		Livestock	
	1st	2nd	1st	2nd	1st	2nd
Un-reliable Rainfall	50	14	22	15	11	13
Low Soil fertility	4	13	1	2	1	7
Labour shortage	8	6	6	1	1	2
Land shortage	5	4	1	3	1	2
Lack of Credit	7	11	18	25	3	6
Poor Input supply	6	13	8	12	3	12
High prices of inputs	3	5	4	14	2	8
Poor Markets	1	1	7	9	1	4
Poor Transport	1	6	4	9	1	8
Inadequate Knowledge	4	11	2	8	2	6
Pests	1	3	0	1	52	7
Others	10	13	4	3	6	8

3.5.2.6 Gender issues

Thirty seven percent of households indicated that the family farm is owned by both the husband and wife. Thirty three percent of households indicated that the husband is owner of the farm while 26% of households indicated that the wife is the owner of the farm (Table 3.27). Except for decisions on fertilizer and pesticides application, women were frequently mentioned as the ones making decisions on other farm operations. This would seem to mean that women play an active role in agricultural decision making. Children participate in all jobs performed by adults (Table 3.20).

3.5.3 Household food energy supply

Households in the study area indicated that maize, sorghum and millet are the staple foods. The extent of use of these staple foods varies very slightly throughout the year (Table 3.28). Informal discussions with villagers in the study area indicated that the length of time when there is relatively adequate supply of

Table 3.27 Distribution of households (%) by decision makers on farm operations

	Decision maker								
	Females only	Males only	Mainly females, males help	Mainly females, children help	Mainly adults, children help	Both males and females	Mainly males, females help	Mainly males, females and children help	Total
Choice of crops grown	37.3	18.6	6.8	5.1	0.0	6.8	25.4	0.0	100
When to plough	30.5	25.4	6.8	8.5	0.0	6.8	20.0	0.0	100
Select seeds	47.5	13.6	15.3	5.1	0.0	10.0	8.5	0.0	100
Sale of crops	28.8	23.7	11.9	5.1	1.7	6.8	16.9	5.1	100
When to plant	31.0	25.4	5.1	8.5	0.0	5.1	20.4	3.4	100
How to plant	30.5	28.8	8.5	6.8	0.0	8.5	15.3	1.7	100
Use of cash	25.4	13.6	23.7	5.1	0.0	6.8	20.3	5.1	100
When to weed	30.5	18.6	8.5	8.5	1.7	8.5	18.6	5.1	100
Whether to apply chemical fertilizer	30.5	45.8	6.8	5.1	1.6	3.4	3.4	3.4	100
Whether to implement soil-water conservation measures	77.1	27.2	6.8	8.5	0.0	6.8	16.9	6.8	100
When to harvest	33.8	16.8	5.7	8.5	0.0	8.5	22.0	5.7	100
Threshing	40.8	11.8	11.8	11.8	1.8	8.4	10.2	3.4	100
Whether to apply pesticides	30.6	46.0	5.0	5.0	0.0	5.0	5.0	3.4	100
Method of storage	32.2	20.0	7.3	11.0	0.0	9.0	14.45	3.5	100
About your shamba	53.3	22.2	11.1	0.0	0.0	6.7	6.7	0.0	100

staple food is 2-3 months immediately after harvest. During this time, about 80% of households indicated that they used own produced food while 5% indicated food purchases. After this period, until the next harvest most household food stocks are very low or non-existent. During this period, forty five percent of households indicated that they made food purchases during the pre-harvest period while 37% indicated that they used own produced food (Table 3.28).

The recommended World Health Organization (WHO) calorie intake is 2000 and 3000 kcal per day for an adult woman and man respectively (Passmore and Eastwood, 1986). The socio-economic survey indicated that per capita consumption per day of cereals is about 25% of the recommended daily requirements (Table 3.29).

Despite the fact that households in the survey areas do not meet their daily food energy requirements, they dispose off part of their cereal stocks into the market in order to raise cash income to purchase other requirements and services like education, health and clothing. However, during pre-harvest, they purchase cereals from the market. In other words, they sell after harvest normally at low price, and re-purchase during pre-harvest period at higher prices.

Table 3.28: Percentage distribution of household by source of staple food

Source	Own	Gifts	Borrowing	Purchase	Other
Pre-harvest	37	14	2	45	2
Post-harvest	80	2	13	5	0

Table 3.29: Per Capita Energy Supply in the study area from cereals

Village	Total Energy 1989/90	KCal/HH/Year 90/91	Energy 89/90	KCal/head/day 90/91
Ipala	2,087,103	4,565,393	816.9	1,786.9
Hombolo	2,400,557	1,745,289	1096.2	796.9
Msanga	1,857,297	4,339,356	848.1	1,935.8
Chamwino	1,353,072	2,864,006	529.6	1,120.9

3.5.4 Environment problems in the study area

3.5.4.1 Farmers' perceptions of environmental problems

Farmers in the area were also aware of rainfall pattern and distribution. The majority of farmers noted that rainfall is not reliable (86.5%) and not evenly distributed (63.2%). Few respondents indicated that rainfall was reliable (13.5%) and 36.8% showed that it is evenly distributed (Table 3.30).

The majority of the households in the study area observed that there was a decline in soil fertility for the past 10 years. The main reasons given for the decline in soil fertility were soil erosion, over cultivation, over grazing and insufficient fallow period. Among the agricultural practices in the area, overgrazing deforestation and ploughing down slopes were mentioned as promoting land degradation (Table 3.31)

Table 3.30: Farmers assessment of rainfall pattern & distribution

Reliability and Distribution	Reliability		Distribution	
	Number of respondents	%	Number of respondents	%
Good	41	13.5	133	36.5
Bad	262	85.5	194	63.5
Total	303	100	307	100

Table 3.31: Percentage distribution of farmers perception on changes in soil fertility and land degradation

Changes in soil fertility		Reasons for soil fertility decline		Reasons for land degradation		Practices used to improve soil fertility	
Trend	%	Reason	%	Reason	%	Practice	%
Large decline	28	Soil Erosion	29	Overgrazing	38	Contour ploughing	22
Little decline	37	Over-cultivation	29	Deforestation	21	Tree planting	23
Remained the same	24	Overgrazing	10	Ploughing down slope	17	Reduce grazing	14
Improved	6	Insufficient fallow	10	Burning	4	Build water catchments	28
Don't know	5	Don't know	14	Reduction of fallow	10	Other	13
		Other	8	Other	10		
	100		100		100		100

3.5.4.2 Attempts to improve soil-water management practices

Very few households in the study area undertook improvements to minimize soil degradation and improve soil fertility. Farmers have however, adopted various strategies to overcome the problem of in-adequate and un-reliable rainfall, as discussed below;

- *Kuberega* is a zero tillage practice comprising of shallow basin hoeing, planting and then weeding when pressure of planting has passed. This practice is usually adopted during periods when rains start earlier than expected. Farmers decide to sow seeds before tillage in order to take advantage of the early rains.

- The application of manure is another practice which increases rain water infiltration into the soil and improves the balance of available soil-water. In the study areas most of the manure applied is on plots near the homestead. Most farmers reported manure application (Table 3.32). Lack of means of transport among farmers partly explain non-application of manure on distant fields.

- Mixed cropping and staggered planting is one of the most important management practice by farmers aimed at reducing the impact of dry spells on crop yields. The practice helps to prevent total crop failure in case of long dry spell at the critical growth stage on one particular crop. These practices were also noted by Rigby (1969). A number of mixed cropping were observed in the study area.

- Weed control plays an important role in the reduction of water lost through evapo-transpiration during the growing period.

- Ridge and furrow is practised only to a limited extent for growing sweet potatoes in the homestead fields. This practice demands a relatively high amount of labour.

- Crop selection and allocation to the appropriate area plays a vital role as a soil-water management tool. For example, maize is normally grown in the fertile alluvial soils found in valley bottoms, where soil water retention is higher due to concentration of run-off from sloping high grounds.

Table 3.32: Soil-water management practices by farmers in the study area

Village	No. of farmers who reported the practice						
	Weed control	Manure application	Tie ridging	Mulching	Tractor tillage	Deep tillage	Staggered ridging
HOMBOLO	5	4	4	1	-	1	1
IPALA	6	6	-	-	-	6	-

3.5.5 Indicative Gross Margins

Table 3.33 gives a gross margin analysis for three levels of management of monocropped sorghum under hand hoe cultivation. The major variable input is the family labour. Family labour does not involve direct cash costs but was valued according to the going rate of hiring labour in the study area. When family labour is excluded from the gross margin calculations farmers record positive gross margins at all levels of management. The margin is seen to improve with the level of management. However, when family labour is costed, farmers obtain negative margins at all levels of management. The loss is however lowest with the full improved management. Due to shortage of other income generating activities, farmers may not attach market value to family labour. This is why they continue production even though gross margins are negative.

Table 3.33: Gross Margin analysis for sorghum ha^{-1} under hand hoe cultivation

Description of costs and revenue			Current Practice[1]	Improved Soil-Water Management[2]	Fully Improved[3]
COSTS IN Tshs	Purchased Inputs	Seed	1,250	1,500	1,500
		FYM - Transport	0	15,000	50,000
		Nitrogen Fertilizer	0	0	18,000
		Pesticides	0	0	9,000
		Sub-total	1,250	16,500	78,500
	Labour	Clearing	900	900	900
		Ridging	0	27,000	27,000
		Sowing	2,700	2,700	2,700
		Weeding	54,000	54,000	54,000
		Harvesting	2,250	4,500	13,500
		Sub-total	59,850	89,100	98,100
	TOTAL		61,100	105,600	176,600
Total Harvest (kg)			500	1,000	3,000
Revenue (Tshs)			25,000	55,000	165,000
Gross Margins	Without costing labour		23,750	38,500	86,500
	Including labour cost		- 36,100	- 50,600	- 11,600

[1] Kuberega without FYM or any improved inputs

[2] Involves tillage, tied-ridging, application of FYM at 3 t ha^{-1} and use of improved seed

[3] Involves tillage, tied-ridging, FYM at 10 t ha^{-1}, improved seed, nitrogen fertilizer and pesticides

4. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

4.1 Discussion

4.1.1 Rainfall pattern

The analysis of the rainfall pattern of the study area, over a 20 year period, shows that many of the early (October and November) starts of rainfall, are in effect false starts as far as plant establishment and growth is concerned. The growing season at Hombolo, effectively starts after December 15th. This is because of the following aspects of the long term behaviour of rainfall:

- Assuming a 70% probability, less than 10 mm cumulative rainfall can be expected up to end of November. Therefore the rainy season does not start effectively until after the 15th of December.
- Considering a wet day to be 3 mm or more, any rainfall received in October or November will usually be followed by a dry spell exceeding two weeks, during November and December. Therefore, if sorghum is sowed early (in August-October) as per current farmers' practice, there is a very high risk that the crop will face severe stress during early growth stages. This stress causes restricted root initiation, development and deep penetration.
- The rainfall in the months of January, February and March is the most reliable because during each of these months:
  - 70% probability rainfall exceeds 80 mm
  - Minimum expected rainfall exceeds 35 mm in January and February
  - Number of wet days [3 mm or more] exceed 7 and mean length of longest dry spell does not exceed two weeks.

The results of the long-term analysis of rainfall are confirmed by the pattern of crop yields during the three years of the experiment. According to the criteria presented above, the three seasons can be categorized as follows:

- 1991/92 was an "average" year as the rainfall did not start until December. However, the longest dry spells in three critical months of January, February and March were rather long. This adversely affected crop growth. The seasonal total rainfall was significantly above the 70% probability rainfall.

Crop performance and yield were correlated to the characteristics of rainfall; for example:

- establishment was successful on the first and only sowing
- yield average of 1,929 kg ha^{-1} which is significantly above the mean yield of sorghum for Dodoma, was obtained.

- 1992/93 was a "bad" year as the rainfall started too early in November, where 87.8 mm fell but was followed by a severe drought in December which received only 17 mm coupled with a dry spell of 25 days. Further to this, most of the rain fell in January, with March being relatively dry with the longest dry spell of 21 days. The seasonal total was 553 mm, which is above the 70% probability rainfall, but below the long term mean. The performance of the crop during the season indicate that the season was bad. For example,
  - Sowing was repeated three times before good crop stand could be achieved
  - The average grain yield (of the hand hoe and zero tillage treatments) was the lowest (1,486 kg ha^{-1}) of the three seasons. The yield was also below (though not significantly) the average sorghum yield for Dodoma region.
- 1993/94 was the "best" season of the three. The rains did not start effectively until January and they were well distributed in the critical months of January, February and March. The longest dry spells were less than two weeks in all the three months. The seasonal total rainfall (616 mm) was significantly above the 70% probability rainfall and long-term mean. This good performance of the rainfall was matched with good performance of the crop, where the yield (3,312 kg ha^{-1}) was more than double of that of 1992/93 and 1.7 times that of 1991/92. However, the risks of early planting were also made clear during this season. The showers which were received in October (23 mm), November (6 mm) and December (3mm) caused seed loss through rotting leading to poor emergence. This necessitated sowing three times, before adequate establishment could be achieved.

The above correlation of rainfall pattern and crop establishment, growth and yield, although limited in number of years, leads to the following assessment:

- Rainfall which starts in November followed by monthly rainfall below the 70% exceeding levels and dry spells of more than two weeks in the months of December and/or January adversely reduce yields, of early sowed crops;
- The rainfall pattern in January, February and March is the most critical for sorghum growth in the study area. Yields are reduced if any of these months receive below the 70% probability rainfall for that month;
- The seasonal crop water requirement for sorghum in the study area is estimated to be 486 mm, which is not significantly different from the 70% probability expected rainfall of 518 mm. Therefore, seasonal total rainfall below the 70% exceeding levels leads to reduced yields of sorghum; and
- Emergence and establishment is correlated to the amount of rainfall received immediately (up to 2 weeks) after sowing.

These findings indicate that soil-surface interventions methods in the study area should aim to capture the maximum possible rain where it falls, by maintaining high infiltration rates, maximizing soil water holding capacity and reducing deep drainage of water below the root zone. However, rain water harvesting coupled with storage may be necessary in order to fully utilize any rain water falling in the months of October, November and early December.

4.1.2 Soil and Hydrological Characteristics

The physical characteristics of the soil show a shallow sandy top layer underlaid by rather clay sub-surface. The top-soil also has low organic matter content, and therefore poor water holding capacity and tends to form surface crusting due to very unstable structure leading to reduced infiltration capacity and thus high run-off and erosion. This explains the relatively low values of run-off as a percent of rainfall observed for the Tied-Ridging, Tractor Tillage, and Tractor Tillage plus Mulch treatments compared to the other treatments, especially during the early stages of crop growth (Table 3.10). The division of the soil into shallow sandy top layer and clay sub-soil may also explain the performance of rain-water harvesting during the 1992/93 season (Table 3.18). Since percolation of water at lower depths is reduced, a perched water table quickly appears. This phenomena is experienced throughout the Dodoma district. The relative performance of the crop for the three seasons may also be partly explained by this characteristic of the soil profile. In the "bad" season (1992/93) shallow cultivation which lead to a concentration of roots near the surface may have caused the crop to suffer from water stress. This is why tied-ridging, for example, performed poorly in 1992/93. This shows that the soils of the study area require some deep tillage from time to time to improve water infiltration and to allow deep penetration of roots.

Chemically, the soils of the study area are very poor in fertility. Thus, successful crop growth and yield requires sufficient use of fertilizer. This is an area which was not fully investigated during the current research. However, the importance of fertilizer is clearly demonstrated by the big difference between the yields of the research plots where N fertilizer was used (>2.0 t ha^{-1}) and the farmers' fields, where no N fertilizer is used (< 1.0 t ha^{-1}). Furthermore, because of the scarcity of soil-moisture in the study area, improvement of soil fertility simultaneously with the soil-water is important so as to enhance crop water use efficiency. The performance of the FYM treatment, which consistently produced yields significantly higher than the control in all the three years, is a good indication of the importance of improving hydrological and fertility properties of the soils simultaneously. This is because application of manure can have beneficial effects on both the physical properties (e.g structure, infiltration & water holding capacity) and chemical fertility of soils (Probet, 1992).

4.1.3 Performance of Intervention Measures

4.1.3.1 Tillage

The analysis of rainfall presented in section 4.1 above, indicated that interventions should aim to capture the maximum possible rain where it falls. This agrees very well with the results from the tillage experiments, with the tied-ridging treatment showing significantly improved yields over the control in the "good" years. The importance of maximizing water holding capacity is shown by the good performance of both tractor tillage and Farm Yard Manure treatments.

. The poor performance of tied-ridging during the dry year (1992/93) has been explained above. The low water content in the elevated ridges during the dry year means that the ridges need to be re-designed so that they are short and broader. The most important observation is that tied-ridging is not practised in the study area perhaps because of the amount of labour involved in making these ridges [Table 3.33]. Therefore, tied-ridging is likely to be adopted by the smallholder farmers of the study area if the problems of labour and farm power are adequately addressed. This can be achieved by designing a system that involve making the ridges only once every three or four years. This implies adopting the no-till tied-ridging described by Vogel (1993). The scope of the current study did not allow an in-depth assessment of no-till tied-ridging as well as the rates of applying FYM.

4.1.3.2 Rain Water Harvesting

The results show the importance of storing harvested water for supplementary irrigation to help the crop overcome stress during dry spells which occur during the season. The different in yields of sorghum and maize was not however large enough to justify the investment necessary to store the harvested water.

4.1.4 The Socio-Economic Situation

There is a general shortage of capital in the study area mainly because agricultural production is for subsistence and very little or no savings are possible. This has lead to acute lack of investment in improved technologies, especially draught power. The lack of draft power is compounded by labour shortage during peak periods, such as tillage and weeding. The crop yields even from the researchers fields are low such that, it is only with zero opportunity cost of labour that sorghum production, for example, become profitable in the study area.

4.2 Conclusions

The performance of different tillage and water conserving techniques, in terms of sorghum (*Sorghum bicolor* var. Tegemeo) and maize (*Zea mays* L.) yields was measured over a period of three consecutive rainy seasons in the semi-arid zone of central Tanzania.

The results of rainfall analysis revealed that, seasonal rainfall amount expected in the study area, in seven out of ten years, is adequate for sorghum production. The rainy season does not start effectively until after December 15th and therefore the current farmer's practice of "early [October & November]" sowing increases the risk of seedling failure.

Farm Yard Manure (FYM) application at 10 t ha^{-1} every rainy season, resulted in the most significant improvement of yields over the control in all the three years. Of the tillage systems, tied-ridging and deep tillage with tractor resulted in improved grain yield over the control. However, tied-ridging did not significantly improve yields during the dry year of 1992/93.

Crop yields in the study area can therefore be improved by introducing the following interventions, in order of importance:

- Optimum application of farm yard manure
- Tied-ridging which are made only once every three or four years
- Deep tillage before the formation of tied-ridges
- Fertilizer (Nitrogen and Phosphorus) application to improve crop water use efficiency.

The low level of income and lack of savings in the study area are likely to limit the adoption of improved soil-water management practices.

For sorghum and maize, the yield increases attributed to rain water harvesting at Hombolo, were not economically significant. Therefore, rain water harvesting should not be practised for sorghum or maize production in the study area.

4.3 Recommendations

The following preliminary recommendations can be made:

- The semi-arid areas should be provided with an extension service which among other things is equipped to train farmers in the use of soil-water management techniques which help to conserve and efficiently utilize rain water.
- Adequate application of farm yard manure (FYM) should be strongly emphasized in the agricultural extension programme in the semi-arid areas. Further to this and in-order to break the vicious circle of poverty and land degradation in the study area, assistance to the farmers in the study area should first and foremost be directed to assisting them to achieve adequate application of FYM on their fields.
- On-farm research should be conducted to establish site specific optimum rates of FYM.

- Further research should be conducted to adapt a system of no-till tied-ridging that will involve the use of deep tillage with tractor and installation of tied-ridges once every three or four years. In subsequent years the farmer can use the current system of 'kuberega' (on the ridges instead of flat land) in-order to save labour and power requirement. More emphasis should be put on analysing the response of economic factors.

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APPENDIX 1: PROFILE DESCRIPTION

A: General information on the site and soil

Profile: Hombolo Agricultural Research Station

Location: Hombolo Agric. Res. Station farm, about 400 m East of the Agric. Research Station offices.

Elevation: 1037 m above mean sea level

Landform: On middle of a long uniform slope of about 2%.

Vegetation/Land use: The area has been under fallow for the past 5 years. However, the native vegetation in the surrounding areas consists of scattered Adansonia digitate (baobab) and Hyperrhenia-acacia bush with grass. Exotic species have also been introduced by the Agric. Res. Institute Hombolo. These include Leucaene spp.

Parent material: Silicon rich gneiss with granite

Ap 0-12 cm: Brown (7.5 YR 5/4) moist and light brown (7.5 YR 6/4) dry, sandy loam; moderately weak medium crumb; slightly sticky, slightly plastic (wet), very friable (moist) and slightly hard (dry); many very fine to fine random pores; porosity 42.7%; common very fine roots; abrupt, smooth boundary.

AB 12-28 cm: Brown to dark brown (7.5 YR 4/4) moist and brown (7.5 YR 5/4) dry, sandy loam; strong coarse granular; slightly sticky, slightly plastic (wet), very friable (moist) and hard (dry); very few medium and common fine and very fine random pores; porosity 36.5%; few very fine roots; clear; smooth boundary.

Bu1 28-46 cm: Strong brown (7.5 YR 5/8) moist and reddish yellow (7.5 YR 6/6) dry, sandy clay loam; moderately weak medium sub-angular blocky, nonsticky, nonplastic (wet), very friable (moist) and hard (dry); common fine and very fine random pores; porosity 38.5%; gradual smooth boundary.

Bu2 46-102 cm: Reddish yellow (5 YR 6/8) moist and reddish yellow (5YR 7/8) dry, sandy clay loam; moderately weak medium sub-angular blocky; nonsticky nonplastic (wet); very friable (moist) and hard (dry); common fine and very fine random pores; porosity 42.3%; gradual smooth boundary.

Bu3 102-158 cm: Reddish yellow (5YR 6/8) moist and reddish yellow (5 YR 7/8) dry, sandy clay loam; moderately weak fine and medium sub-angular blocky; slightly stick slightly plastic (wet), very friable (moist) and hard (dry) common fine and very fine random pores; porosity 40.4%; clear smooth boundary.

Bgcs 158-178 cm: Light brown (7.5 YR 6/4) moist and pink (7.5 YR 7/4) dry, common fine faint clear strong brown (7.5 YR 5/6 and 7.5 YR 5/8) mottles; slightly gravelly sandy clay loam; moderate coarse sub-angular blocky sticky and plastic (wet), firm (moist) and very hard (dry); few fine to medium pores;porosity 35%; very few angular quartz gravels (2-4 mm) very few large (1.0-1.5 cm) slightly soft irregular dark red ironstone nodules; abrupt smooth boundary.

Ccs 178-184 cm: Pinkish gray (7.5 YR 6/2) moist and pinkish gray 7.5 YR 7/2) dry; common medium distinct clear strong brown mottles, slightly gravelly sandy clay loam; massive; sticky and plastic (wet), firm (moist) and extremely hard (dry); few fine pores;porosity 30.7%; very few large (1.0-1.5 cm) slightly soft irregular dark red ironstone nodules.

Table 1: Analytical data of the profile

Horizon		Ap	AB	Bu1	Bu2	Bu3	Bgcs	Ccs
Depth (cm)		0-12	12-28	28-46	46-102	102-158	158-178	178-184+
Clay (%)		16.0	17.0	22.0	23.0	32.0	27.0	24.0
Silt (%)		5.0	5.0	4.0	5.0	2.0	4.0	2.0
Sand (%)		79.0	78.0	74.0	72.0	66.0	69.0	74.0
Textural class		SL	SL	SCL	SCL	SCL	SCL	SCL
pH	(1:2.5 water)	5.4	5.1	5.2	6.0	5.5	5.4	5.3
	(1:2.5 KCl)	4.2	4.0	3.8	3.8	3.8	3.7	5.8
Organic C (%)		0.60	0.36	0.33	0.16	0.16	0.20	0.11
Organic matter (%)		1.03	0.62	0.57	0.28	0.28	0.34	0.19
Total N (%)		0.05	0.03	0.04	0.02	0.03	0.03	0.02
Available P (mg/kg)		11.6	5.6	2.8	2.8	2.8	2.5	2.8
Exchangeable Cations (cmol(+)kg^{-1}	Ca^{2+}	2.0	5.2	2.8	2.0	2.4	4.2	4.4
	Mg^{2+}	0.6	0.4	0.3	0.2	0.6	1.1	2.3
	Na^{+}	1.4	0.9	1.5	1.1	4.0	1.6	1.5
	K^{+}	0.9	0.3	0.3	0.3	0.2	0.3	0.6
Total Exch. bases		6.8	4.9	3.6	7.2	7.2	8.8	
Exchangeable Al		0,8	1.4	2.4	3.0	2.9	2.0	1.0
Cation Exchange capacity		12.6	9.6	11.6	14.0	13.6	15.6	9.0
% Base saturation		38.9	70.8	42.2	25.7	52.9	46.2	97.8