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FINAL REPORT

SOIL–WATER MANAGEMENT PROGRAM

FOR THE

1981, 1982, 1983 AND 1984 GROWING SEASONS

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Kamboinse Agricultural Experiment Station

ICRISAT/SAFGRAD

c/o Bureau de Coordination

OAU/STRC

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THE ICRISAT/SAFGRAD SOIL-WATER MANAGEMENT PROGRAM IN BURKINA FASO

FOR THE 1981, 1982, 1983, AND 1984 GROWING SEASONS

Submitted by

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INTRODUCTION

The entire field of study involving the soil-plant-atmosphere is intimately integrated into water relationships which are closely linked to production agronomy. As the World's population increases, our knowledge of the limits of our finite resources becomes ever clearer. Soil-water management has been a most valuable agronomic practice for many, many years and this technology and information can lead to production maximization and the most efficient use of human resources. Generally, the conceptual understanding of water supply is that it is a natural resource for agriculture (God given) and is oftentimes viewed as uncontrollable; whereas, it should be considered a resource which can be modified, conserved, and managed.

Construction of necessary embankments, structures and field designs as well as soil tillage by animal traction can have an important effect on farmers who have limited machinery and draft power. The potential is challenging for implementation of an extensive soil-water management program through employment of known soil-water conservation techniques. To fulfill project objectives, animal traction was needed to build the facilities necessary for water harvesting, contour terraces, contour furrows and ridges, conveyance systems, and grass waterways.

Goals

To develop and improve techniques of water use efficiency through controlled field plot studies, water harvesting technology and soil conservation practices for rainfed agriculture in the semi-arid tropics.

Objectives

1. To measure, using controlled studies, the effect of soil surface management techniques on yield with the use of mulches, tied-ridges, anti-transpirants, and crops.

2. To design and build terraces, contour ridges, and conveyance systems for the most efficient use of soil-water management employing animal traction.

3. To develop and evaluate rainfall-runoff and water harvesting techniques to restrict surface water losses, prevent soil erosion, and increase availability of soil water for improved crop production.

THE SEMI-ARID TROPIC ENVIRONMENT OF BURKINA FASO

Climate

The semi-arid tropics of Burkina Faso in West Africa lie between the 10th and 14th northern latitudes and near the zero west longitude of the dry tropical climatic zones. This region is characterized by its 2-season climate: a dry season that lasts roughly from October to May followed by 4 to 6 months of rain. More than 90% of the rainfall occurs during the rainy season. The rainfall is highly erratic and varies from 400mm in the north of Burkina Faso to 1500mm in the south. The storms are convectional in nature and seasonally balanced by high pressure ridges of the Sahara Desert and low pressure cells off the Bight of Benin.

Air temperatures tend to be moderate, averaging nearly 30 degrees Celcius, with maximums of 44 degrees during the dry season of April and minimums of 3 degrees (with no frosts) during the winter season of January. The high annual potential evapotranspiration (1800mm) is much greater than annual rainfall.

Soils

The West African land mass is made up of ancient crystalline rocks which are mainly granite of the PreCambrian age. These rocks have been above sea level long enough to be worn to plateau surfaces of highly indurated sediments which form the substrate (FAO-Unesco, 1977). Although some folding occurred during the Mesozoic period, French West Africa has no true fold mountains like the Alps of Europe. During the Jurassic period, great volcanic activity caused basalt flows in the western regions. After this period, the Sahara and the western coast was once again covered by the sea and these western areas (including Mali and Burkina Faso) have marine deposits of the PostCambrian age.

The alfisols of the Sahel, south of the Sahara Desert, consist mainly of Ustalfs. These soils of an ustic environment are characterized by long warm, and intermittent dry periods. They have gentle to moderate slopes planted to crops of sorghum and millet (94% of the arable land in Burkina Faso) and pasturage with some small irrigated acreages. On the upper parts of slopes, the drainage colluvium has a loamy sand to sandy loam surface followed by a clayey horizon that contains a few iron nodules. Further down the slopes, surface soils tend to be loams with restricted internal drainage.

Soils have poor structural properties because of lower clay and organic matter contents in the surface layers (A horizons) and the absence of clay coatings on these peds. Iron concretions increase in abundance with depth which progressively impedes internal drainage (Sanchez, 1976). Management of alfisols in West Africa is different from other areas because erosion of the coarse topsoils can expose plinthite (laterite) or gravel layers.

In Burkina Faso, severe desication and high soil surface temperatures may be followed by an abrupt change caused by intense rainstorms. Many of the soil physical properties deteriorate with cultivation, leaving the soil less permeable and more susceptible to runoff and erosion losses. As textural changes occur, the erosion hazard increases and erosion losses of the sandy types of surface soils helps to render them unproductive. The estimates of surface runoff from any given area in the country can vary from 40 to 80 percent with the former value being applied early in the season and the latter value towards the end of the growing season. Effectively, the farmers are losing more than 3/4ths of the rainfall that reaches their plot of earth.

Kamboinse Agricultural Experimental Station

The alfisols for sorghum and millet production at Kamboinse Experimental Station in Burkina Faso are described as ferralitic soils with reddish colors and with low base saturation and poor internal drainage. These soils are subject to considerable micro-variations, often linked to position in the toposequence (Stoop, 1980), Topsoils are usually shallow and their surface, if not properly managed, will crust readily under raindrop impact resulting in considerable runoff. These soils show deficiencies in phosphorus and nitrogen.

Basic research studies on alfisols were conducted at the station where variables were controlled and techniques for surface catchment of water were investigated to evaluate management techniques such as crop residues for mulching, flat plantings, tied-ridges and contour ridges. These soil surface management studies on alfisols were designed to evaluate conservation practices to save water, increase infiltration, and restrict runoff.

SOIL-SURFACE MANAGEMENT ON ALFISOLS

Climatic Characteristics

Variation of rainfall within each year is summarized in Table 1 for periods of drought (Zaongo, 1983). These periods of drought put a severe stress on the plants and if the alfisol's surface has been puddled and crusted from previous rainfall, then the opportunity for infiltration with the oncoming rains is limited. In addition, during 1981 when the rainfall effectively ceased after the 10th of September, the seed size was affected as well as the grain weight resulting in a severe reduction in yield. In 1982, a midseason drought restricted growth rate of the plants which reduced their normal size and, in consequence, the yield. During 1983, a drought occurred at time of flowering which severely reduced the number of seeds per head and final yield.

During 1984, normal planting occurred after the 1st of August or 12th of August rainfall, about 2 months late, which will have a severe effect on the 1984 yields.

TABLE 1. Periods of Drought During the Rainy Season

1981	1982	1983
31 July to 11 August (11 days with 5.1mm)	28 June to 19 July (20 days with 9.8mm)	23 June to 4 July (12 days with 9.7mm)
10 Sept. to 26 Sept. (16 days with 10.4mm)	20 July to 30 July (10 days with 22.3mm)	27 August to 7 Sept. (12 days with 7.1mm)
	29 August to 22 Sept. (24 days with 24.4mm)	
27 days of drought 39 days of rainfall	54 days of drought 31 days of rainfall	24 days of drought 43 days of rainfall

Kamboinse Agricultural Experimental Station is situated 14 kilometers north of Ouagadougou. The climate at Kamboinse is similar to Ouagadougou but the 60 year mean annual rainfall for Ouagadougou is 860mm whereas it is only 751mm for the 13 year mean annual rainfall at Kamboinse. The mean monthly rainfall and the annual rainfall for the 4 years under study, 1981, 1982, 1983 and 1984, are shown in Figure 1. This figure shows that the mean annual rainfall for 1981 was 700mm, 717mm for 1982, and 663mm for 1983. For the past 3 years, there has been a deficit in the annual rainfall and 1984 is expected to be even lower.

FIGURE 1. Mean Monthly Rainfall for 1981, 1982, 1983, 1984 and the Mean Annual Rainfall for the Kamboinse Experimental Research Station (Jan., Feb., Mar., Nov., Dec. were negligible and deleted)

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------------------------------------------------------------------
MONTH |                    MEAN RAINFALL (mm)
      0      30      60      90     120     150      180      210
------------------------------------------------------------------

      |XXXX                XXXXXX  Mean Annual Rainfall (13 years)
Apr   |<<<<<<<<<           <<<<<<  1981
      |00000000000         000000  1982
      |/                   //////  1983
      |>>>>>>>>            >>>>>>  1984

      |XXXXXXXXXXXXXX
May   |<<<<<<<<<<<<<
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Jun   |<<<<<<<<<<<<<<<<<<<<
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Sep   |<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
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Oct   |<
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------------------------------------------------------------------
      0      30      60      90     120     150      180      210
MONTH |                    MEAN RAINFALL (mm)
------------------------------------------------------------------
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Soil Characteristics

The alfisols at Kamboinse Station which were used for these studies have the general characteristics as presented in Table 2. Additional information on these types of alfisols has been presented by Roose (1981).

TABLE 2. Average Characteristics of the Loam (Sorghum soil) and Sandy Loam (Millet Soil) Showing the Percentage Particle Size Fraction, Bulk Densities gm/cm^3, Hydraulic Conductivity (K) cm/h, pH, Percent Base Saturation (BS), and Cation Exchange Capacity (CEC) me/100gm of Soil by Depth

SOIL Depth (cm)	PARTICLE SIZE DISTRIBUTION sand	silt	clay	BULK DENSITY	K	pH	BS	CEC
Loam								
0 - 10	52.3	32.1	15.6	1.25	4.8	6.2	61	4.82
10 - 20	61.4	17.4	21.2	1.43	3.2	6.0	54	5.74
20 - 50	49.7	21.6	28.7	1.69	3.5	5.7	69	5.34
50 - 100	50.1	20.4	29.5	1.84	3.0	5.4	74	4.46
Sandy loam								
0 - 10	68.6	12.2	19.2	1.33	8.7	6.8	52	3.37
10 - 20	62.2	15.1	22.7	1.52	4.5	5.9	76	4.41
20 - 50	54.1	17.8	28.1	1.68	3.1	5.6	73	4.04
50 - 100	48.4	22.1	29.5	1.78	2.3	5.9	74	3.96

Water relationships for these alfisols are summarized in Table 3.

TABLE 3. Soil-Water Relationships for Loams and Sandy Loams at the 0-15cm depth

SOIL	SATURATION %	FIELD CAPACITY %	WILTING POINT %	INFILTRATION RATE cm/hr
Loam	39	15	7	1.8
Sandy Loam	30	8	4	2.2

As the soil depth increases, bulk density increases which is caused by either compaction or by the ferralitic gravelly materials that are formed at the lower soil depths. The major change in increasing density occurs between the 20cm to 50cm depths. In addition, for these alfisols on the upper portions of the colluvium, clay content increases with depth.

Two factors which may govern increases in clay content with depth are:

1. the downward movement of the finer particles with water percolation; and,
2. the upward movement of clay particles caused by the action of termites and eventual loss of these fine particles by erosion.

As the clay content and the bulk density increase with depth, the rate of percolation[1] is restricted and, with time, the infiltration rate continues to decline. These relations can be put in perspective by the *in situ* lysimetric data of Charreau (1972) for an alfisol in Burkina Faso which shows runoff of as much as 32% of the annual rainfall for a cultivated soil and as high as 60% for a bare soil. He also notes, that as much as 8 tons/ha of soil can be lost from a cultivated soil and 20 tons/ha from a bare soil attributable to the forces of soil-water erosion.

The "No-Till" Concept

No-Till or minimum tillage practices have been consistently successful throughout West Africa (Greenland, 1975). This concept implies hand sowing or tilling the rows only and use of mulch between plant rows. When crop residues or straw from other areas are used, yield responses have been as high or higher than those obtained with the application of fertilizers or manures (Sanchez, 1976).

A surface mulch keeps the soil layers both cooler and at a more even temperature. It reduces weed growth and keeps the soil surface more permeable to water. Mulch slows the rate of soil evaporation because water vapor must first diffuse through a stationary air layer of the mulch before entering the turbulent boundary layer of the air mass. In addition, there is an increase in biological activity which allows decomposition of organic matter and decomposition by the field termite which greatly increases infiltration.

Reduction of erosion and surface crusting is the greatest benefit derived from use of mulch. The damage caused by raindrops hitting the soil at a high velocity is the first step in the erosion process (Beasley, 1972). Mulching impedes the impact of raindrops and soil splash which restricts the erosion process. When rate of rainfall exceeds rate of infiltration then loss of water and soil can be severe on even the lower slopes. The use of mulch helps to alleviate this condition.

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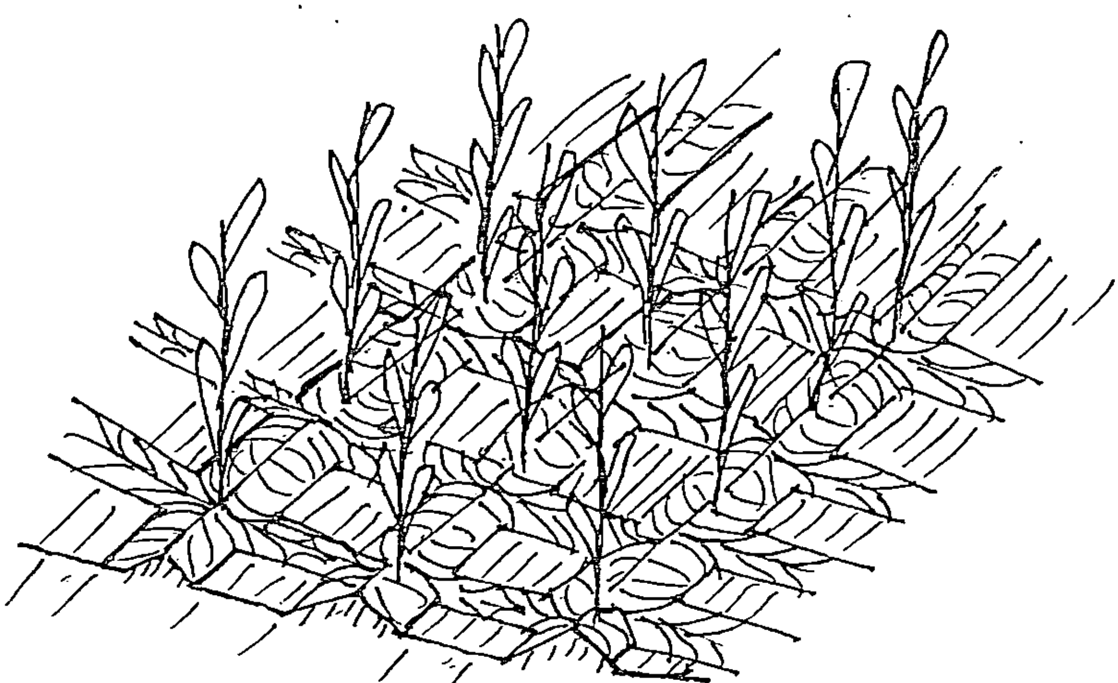
1. Percolation is the term describing the downward movement of free water which drains the soil profile of excess water (Buckman and Brady, 1960).

The sources of mulch material have always been a topic for debate because of a general acceptance that a scarcity of material exists in the semi-arid tropics. This and the competitive uses of crop residues may be a limitation to their utilization for soil structural improvement. However, increased yields which occur with use of mulch also increase plant dry matter production. Since the benefits of mulch have been quantitatively demonstrated on alfisols, trade-offs between fodder, fuel and building materials and the benefits from yield gains should not be overlooked. Accumulation of mulch materials is a management problem and could be solved through agricultural extension programs.

Basic Soil Physics of Tied-Ridges

The concept of zero-runoff implies that precipitation remains on the soil surface until it infiltrates into the soil or is collected for future use. Techniques which have been used throughout Africa for retaining rainfall in place are called tied-ridges or with slight modifications are called micro-catchment basins (as pictured in Figure 2.).

FIGURE 2. Schematic View of Tied-Ridges



Tied-ridges consist of covering the soil surface with closely spaced ridges in 2 directions at right angles, so that the ground is formed into a series of rectangular depressions (Hudson, 1971). There are a great many mechanical devices available for both animal traction and tractor power especially designed to make tied-ridges in a single operation, some of the equipment has been successful and some only partially successful. In Burkina Faso, ridges may be formed by tractor or oxen with ridgers (listers); however, ties are usually constructed by hand with the aid of the "daba", a short-handled hoe.

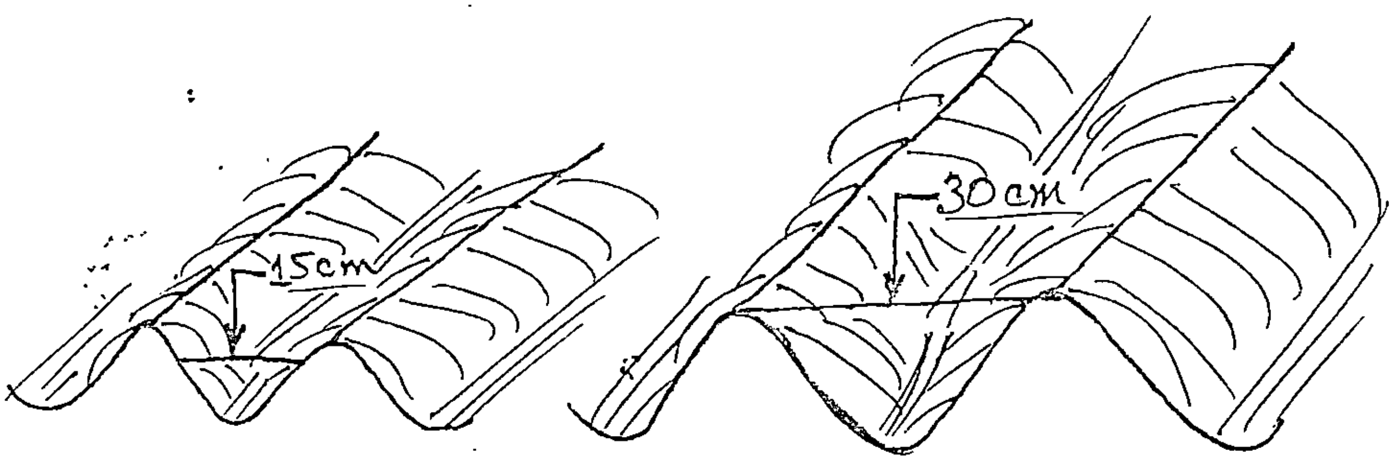
Ridges and depressions increase the potential for storage of water on the surface and provide for runoff trapping which increases the potential for infiltration and storage of water in the soil profile (Boa, 1966). Tied-ridges can be an effective system but they help to produce increased yields only when surface runoff occurs at a greater rate than infiltration. They can help if water is lost which is needed to refill the soil profile in the root zone. If the infiltration rate of soil is adequate to replenish soil moisture in the root zone during rainfall or within a day after rainfall then whether surface water is captured or permitted to runoff may be immaterial.

When the soil profile to the root zone has been refilled and drained to "field capacity", more water being added can only result in a saturated soil profile and an imbalance of soil-air-water plus the possible loss of plant nutrients by leaching. Also, when ponding occurs for an extended period of time, say 2 to 3 days, then tied-ridges may be detrimental to plant growth by limiting soil aeration and creating anaerobic conditions in the upper layers of the soil surface. It is not uncommon to see algal blooms when ponding occurs for more than 1 day and infiltration can be limited because of puddling and crusting of surface soil. Puddling and crusting caused by raindrop impact and ponding requires that surface cultivation increase to restart infiltration.

Construction of Tied-Ridges: Tied-ridges can be, and are, constructed by a variety of methods. But usually, ridges are formed parallel to one another, planted on the tops, and tied or dammed in the furrows. Sometimes the tieing, damming, or blocking of the ridges are made at the same height as the ridge. Hudson (1971) gives a word of caution about this construction technique that, if the soil becomes saturated with the depressions filling up and then overflowing, the ties or dams may break. On sloping ground, once 1 ridge breaks it releases a small flood which can burst the next ridge releasing more stored water and so on down the slope. This can have a disastrous effect on soil erosion. Hudson suggests that, to correct this situation, ridges should be constructed on-grade with the ties lower than the ridges. Therefore, failure of the ridges or ties would not result in a sudden release of runoff across each contour with continuous cutting down the slope.

Construction of Micro-Catchment Basins: Tied-ridges can be constructed as micro-catchment basins. Figure 3 shows that ridges can be deep (20cm to 30cm) so that all the water that falls or runs into them will be captured. If the rainfall probability curve shows that the 100-year storm is, say 158mm, then a micro-catchment basin, if deep enough, could capture all rainfall and hold it in storage for eventual infiltration. In general, the differences between the 2 systems involves labor, soil type, and slope as well as maintenance and the amount of hand labor required to rebuild the ties and ridges after storms.

FIGURE 3. Schematic Diagram Showing the Cross Sections of Tied-Ridges and Micro-Catchment Basins



TIED-RIDGE MICRO-CATCHMENT BASIN

1981 Sorghum Studies

In 1981, the sorghum research fields were designed on a split-split plot basis to evaluate effects of soil surface treatments on yield and growth characteristics of 2 varieties of sorghum, E 35-1 and local Kamboinse (described in the Appendix), with and without plowing. Soil surface treatments were as follows: flat planting; flat planting with rice straw mulch (6 tons/ha); flat planting with surface cultivation after each rainfall; open ridges (no ties); open ridges with rice straw mulch; tied-ridges; and, tied-ridges with rice straw mulch.

These soils were planted at or near field capacity. An application of 100 kg/ha of cotton fertilizer (14-23-15) was made before seeding and a side dressing of 65 kg/ha of urea was applied about a month later. All plots were 5m x 10m with each variety planted in pockets along plant rows with rows spaced 80cm apart. E 35-1 was seeded in pockets 30cm apart within the row and thinned to 2 plants/pocket at a rate of 90,000 plants/ha. Local Kamboinse was planted in pockets 45cm apart at a rate of 60,000 plants/ha.

Plots with ridges were tied or dammed immediately after germination and followed by an application of rice straw mulch. Tied-ridges required some maintenance on the ties twice during the growing season. Storms tend to wash and erode ties which eventually leak and, without maintenance, they will not function properly as a water catchment device.

Table 4 presents the mean and LSD values of sorghum heights measured in August. At this late stage of plant development, effect of plowing was not discernible and, as expected, the varieties were different with local Kamboinse growing taller, at a faster rate than E 35-1; however, the effect of not plowing slowed the growth rate of E 35-1. E 35-1 did not produce strong seedlings in non-plowed plots and it was necessary to transplant seedlings about ten (10) days after germination to insure a complete stand in these plots. This effect was not found in the plowed treatments.

By partitioning sum of squares for orthogonal comparison of mulched versus non-mulched plots, it was shown that sorghum in mulched plots was significantly taller (mean = 215cm) than in the non-mulched plots (mean = 163cm). Final height measurements taken on the 19th of September showed similar comparisons with mean height of E 35-1 at 240cm (range of 185cm to 278cm) and mean height of local Kamboinse at 376cm (range of 285cm to 445cm). However, an additional comparison was found as the effect of plowing was significant and benefited the final heights of the plants ($F = 36.1$, $df = 1/17$). At both measurements of plant height, flat planting with mulch treatment was not significantly different from the ridge or tied-ridge with mulch treatment.

Therefore, the mulch treatment with the least labor requirement (flat with mulch and not plowed) grew to the same height as the more labor dependent treatments.

TABLE 4. Effect of Plow Treatment, Sorghum Variety, and Soil Surface Treatment on Plant Heights (cm), 24/08/81

		SOIL SURFACE TREATMENTS (c)							
PLOW TREATMENT	SORGHUM VARIETY	Flat	Flat With Mulch	Flat Cult.	Ridges Open	Ridges Open/ Mulch	Ridges Tied	Ridges Tied/ Mulch	PLOW TREATMENT VARIETY MEANS (b)
Plow	E 35-1	124	194	150	172	186	170	192	170
	Local	158	255	186	175	227	242	312	218
No Plow	E 35-1	96	162	158	119	140	144	181	143
	Local	164	272	204	199	237	201	249	218
MEANS (a)		136	218	166	163	198	179	235	

a: LSD, 5% = 34
b: LSD, 5% = 24
c: LSD, 5% among SST for same variety = 48
among same SST for different varieties and plow treatments = 47

The analysis of variance for the height measurements showed:

1. varieties -- significant ($F = 50.22$, $df = 1/56$);
2. soil surface treatment -- significant ($F = 10.95$, $df = 6/56$);
3. interaction between plowing treatment and variety -- significant ($F = 6.02$, $df = 1/56$);
4. comparison between mulched and non-mulched plots -- significant ($F = 55.44$, $df = 1/23$).

Yield more than doubled by using mulch over traditional flat planting and open ridge methods for E 35-1 and local Kamboinse on both non-plowed and plowed treatments. There were no significant differences in yield between open and tied-ridges for the same treatment with mulch or no-till versus tillage; however, the open and tied-ridge treatments were significantly different when mulch was not applied. Interaction between plowing treatment and variety showed that the yield of E 35-1 was lowered by a greater amount without mulch than the yield reduction of local Kamboinse for similar treatments. When flat planting was cultivated after each rain, a slight but not significant increase in yield occurred when compared with flat planting without cultivation.

Table 5 shows plot yield of sorghum expressed as grain weight where moisture content of grain has been adjusted to 8%.

TABLE 5. Effect of Plow Treatment, Sorghum Variety and Soil Surface Treatment on Yield of Grain (tons/ha)

PLOW TREATMENT	SORGHUM VARIETY	SOIL SURFACE TREATMENT (c) Flat	Flat With Mulch	Flat Cult.	Ridges Open	Ridges Open/ Mulch	Ridges Tied	Ridges Tied/ Mulch	PLOW VERSUS VARIETY MEANS (b
Plow	E 35-1	1.57	3.60	2.02	2.41	3.10	2.20	3.29	2.60
	Local	1.10	2.66	1.39	1.63	2.32	2.32	2.83	2.03
No Plow	E 35-1	0.67	2.59	1.45	0.50	2.20	1.86	2.93	1.76
	Local	0.91	2.80	1.46	1.00	2.18	1.50	2.30	1.73
MEANS (a)		1.06	2.91	1.58	1.39	2.45	2.00	2.84	

a: LSD, 5% = 0.54
b: LSD, 5% = 0.18
c: LSD, 5% among SST for same variety = 0.77
among same SST treatment for different varieties and plow treatment = 0.77

The analysis of variance showed:

1. plowing treatments -- significant ($F = 26.3$, $df = 1/56$);
2. varieties -- significant ($F = 6.88$, $df = 1/56$);
3. soil surface treatment -- significant ($F = 24.1$, $df = 6/56$);
4. interaction between plowing treatment and variety -- significant ($F = 5.89$, $df = 1/56$);
5. comparison between mulched and non-mulched plots -- significant ($F = 128$, $df = 1/23$).

The effect of mulch on mean sorghum yields for soil surface treatments (SST) is shown in Figure 4. The dramatic effect of mulch on yields (exploded portions of Figure 4) shows the importance of using plant residues for a soil surface cover. However, yield for the non-plowed treatment with mulch (Figure 5) produced the same results as did the more labor dependent techniques of ridges and tied-ridges. Yields of other non-plowed treatments were lower.

FIGURE 4. Effect of SST on Sorghum Yields.

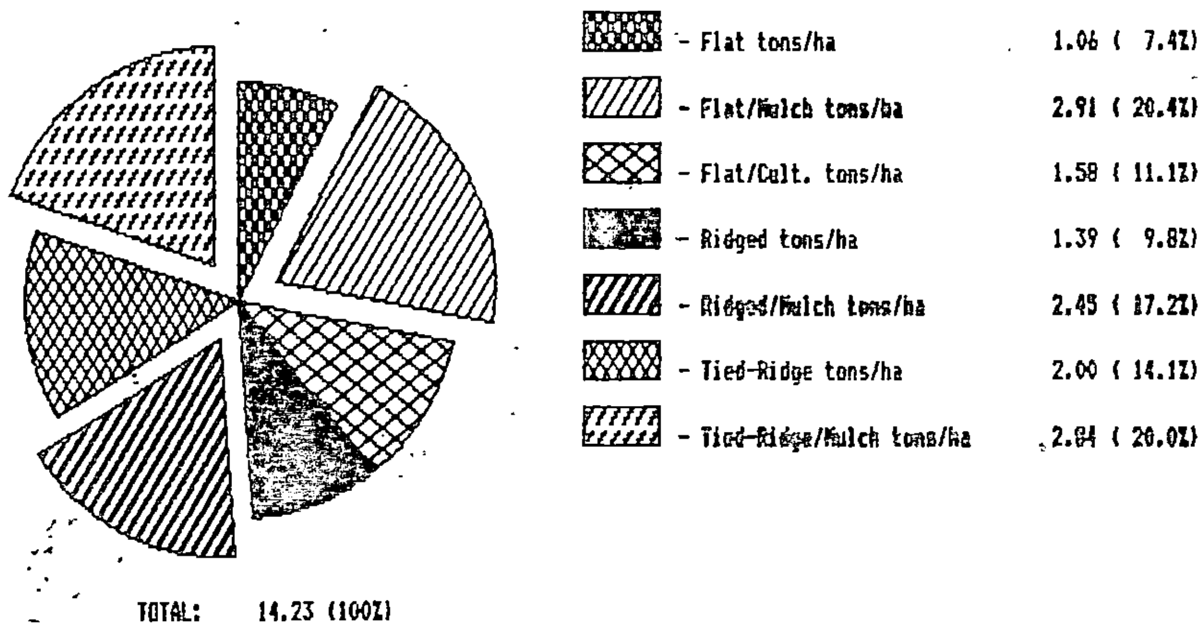


FIGURE 5. Effect of SST on Sorghum Yields.

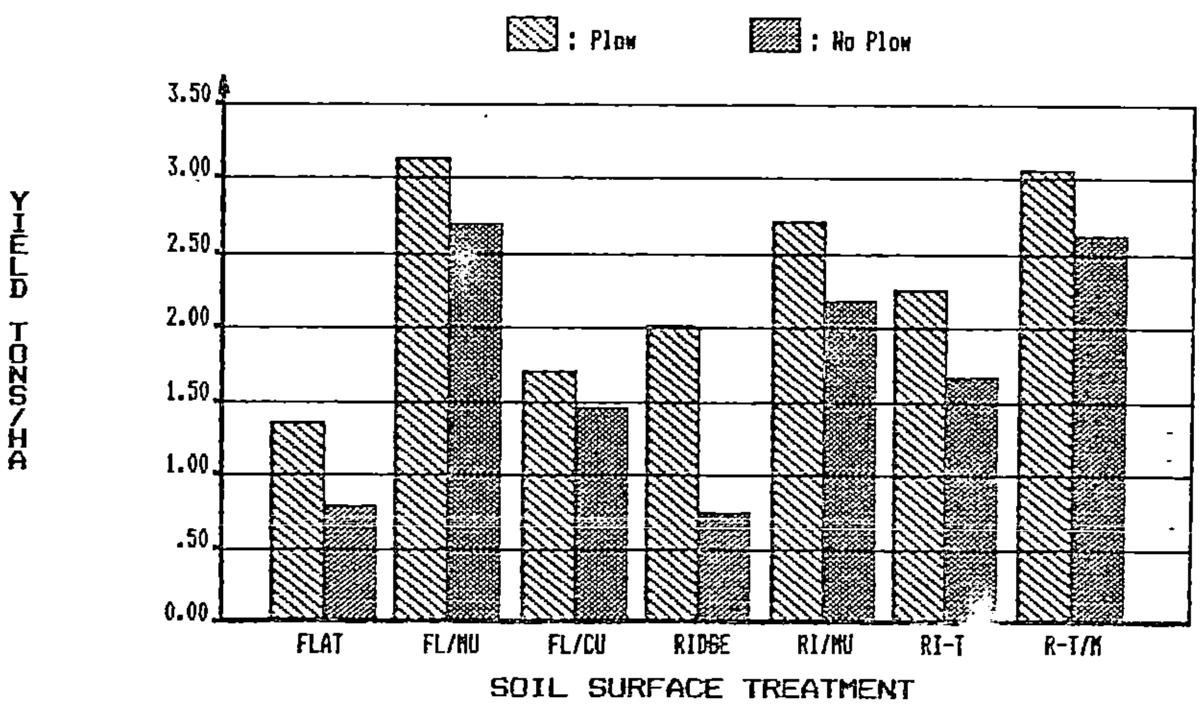
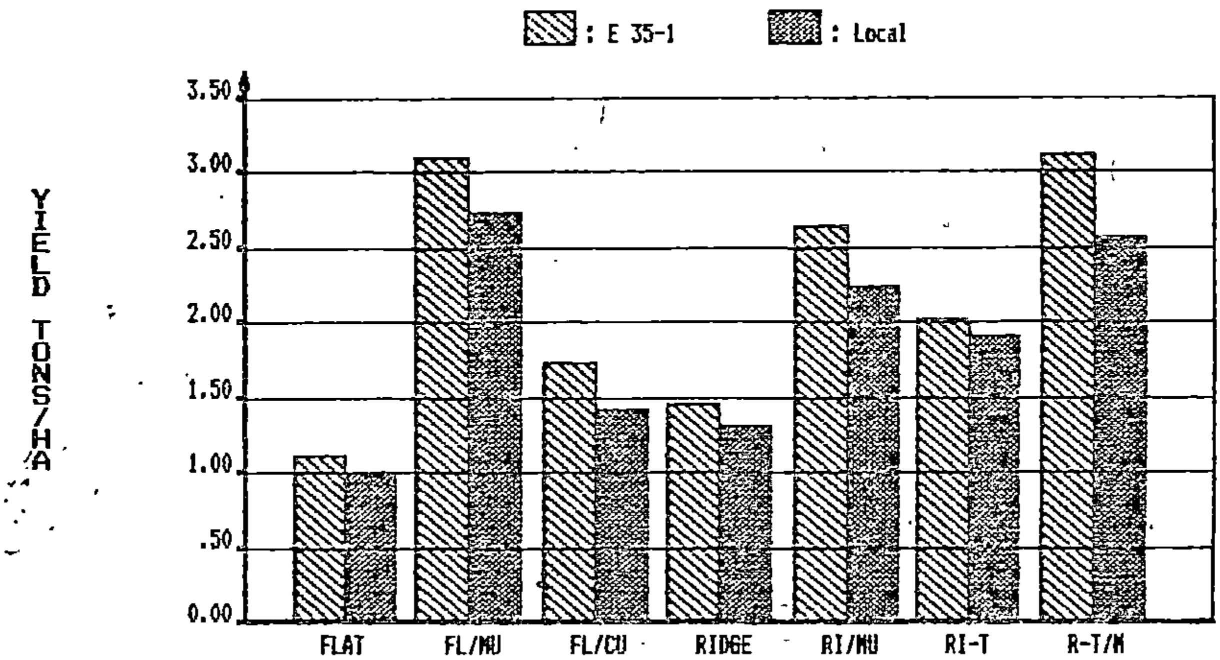


Figure 6 shows effect of soil surface treatment (SST) on Sorghum yields where varieties E 35-1 and local Kamboinse are the parameters. Highest yields for both varieties are because of mulch treatments. E 35-1 produced superior yields in mulched treatments.

FIGURE 6. Effect of SST on Sorghum Yields.



Additional results of interest show that seed weight/1000 grains for E 35-1 was significantly effected by the plowing treatment as plowing = 23.9gm and non-plowing = 20.7gm; however, there was no effect on local Kamboinse. Also, use of mulch reduced number of days until 50% flowering as E 35-1 = 81 days versus 83 days and the local = 75 days versus 77 days. Plowing, in general, reduced days until 50% flowering as plowing = 77 days and non-plowing = 80 days for both varieties. E 35-1 required more days to 50% flowering (82 days) than did local Kamboinse (76 days).

Analysis of number of good heads/plot showed that E 35-1 had significantly more heads (145) than did local Kamboinse (120). Total number of good heads/plot were significantly greater for mulched plots (168) than for unmulched plots (122). Also, effect of plowing was significant for plowed plots (154 heads) versus non-plowed plots (135 heads).

1982 Sorghum Studies

A 3-factor experiment was designed to keep treatment combinations together. The design for the sorghum experiments had main plots with the same 2 varieties as in 1981, E 35-1 and local Kamboinse. Subplots were quantity of mulch applied at rates of 0, 10, 15, and 20 tons/ha of dry material and sub-subplots had 5 levels of tied-ridges at row spacings of 0.50m, 0.75m, 1.00m, 1.25m, and 1.50m with all ties at the 1.00m spacing. These plots were randomized into complete blocks of 6 replications.

During this season, both sorghum varieties were planted at a spacing of 0.22m between pockets and thinned to 1 plant/pocket. Planting rate varied with spacing of ridges: at a spacing of 0.50m the rate was 105,000 plants/ha; at 0.75m spacing the rate was 66,000 plants/ha; at 1.00m spacing the rate was 40,000 plants/ha; and at both the 1.25m and the 1.50m spacing the rate was 27,000 plants/ha.

Table 6 presents the mean and LSDs for grain yield for the plant variety to size of catchment area. As mulch was added late in the growing season, effect of mulching for 1982 was statistically non-significant on all collected data sets; therefore, these data are not presented. The bundles of sorghum and millet stalks to be used as mulch were stolen from the field and although rice straw was later located for mulch treatments, it could not be applied until late August.

TABLE 6. Effect of Sorghum Variety and Size of Catchment Area (m^2) on Grain Yield (tons/ha)

SORGHUM VARIETY	SIZE OF CATCHMENT AREA (c) 0.50	0.75	1.00	1.25	1.50	VARIETY MEANS (b)
E 35-1	5.17	4.33	4.11	3.56	2.72	4.02
Local	3.00	2.76	2.45	2.24	1.90	2.49
MEANS (a)	4.08	3.55	3.28	2.90	2.35	

a: LSD, 5% = 0.28
b: LSD, 5% = 0.11
c: LSD, 5% among size of catchment area for same variety = 0.80
among same catchment area but for different varieties = 0.76

The analysis of variance for the split-split plot showed:

1. varieties -- significant (F = 867, df = 1/23);
2. size of catchment area -- significant (F = 70.5, df = 4/99);
3. interaction of variety by size of area -- significant (F = 8.2, df = 4/99).

Yield at a 0.50m row spacing was nearly double to that at a 1.50m row spacing (see Figure 7). E 35-1 responded to size of catchment area at a greater rate than did local Kamboinse.

Moisture content of plant material was determined by taking 1 plant/plot as a sample at time of harvest. Moisture content was significantly greater for E 35-1 at 62.1% with a range of 54.9% to 67.5% than that for local Kamboinse at 50.0% with a range of 45.0% to 54.1%. However, unlike dry matter production, moisture content of plant material was not related to size of catchment area.

When grain weight was corrected for moisture content, the harvest index was determined. The harvest index or plant index is the percentage ratio of grain weight to dry weight of plant material times 100. This calculation showed that E 35-1 had 38.5% more plant material than grain with a range of 28.6% to 50.0% and local Kamboinse had a harvest index of 20.8% with a range of 18.2% to 25.0%. The harvest index is a comparative energy efficiency rating showing that E 35-1 is more energy efficient than local Kamboinse. The harvest index was not related to size of catchment area. Wet weight of plant material averaged 25.7 tons/ha for E 35-1 with a range of 16.0 tons/ha to 43.9 tons/ha whereas local Kamboinse wet weight averaged 22.0 tons/ha with a range of 15.0 tons/ha to 33.3 tons/ha.

Total plant height of local Kamboinse is taller than E 35-1. However, the height of both varieties was not affected by size of catchment area. Table 9 shows the relationship of the means and LSDs for total plant height to size of catchment area and plant variety.

TABLE 9. Effect of Sorghum Variety and Size of Catchment Area (m^2) on Total Plant Height (cm)

SORGHUM VARIETY	SIZE OF CATCHMENT AREA 0.50	0.75	1.00	1.25	1.50	VARIETY MEANS (b)
E 35-1	264	258	256	250	242	254
Local	414	424	425	420	426	423
MEANS	341	339	340	335	334	

b: LSD, 5% = 44

The analysis of variance for the split-split plot showed:
varieties -- significant (F = 6400, df = 1/23);

Additional results of interest showed that E 35-1 had the greatest head weight/plot with 12.2 kg/plot and 8.4 kg/plot for local Kamboinse. However, local Kamboinse had the largest number of heads with 320 versus 168 heads for the E 35-1. A comparison of these values shows the much smaller heads of the local variety. There was an average of 1 tiller/plant for local Kamboinse but there were no tillers on the E 35-1.

Maintenance on tied-ridges was needed twice during the season; late July and early September. Weeding was needed only once during the season and was done at time of thinning. Water ponding on the catchment areas for 1 to 2 days after a rainfall discouraged weed growth between rows.

1983 Sorghum Studies

In 1983, the sorghum research fields were designed to evaluate:

1. the effects of plant density; and,
2. the effects of quantity of mulch.

These treatments were subplots for yield and growth characteristics of 3 varieties of sorghum, local Kamboinse, E 35-1, and Framida, which were main plots. Results from the previous years' experiments were used to define soil surface treatments: tied-ridges were spaced at 0.50m and tied 1.0m down the row immediately following planting. Severe storms washed and eroded ties and maintenance on the tied-ridges was done twice during the growing season. Because of an inadequate supply of mulch material, no mulch was applied to the plant density study. Plots for both studies were randomized into complete blocks of 8 replications.

Sorghum Density Studies: For the density studies, all sorghum varieties were planted as follows:

1. 220,000 Plants/ha, 10cm between pockets,
2. 140,000 Plants/ha, 15cm between pockets,
3. 110,000 Plants/ha, 20cm between pockets, and
4. 88,000 Plants/ha, 25cm between pockets.

Ridges in these plots were tied immediately following planting and after germination plants were thinned to 1 plant/pocket. Table 10 presents the mean and LSD values of sorghum heights measured in July. These heights represent the mean measurement of 10 plants/plot and 8 replications.

These plants were young at time of measurement; however, the effect of stand density is readily apparent. In general, the higher the density, the taller the plants. The more rapid growth rate of Framida is an example of it's seedling vigor. Framida had the longest leaves (38.7cm versus 35.0cm for E 35-1 and 37.6cm for local Kamboinse) but E 35-1 had the widest leaves (4.5cm versus 4.2cm for Framida and 3.9cm for local Kamboinse). Final height measurements were taken on the 10th of September and showed similar results with the mean height of E 35-1 at 203cm (range of 186cm to 213cm), Framida at 190cm (range of 183cm to 206cm), and local at 233cm (range of 227cm to 239cm). Because of rainfall shortage during 1983, final heights of these plants were somewhat reduced from those of previous years.

TABLE 10. Effect of Sorghum Variety and Stand Density (plant/ha) on Plant Heights (cm), 19/7/83

SORGHUM VARIETY	222,000	STAND DENSITY 140,000	110,000	88,000	VARIETY MEANS (b)
E 35-1	56.6	52.5	55.9	41.6	51.6
Framida	58.0	57.1	60.3	51.9	56.8
Local	51.9	55.0	54.8	46.3	52.0
MEANS (a)	55.5	54.9	57.0	46.6	

a: LSD, 5% = 2.7
b: LSD, 5% = 4.7
The analysis of variance for height measurements showed:

1. varieties -- significant (F = 62.8, df = 2/14);
2. stand density -- significant (F = 3.94, df = 3/63).

Yields for the 1983 season were lower, less than half, caused by less rainfall (663mm, mean = 751mm) and the effect of a late August drought which seriously affected seed set. Table 11 shows the mean and LSDs for grain yield for each sorghum variety to stand density.

TABLE 11. Effect of Sorghum Variety and Stand Density (plants/ha) on Grain Yield (tons/ha)

SORGHUM VARIETY	220,000	STAND DENSITY (c) 140,000	110,000	88,000	VARIETY MEANS (b)
E 35-1	1.15	1.33	1.35	1.83	1.42
Framida	1.08	1.27	1.28	1.72	1.34
Local	0.81	0.74	0.72	0.72	0.75
MEANS (a)	1.02	1.11	1.12	1.41	

a: LSD, 5% = 0.22
b: LSD, 5% = 0.06
c: LSD, 5% among stand density treatments for same variety = 0.34
among stand density treatments for different varieties = 0.30
The analysis of variance for the split plot showed:

1. varieties -- significant (F = 19.0, df = 2/14);
2. plant density -- significant (F = 4.9, df = 3/63).

Grain weight for all varieties has been adjusted to a moisture content of 8%. A stand density of 88,000 plants/ha gave the highest yields; however, local Kamboinse showed a reverse trend with stand density, although it was not statistically significant. Also, E 35-1 had the highest yield followed by Framida (red) and then local Kamboinse with each variety being significantly different. The means and LSDs of sorghum varieties and stand density for total dry matter is shown in Table 12.

Quantity of plant dry matter was greatest for E 35-1, followed by Framida (red), and lastly local Kamboinse. These results show dramatically the effects of climate as there is an apparent contradiction to production of plant material. During the 1982 season, local Kamboinse produced about the same as E 35-1 for a 0.50m row spacing (14.8 tons/ha versus 14.3 tons/ha).

TABLE 12. Effect of Sorghum Variety and Stand Density (plants/ha) on Total Plant Dry Matter (tons/ha)

SORGHUM VARIETY	STAND DENSITY 220,000	140,000	110,000	88,000	VARIETY MEANS (b)
E 35-1	9.20	10.71	8.89	7.82	9.15
Framida	8.75	7.02	7.53	8.01	7.83
Local	5.09	4.40	4.74	4.53	4.69
MEANS	7.68	7.37	7.05	6.79	

b: LSD, 5% = 1.06
The analysis of variance showed:
varieties -- significant (F = 43, df = 2/14);

From these measurements it is possible to calculate the harvest index. Table 13 shows harvest index, plant moisture content, and wet weight of plant material.

TABLE 13. The Harvest Index (%), Plant Moisture Content (%), and Plant Material Wet Weight (tons/ha)

SORGHUM VARIETY	HARVEST INDEX, %	PLANT MOISTURE, %	PLANT MATERIAL WET WEIGHT (tons/ha)
E 35-1	15.5	50.1	18.4
Framida	17.1	52.7	16.7
Local	16.0	54.7	11.6

The magnitudes of the harvest index for each variety is essentially the same with a slight edge given to Framida as the most efficient grain producer. The effect of a mid-summer drought can be seen by comparing last year's harvest index data where E 35-1 had an index of 38.5% and local Kamboinse had an index of 20.8%.

Additional results of interest showed that number of days until 50% flowering was shortest for Framida (83 days) and the same for E 35-1 and local Kamboinse (86 days). Also, stand density had a significant effect on number of days until 50% flowering with 86 days = 220,000 plants/ha down to 84 days = 88,000 plants/ha. Seed weight/1000 grains was significantly different for each variety as E 35-1 = 22.2gm, Framida = 21.1gm and local = 19.8gm; stand density was non-significant.

Plant measurements of plant node diameter, distance between nodes, leaf length, and leaf width all showed significant differences attributed to varieties; however, there was no effect caused by stand density. Number of good heads/plot showed that varieties and stand density were both significantly different.

Sorghum Mulch Studies: For quantity of mulch studies the following treatments were applied:

1. 0.0 tons/ha of sorghum stalks;
2. 7.5 tons/ha of sorghum stalks; and
3. 15.0 tons/ha of sorghum stalks.

After an adequate rainfall, plots were planted at a density of 80,000 plants/ha at a row width of 50cm. Ridges were immediately tied at 1.0m intervals and mulch placed within the catchment basins. Table 14 presents the mean and LSDs of sorghum heights which represent the means of 8 plants/plot.

TABLE 14. Effect of Sorghum Variety and Quantity of Mulch (tons/ha) on Plant Heights (cm), 10/8/83

SORGHUM VARIETY	QUANTITY OF MULCH (tons/ha) 0.0	7.5	15.0	VARIETY MEANS (b)
E 35-1	154	176	198	176
Framida	154	178	197	177
Local	119	141	139	133
MEANS (a)	142	165	178	

a: LSD, 5% = 18
b: LSD, 5% = 13
The analysis of variance showed:
1. varieties -- significant (F = 28, df = 2/10);
2. quantity of mulch -- significant (F = 8.1, df = 2/30).

Figure 8 shows the relationship of growth with time for each variety. Plant growth characteristics are clearly shown for each variety: local Kamboinse may start off slowly and appear to be sluggish in growth but after about 50 days the growth rate accelerates and eventually passes the other 2 varieties. Framida (red) has rapid growth characteristics after germination and after this accelerated growth period it grows at a constant rate of 2 cm/day up to flowering time which was about 82 days for this year. E 35-1 follows a similar pattern of growth except that there is a tendency for weakness during the period from germination to about 10 days of growth. If rainfall is inadequate or if evapotranspiration is exceptionally high during this period then it may be necessary to replant or transplant to maintain an established stand.

FIGURE 8. Sorghum Plant Height to Time.

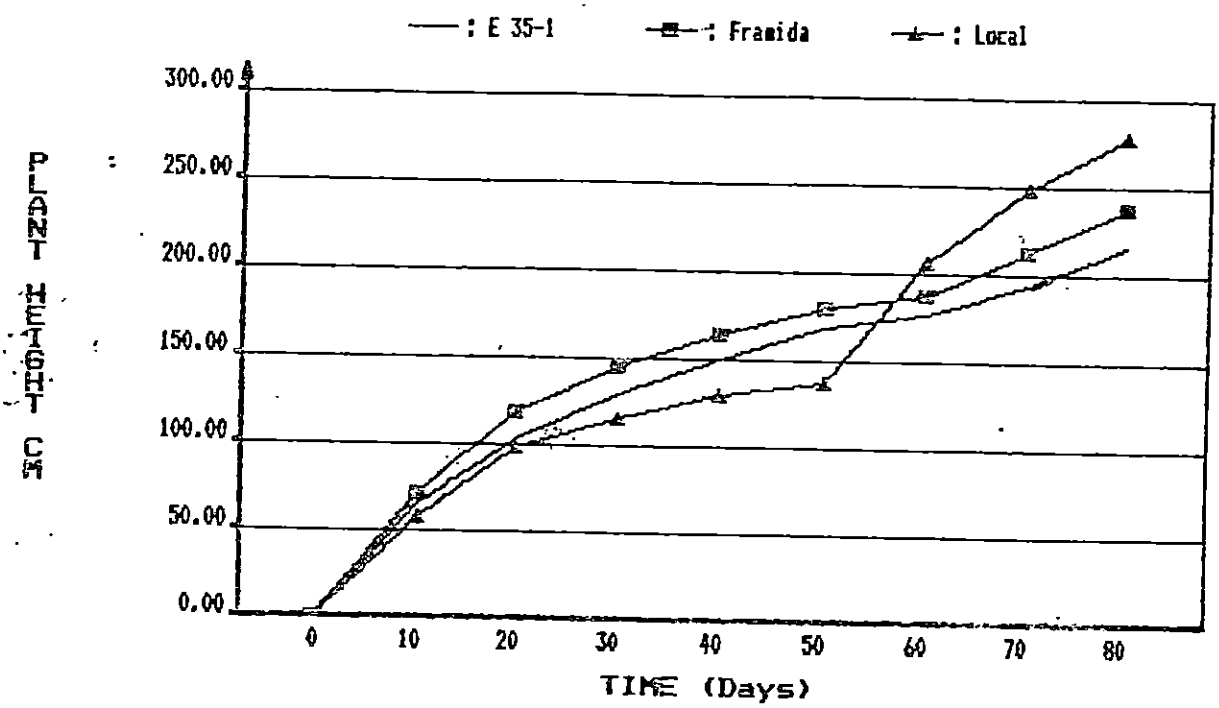
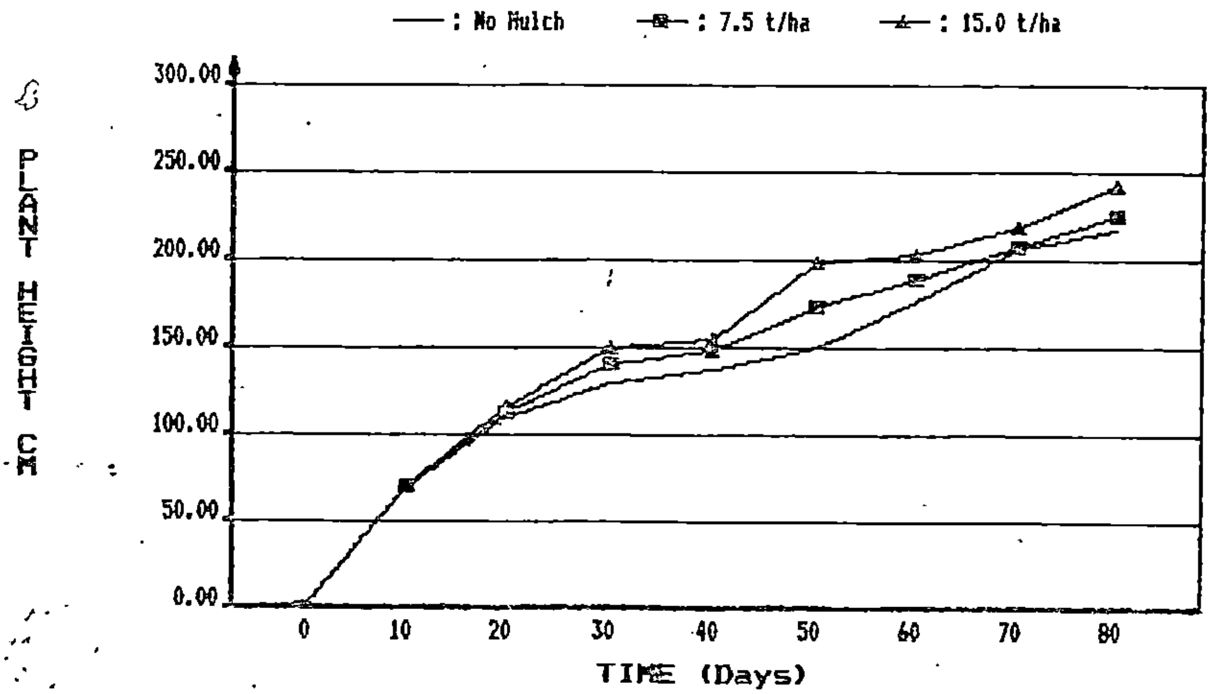


Figure 9 shows the relationship of the growth of these sorghum varieties to soil surface treatment of mulch. It must be remembered that, in this instance, the soil surface had been constructed into tied-ridges and the rows were spaced at 50cm.

FIGURE 9. Sorghum Plant Height to Time.



Framida responded at a greater rate to the application of mulch with a better response to soil surface management. However, E 35-1 responds well also; whereas, local Kamboinse responds the least demonstrating why it is well suited to low management conditions found in Burkina Faso. There was no response to applied mulch during the first 20 days of growth but then an increased growth rate was measured for the mulched plots; 1.9 cm/day for 15.0 tons/ha, 1.8 cm/day for 7.5 tons/ha, and 1.7 cm/day for 0.0 tons/ha. Analysis of variance on the split plot design showed that these rates are significantly different from each other.

Although yields for the 1983 season are lower than the previous years, the field for this study had a better soil (higher and deeper clay content) than the soil for the stand density study. Table 15 shows the mean and LSDs for grain yield for each sorghum variety to quantity of mulch. Grain weight for yield was adjusted to a moisture content of 8%.

Yield increased as quantity of mulch increased for all varieties. Framida responded to mulch by increasing grain yield by 0.87 tons/ha when 15.0 tons/ha of mulch was applied. E 35-1 increased by 0.58 tons/ha and local Kamboinse increased by 0.54 tons/ha. In addition, Framida increased yield by 0.57 tons/ha when 7.5 tons/ha of mulch was applied; whereas, both E 35-1 and local Kamboinse increased by 0.22 tons/ha. Under the climatic conditions of 1983 Framida responded better to increased mulch when tied-ridges were used.

TABLE 15. Effect of Sorghum Variety and Quantity of Mulch (tons/ha) on Grain Yield (tons/ha)

SORGHUM VARIETY	QUANTITY OF MULCH (c) 0.0	7.5	15.0	VARIETY MEANS (b)
E 35-1	1.44	1.65	2.02	1.70
Framida	1.84	2.41	2.71	2.32
Local	0.88	1.10	1.43	1.14
MEANS (a)	1.36	1.69	2.02	

a: LSD, 5% = 0.25
b: LSD, 5% = 0.55
c: LSD, 5% among mulch treatments for same variety = 0.32
among mulch treatments for different varieties = 0.43

The analysis of variance for the split plot design showed:

1. varieties -- significant (F = 15.6, df = 2/14);
2. quantity of mulch -- significant (F = 13.1, df = 2/42).

The means and LSDs of the sorghum varieties and quantity of mulch applied is shown in Table 16 for total plant dry matter.

TABLE 16. Effect of Sorghum Variety and Quantity of Mulch (tons/ha) on Total Plant Dry Matter (tons/ha)

SORGHUM VARIETY	QUANTITY OF MULCH 0.0	7.5	15.0	VARIETY MEANS (b)
E 35-1	12.0	12.2	13.1	12.5
Framida	7.9	9.6	9.4	9.1
Local	5.6	6.3	6.6	6.2
MEANS	8.5	9.5	9.7	

b: LSD, 5% = 1.6
The analysis of variance for the split plot design showed:
varieties -- significant (F = 35.6, df = 2/14).

Quantity of dry matter in this study was essentially the same as acquired on previous years; only the effect of a midseason drought on seed-set can be seen. However, the large amount of dry matter produced could only be attributed to tied-ridges, as no effect from added mulch was discerned. E 35-1 produced more dry matter than Framida and Framida produced more dry matter than local Kamboinse.

Again, using these data for dry matter and grain yield, the harvest index was calculated which is shown in Table 17.

TABLE 17. The Harvest Index (%), Plant Moisture Content (%), and Plant Material Wet Weight (tons/ha)

SORGHUM VARIETY	HARVEST INDEX, %	PLANT MOISTURE, %	PLANT MATERIAL WET WEIGHT (tons/ha)
E 35-1	13.7	40.0	20.7
Framida	25.6	45.7	16.6
Local	18.5	57.7	14.7

In this calculation, high yields and effect of mulch gave Framida a much higher harvest index than either E 35-1 or local Kamboinse. The low harvest index for E 35-1 was attributed to the mid-season drought which affected yield but not production of plant dry matter. Plant moisture content and wet weight of plant material are presented for additional information of these plants at harvest time.

Seed weight/1000 grains was significantly different for variety with E 35-1 = 23.5gm, Framida = 23.8gm, and local Kamboinse = 21.7gm. These weights are all greater than those for the stand density study. However, plant measurements of node diameter, distance between nodes, leaf length and leaf width were significantly different for variety but were not affected by quantity of mulch treatment. These measurements will no longer be used to detect soil surface treatment effects.

Total number of good heads/plot were significant for both variety and quantity of mulch treatments; however, number of heads were lower in the mulch study than in the stand density study. For example, E 35-1 = 172 heads/plot for the mulch study but 228 heads/plot for the stand density study. Framida had 201 heads/plot versus 291 heads/plot and local Kamboinse had 165 heads/plot versus 218 heads/plot. The differences were attributed to soil differences and effect of the summer drought on these differences. Total number of good heads/plot significantly increased with increasing quantities of mulch as 160 heads/plot = 0.0 tons/ha, 186 heads/plot = 7.5 tons/ha, and 192 heads/plot = 15.0 tons/ha.

1984 Sorghum Studies

The 1984 studies for soil surface treatments follow the same field design as used in previous years. (copies are in the Appendices) A severe early drought (Figure 1) limited cultivation and planting until late in the season. All plots were dry planted by the 10th of July, gambling that sufficient rainfall would occur. After the 25th of July rainfall (12mm) all local varieties (photosensitive and a long growth cycle) were replanted to non-photosensitive and short growth cycle varieties. On 9 August 1984 estimates were made on the % area of plant emergence/plot. These results are presented in Table 18.

TABLE 18. Effect of Sorghum Variety and Soil Surface Treatment on Plant Emergence Percentage

SORGHUM VARIETY	SOIL SURFACE TREATMENTS (c)				VARIETY MEANS (b)
	Flat	Flat With Mulch	Ridges Tied	Ridges Tied/ Mulch	
82 S 104	18	68	37	22	36
84 S 50	28	26	0	0.2	13
MEANS (a)	23	47	19	11	

a: LSD, 5% = 20
b: LSD, 5% = 14
c: LSD, 5% among SST for same variety = 29
among SST for different varieties = 28

The analysis of variance showed:

1. varieties -- significant (F = 17.0, df = 1/5);
2. soil surface treatments -- significant (F = 5.0, df = 3/30).

Flat plantings with mulch had significantly more pockets germinate than any other treatment. The short cycle variety 82 S 104 which was planted at the later date had a higher percentage of emergence than did the long cycle variety 84 S 50. Planting dry and flat has the distinct advantage of being able to use light rainfalls more efficiently than the loosely formed ridges which require a larger volume of water to saturate the ridge from the catchment basin. The significant effect of mulch with flat planting shows the need to protect the soil surface. Also, termites were actively eating the mulch throughout the field which benefits infiltration. Mound building termites which make larger and heavier tubes were found for the first time in 4 years in 1 corner of the field. Their presence was attributed to the extended drought.

1981 Millet Studies

A small field using a split-plot design was implemented to test the effect of soil surface treatments (SST) for water conservation on the subsequent production of 2 varieties of millet. At the outset, it was assumed that millet would respond differentially to soil surface treatments on alfisols; therefore, the objective was to compare the effect of soil surface treatments as precisely as possible for each variety. Main plots used 2 varieties of millet, Ex-bornu and local Kamboinse, and subplots included the following soil surface treatments: flat planting; open-ridges; tied-ridges; and, tied-ridges with rice straw mulch (at a rate of 6 tons/ha) with 3 replications.

The field was seeded 2 days after a rainstorm on the 26th of June. An application of 100 kg/ha of cotton fertilizer (14-23-15) was made with a side dressing of 65 kg/ha of urea applied on 5 August. Plot size was 5m x 10m with rows spaced 80cm apart. Ex-bornu was planted with 1 plant/pocket spaced every 30cm and at a rate of 45,000 plants/ha. Local Kamboinse was planted with 1 plant/pocket spaced every 45cm and at a rate of 30,000 plants/ha.

The sandy loam soil for the millet trial was easy to manage when making tied-ridges; however, these sandy soils tended to "melt" under severe rainstorms and maintenance was increased. During this study, ridges were tied or dammed immediately after germination and rice straw mulch was applied. The tied-ridges were reformed 3 times throughout the growing season.

Separation of treatment totals and development of sets of orthogonal coefficients showed that each soil surface treatment was significantly different from each other. At this stage of plant growth Ex-bornu was taller but later in the season local Kamboinse grew almost a meter taller. The local millet responded to increased management and produced another 100cm of height whereas Ex-bornu produced 80cm. The means of millet height taken during the growing season on 24 July are shown in Table 19 along with the LSDs for comparison purposes.

Final height measurements taken on the 5th of September showed essentially the same comparisons with the mean height of Ex-bornu at 248cm (range of 212cm to 276cm) and the mean height of local Kamboinse at 325cm (range of 267cm to 365cm). Using the test for single degrees of freedom, comparisons showed that for soil surface treatments, heights for flat plantings versus open ridges were significantly different ($F = 14.7$, $df = 1/12$) as was comparison between tied-ridges and other surface treatments ($F = 97.2$, $df = 1/12$) but no significant difference was found between tied-ridges and tied-ridges with mulch.

TABLE 19. Effect of Millet Variety and Soil Surface Treatment on Plant Height (cm), 24/07/81

MILLET VARIETY	SOIL SURFACE TREATMENT (c) Flat	Ridge Open	Ridge Tied	Ridge Tied/Mulch	VARIETY MEANS (b)
Local	125	148	187	226	172
Ex-bornu	179	212	236	258	221
MEAN (a)	152	180	211	242	

a: LSD, 5% = 26
b: LSD, 5% = 42
c: LSD, 5% among SST soil for same millet variety = 37;
among SST for different millet varieties = 67.

The analysis of variance for height measurements gave the following results:

1. varieties -- significant (F = 20.86, df = 1/16);
2. soil surface treatment -- significant (F = 12.69, df = 2/16).

Yield of millet expressed as grain weight for plant variety and soil surface treatment along with the LSDs are presented in Table 20.

TABLE 20. Effect of Millet Variety and Soil Surface Treatment on Yield by Grain Weight (tons/ha)

MILLET VARIETY	SOIL SURFACE TREATMENT (c) Flat	Ridge Open	Ridge Tied	Ridge Tied/Mulch	VARIETY MEANS (b)
Local	0.14	0.12	0.36	0.65	0.32
Ex-bornu	0.24	0.30	1.15	0.62	0.58
MEANS (a)	0.19	0.21	0.75	0.63	

a: LSD, 5% = 0.15
b: LSD, 5% = 0.19
c: LSD, 5% among different SSTs and the same millet variety = 0.21;
among the same SST and different millet varieties = 0.22.

The analysis of variance showed:

1. varieties -- significant (F = 59.48, df = 1/7);
2. soil surface treatments -- significant (F = 33.00, df = 3/12);
3. interaction between soil surface treatments and variety -- significant (F = 12.73, df = 3/12).

The significant interaction of soil surface treatment as a function of variety resulted from the effect of pollen wash on the Ex-bornu variety for the treatment using tied-ridges with mulch. Nonetheless, local Kamboinse did not suffer from pollen wash and more than doubled yield of flat traditional planting with tied-ridges and tied-ridges with mulch. Other plant measurements evaded the problem of pollen wash. Also, these yields are somewhat low when compared to the following years.

Total number of heads/plot as a function of plant variety and soil surface treatment are shown in Table 21.

TABLE 21. Effect of Millet Variety and Soil Surface Treatment on Total Number of Heads/Plot

MILLET VARIETY	SOIL SURFACE TREATMENT (c) Flat	Ridges Open	Ridges Tied	Ridges Tied/Mulch	VARIETY MEANS (b)
Local	177	140	314	393	256
Ex-bornu	226	279	462	769	434
MEANS (a)	201	209	388	581	

a: LSD, 5% = 49
b: LSD, 5% = 113
c: LSD, 5% among SST for same variety = 70;
among SST for different varieties = 123.

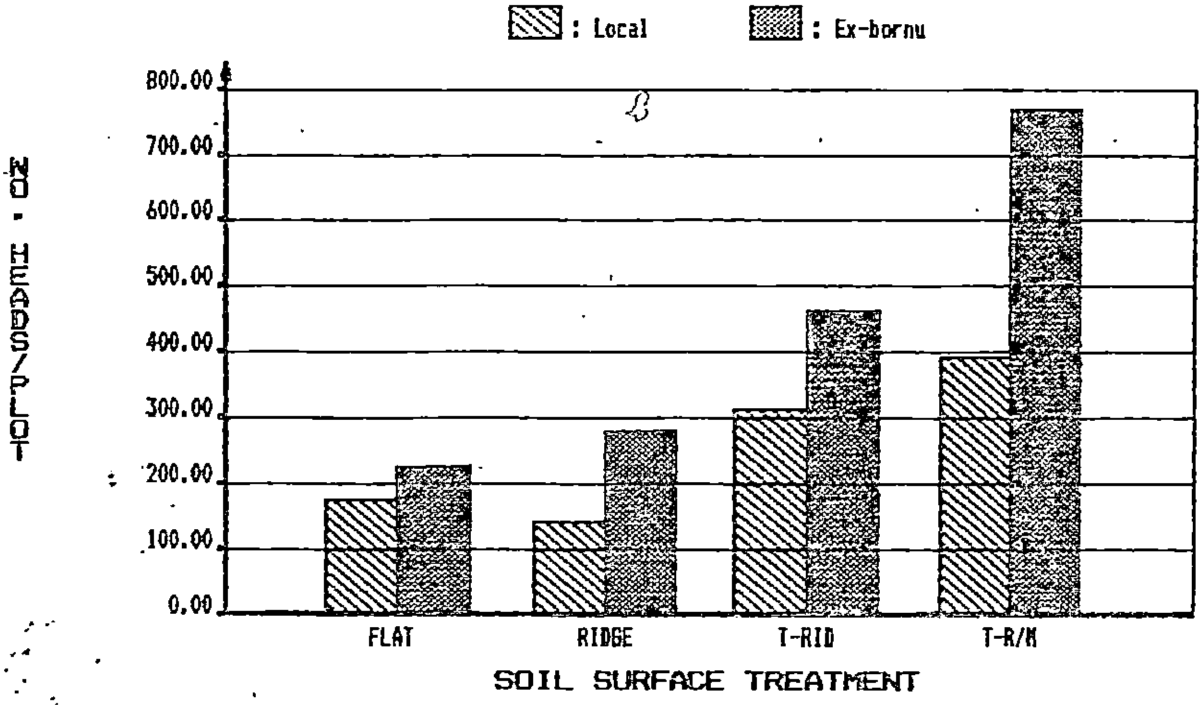
The analysis of variance showed:

1. varieties — significant (F = 44.6, df = 1/2);
2. soil surface treatments — significant (F = 122.84, df = 3.12);
3. interaction — significant (F = 18.5, df = 3/12).

The results for analysis of variance are similar to those of Table 20 except interaction between soil surface treatments and varieties was attributed to a significant increase in total number of heads in the tied ridges with mulch (see Figure 10).

By simple ratios, it follows that "if" pollen wash had not occurred (610 empty heads) yield for Ex-bornu would have been closer to 2.00 tons/ha. These data show that Ex-bornu responds to soil management at a much greater rate than local Kamboinse consequently the potential yield of Ex-bornu could be larger if management problems were solved. Pollen wash occurred heaviest on the tied-ridge with mulch treatment because time for flowering coincided exactly with rainfall which was enough to stop fertilization.

FIGURE 10. Effect of Millet Variety and SST.



The pollen wash effect on Ex-bornu is further exemplified in Table 22 for the effect of variety and soil surface treatment on the number of good heads/plot.

TABLE 22. Effect of Millet Variety And Soil Surface Treatment on Number of Good Heads/Plot

MILLET VARIETY	SOIL SURFACE TREATMENT (c) Flat	Ridge Open	Ridge Tied	Ridge Tied/Mulch	VARIETY MEANS (b)
Local	41	23	65	112	60
Ex-bornu	36	51	140	95	81
MEAN (a)	38	37	102	104	

a: LSD, 5% = 31
b: LSD, 5% = 34
c: LSD, 5% between different SST's for the same variety = 31; between the same SST and different varieties = 36.

The analysis of variance showed:

1. soil surface treatments -- significant ($F = 26.73$, $df = 3/12$);
2. interaction -- significant ($F = 6.21$, $df = 3/12$).

Loss of good heads in the tied-ridge with mulch treatment demonstrates that pollen wash is a serious limitation for Ex-bornu. However, ratios of these data with yield/plot show average yield/head for Ex-bornu was 16.3gm; whereas, yield/head for local Kamboinse was 12.0gm, a substantial decrease in potential yield.

Table 23 shows the relation of plant variety and soil surface treatment on seed weight/1000 grains. Seed weights increased significantly with soil surface treatment, except Ex-bornu, when planted on tied-ridges with mulch. This effect on Ex-bornu may have been because of pollen wash. The test of orthogonal coefficients showed that tied-ridges and tied-ridges with mulch were significantly different from flat and open ridge treatments (F = 24.73, df = 1/12).

TABLE 23. Effect of Millet Variety and Soil Surface Treatment on Seed Weight/1000 Grains (gm)

MILLET VARIETY	SOIL SURFACE TREATMENT (c) Flat	Ridge Open	Ridge Tied	Ridge Tied/Mulch	VARIETY MEANS
Local	6.73	7.67	9.70	10.30	8.60
Ex-bornu	4.83	5.63	9.86	9.23	7.39
MEAN (a)	5.78	7.65	9.78	9.77	

a: LSD, 5% = 1.89
c: LSD, 5% among SSTs for the same variety = 2.68
among SSTs for different varieties = 4.83
The analysis of variance gave the following statistics:
soil surface treatment -- significant
(F = 9.78, df = 3/12).

The effect of variety and soil surface treatment on number of days until 50% flowering is shown in Table 24.

TABLE 24. Effect of Millet Variety and Soil Surface Treatment on Number of Days Until 50% Flowering

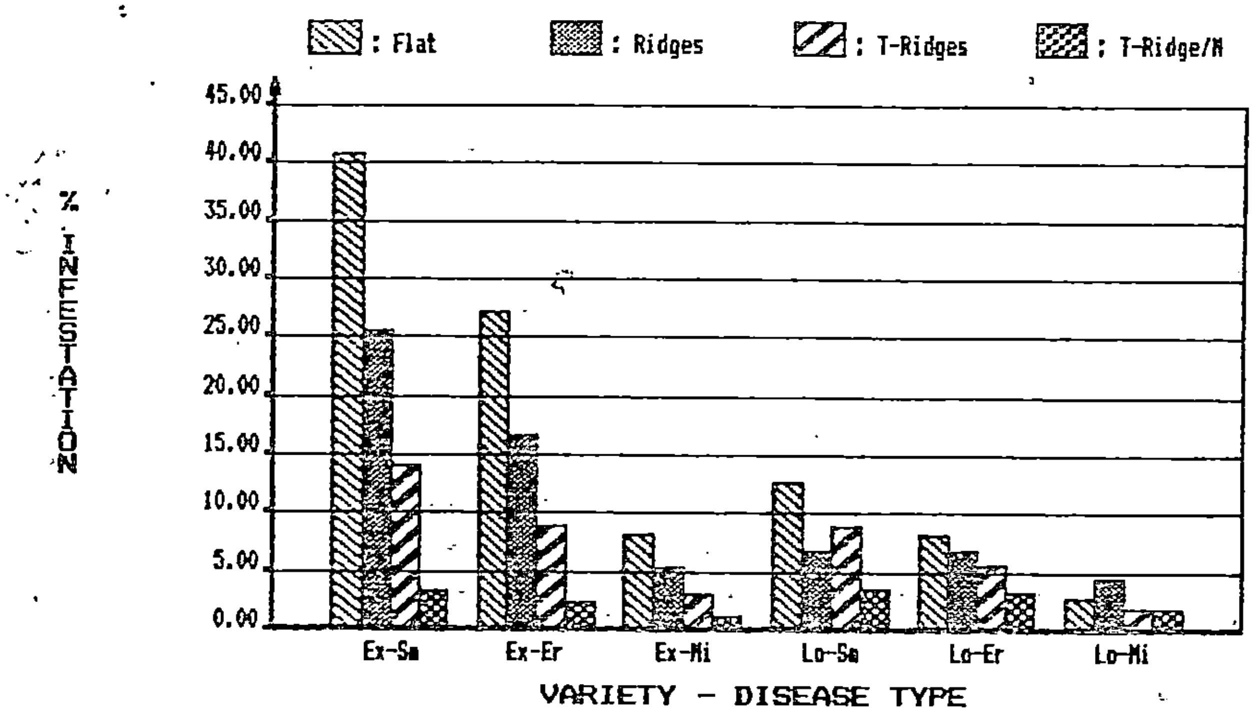
MILLET VARIETY	SOIL SURFACE TREATMENT Flat	Ridges Open	Ridges Tied	Ridges Tied/Mulch	VARIETY MEANS (b)
Local	81	79	80	79	80
Ex-bornu	58	57	52	51	55
MEANS (a)	70	68	66	65	

a: LSD, 5% = 4
b: LSD, 5% = 20
The analysis of variance for the split plot design showed:
1. varieties -- significant (F = 32, df = 1/16);
2. soil surface treatment -- significant
(F = 8.98, df = 3/12).

Although number of days until 50% flowering for the local variety was constant at 80 days, the Ex-bornu variety on tied-ridges was significantly reduced by 6 to 7 days. Number of days until 50% flowering is significantly affected by soil surface treatment. This explains why pollen wash differed between tied-ridge treatments. Because of the random probability of rainfall occurrence, the 1 day difference and the rainstorm at that time affected Ex-bornu on the tied-ridge plots with pollen wash but not on the other soil surface treatments.

Additional results for various measurements are presented in Figure 11 which presents the incidence of disease infestation (%) to variety and soil surface treatment.

FIGURE 11. Effect of SST on Millet Diseases.



Smut, ergot, and downy mildew infected Ex-bornu significantly greater than local Kamboinse. All 3 disease infestations were significantly affected by soil surface treatments. Tied-ridge treatments were significantly less infested than flat and open ridges with mulched tied-ridges being the least affected. Data for smut infestation showed that each soil surface treatment for Ex-bornu was significantly different and nearly so for local Kamboinse with the LSD at 5% for different soil surface treatments and the same variety = 5.0%.

1982 Millet Studies

A split-split plot design was used for the 1982 millet study to test the effect of size of catchment area (SCA) to quantity of mulch on 3 varieties of millet. Main plots contained the varieties, Ex-bornu, Souna-3, and local Kamboinse, which were arranged in randomized complete blocks of 5 replications. Subplots were arranged using 4 levels of rice straw mulch (0, 10, 15, and 20 tons/ha) and sub-subplots were 5 levels of tied-ridges with rows spaced at 0.50m, 0.75m, 1.00m, 1.25m, and 1.50m with all ties at the 1.0m length. This design is essentially the same as for the sorghum study in 1982 season except the alfisols were a sandy loam instead of a loam.

The field was seeded on 9 June 1982. An application of 100 kg/ha of cotton fertilizer (14-23-15) was made in addition to a side dressing of 65 kg/ha of urea applied on the 3rd of July. All 3 varieties were planted at the same spacing of 0.22m between pockets and thinned to 1 plant/pocket at a rate of 105,000 plants/ha at the 0.50m row spacing; 66,000 plants/ha at the 0.75m row spacing; 40,000 plants/ha at the 1.00m row spacing; and, 27,000 plants/ha at both 1.25m and 1.50m row spacing.

The means and LSDs of the grain yield are presented in Table 25 for each plant variety to size of catchment area (SCA). As previously mentioned, the effect of mulching was non-significant for all data sets because of the late application of the rice straw and these data will not be presented.

TABLE 25. Effect of Millet Variety and Size of Catchment Area (m^2) on Grain Yield (tons/ha)

MILLET VARIETY	SIZE OF CATCHMENT AREA (c) 0.50	0.75	1.00	1.25	1.50	VARIETY MEANS (b)
Local	1.00	1.12	1.14	1.02	1.07	1.07
Ex-bornu	2.11	2.33	2.41	1.97	2.14	2.19
Souna-3	2.23	2.18	2.59	2.39	2.33	2.35
MEANS (a)	1.79	1.88	2.08	1.79	1.84	

a: LSD, 5% = 0.19
b: LSD, 5% = 0.14
c: LSD, 5% among size of catchment area
for the same variety = 0.38
among the same size of catchment area
for different varieties = 0.62

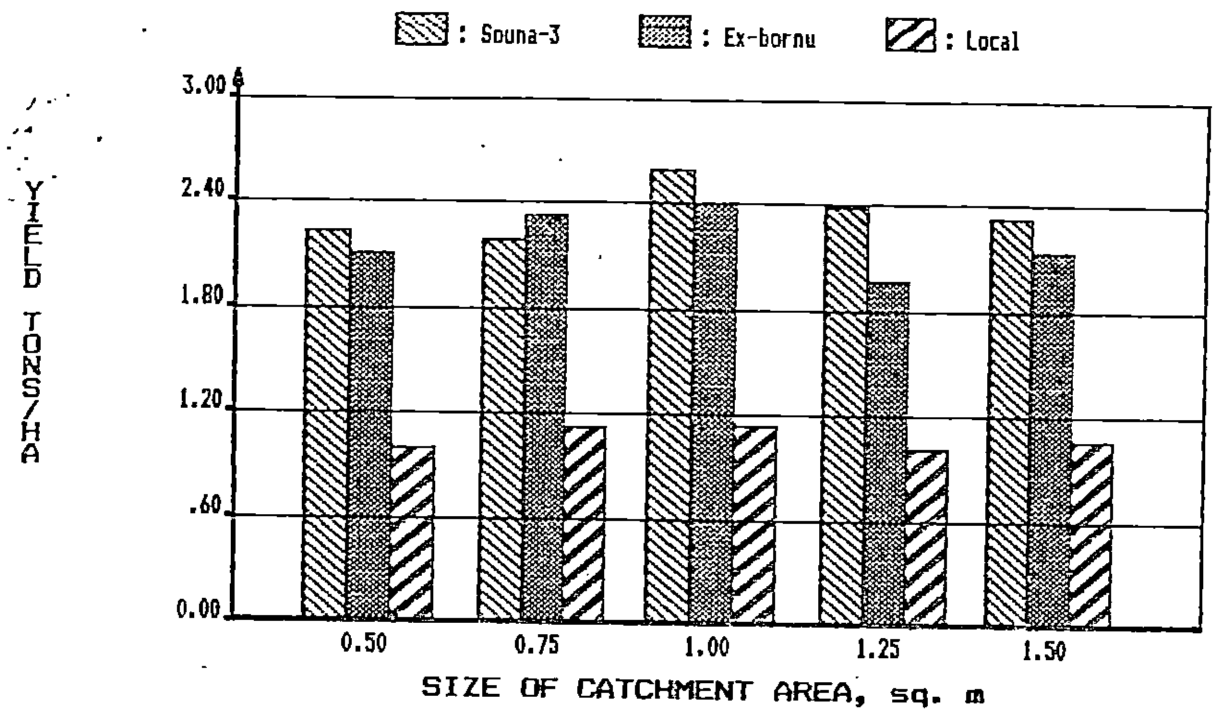
The analysis of variance for the split-split plot showed:

1. varieties -- significant (F = 165, df = 2/18);
2. size of catchment area -- significant (F = 7.12, df = 4/162);
3. interaction between varieties and catchment area size -- significant (F = 2.19, df = 8/162).

Millet yields were affected by downy mildew especially in the 0.50m and 0.75m row spacings with local Kamboinse the most severely affected throughout all treatments. Plot yields ranged from a high of 3.22 tons/ha for the Souna-3 to a minimum of 0.81 tons/ha for the local Kamboinse variety. These data show that a catchment area of 1.00m² was best for millet production during the 1982 growing season. However, had these varieties been resistant to downy mildew the data set would have probably paralleled that for the sorghum data on a 0.50m² area.

Figure 12 shows the means of the grain yield as affected by size of catchment area. A 1.00m² catchment area was the upper limit for disease infestation. In addition, Souna-3 produced significantly more grain than Ex-bornu and both of these varieties produced significantly more grain than local Kamboinse. Unlike the sorghum data, there is little, if any, evidence of plant density affecting the relationship of grain yield with size of catchment area.

FIGURE 12. Catchment Size on Grain Yield



Millet seed weight/1000 grains showed no relation to size of catchment area. However, the trend is towards heavier weights on the larger sized catchment areas. Moisture content of grain was 8.96% for local Kamboinse, 8.60% for Ex-bornu, and 8.77% for Souna-3 and all were significantly different from each other. All calculations for grain weight were adjusted to the 8% water content. Although Souna-3 produced the highest grain yield, it did not produce the heaviest grain; Ex-bornu had the heaviest grain. The relationship of the means and LSDs for seed weight/1000 grains to size of catchment area and plant variety is presented in Table 26.

TABLE 26. Effect of Millet Variety and Size of Catchment Area (m^2) on Seed Weight per 1000 grains(gm)

MILLET VARIETY	SIZE OF CATCHMENT AREA 0.50	0.75	1.00	1.25	1.50	VARIETY MEANS (b)
Local	9.49	10.73	9.82	10.77	11.00	10.36
Ex-bornu	11.16	11.06	11.14	11.80	11.38	11.30
Souna-3	10.37	9.56	10.72	10.03	10.78	10.29
MEANS	10.34	10.45	10.56	10.86	11.05	

b: LSD, 5% = 0.53

The analysis of variance for the split-split plot showed:

varieties -- significant (F = 10.2, df = 2/18).

Table 27 presents the means and LSDs for total plant dry matter to size of catchment area and millet variety.

TABLE 27. Effect of Millet Variety and Size of Catchment Area (m^2) on Total Plant Dry Matter (tons/ha)

MILLET VARIETY	SIZE OF CATCHMENT AREA (c) 0.50	0.75	1.00	1.25	1.50	VARIETY MEANS (b)
Local	5.82	5.23	5.24	4.86	5.14	5.26
Ex-bornu	4.31	4.46	4.95	3.75	3.77	4.25
Souna-3	4.01	3.33	4.08	3.31	3.35	3.61
MEANS (a)	4.71	4.34	4.76	3.97	4.09	

a: LSD, 5% = 0.57

b: LSD, 5% = 0.75

c: LSD, 5% among size of catchment area for the same variety = 1.06

among the same size of catchment area for different varieties = 1.78

The analysis of variance for the split-split plot showed:

1. varieties -- significant (F = 20.9, df = 2/18);
2. size of catchment area -- significant (F = 12.8, df = 4/162);
3. interaction of area size to variety -- significant (F = 14.5, df = 8/162).

Local Kamboinse produced the greatest amount of dry matter at 5.26 tons/ha with a range of 4.27 tons/ha to 6.45 tons/ha followed by Ex-bornu with 4.25 tons/ha with a range of 2.81 tons/ha to 5.67 tons/ha and lastly Souna-3 with 3.61 tons/ha with a range of 2.95 tons/ha to 5.58 tons/ha. Also, closer row spacings produced significantly more dry matter for Ex-bornu and Souna-3 than the 1.25m or 1.50m row spacings. Dry matter of Ex-bornu and Souna-3 plants weighed about the same at time of harvest. In addition, the test of individual degrees of freedom showed that dry matter production for local Kamboinse was not related to size of catchment area.

In Table 28 the harvest index, plant moisture content, and wet weight of plant material are presented.

TABLE 28. Relation of Millet Variety to Harvest Index (%), Plant Moisture Content (%), and Wet Weight of Plant Material (tons/ha)

MILLET VARIETY	HARVEST INDEX, %	PLANT MOISTURE, %	PLANT MATERIAL WET WEIGHT (tons/ha)
Local	20.3	61.0	13.5
Ex-bornu	51.5	61.3	11.0
Souna-3	65.1	68.7	11.6

Souna-3 had the highest percentage harvest index and was the most efficient grain producer with less energy used to produce dry matter. In this study, local Kamboinse had the lowest harvest index. At harvest, the stalks of Souna-3 contained the highest moisture content at 68.7%. Ex-bornu and Souna-3 wet weight of plant material weighed about the same at time of harvest.

The relation of the average number of tillers/plant to size of catchment area and plant variety is shown in Table 29.

TABLE 29. Effect of Millet Variety and Size of Catchment Area (m^2) on Average Number of Tillers per Plant

MILLET VARIETY	SIZE OF CATCHMENT AREA 0.50	0.75	1.00	1.25	1.50	VARIETY MEANS
Local	3.0	4.8	5.9	7.4	7.0	5.6
Ex-bornu	3.1	3.7	4.2	5.3	5.1	4.3
Souna-3	2.5	3.0	4.1	5.3	5.1	4.0
MEANS	2.8	3.8	4.7	6.0	5.8	

The analysis of variance for the split-split plot showed:

1. varieties -- significant ($F = 8.11$, $df = 2/18$);
2. size of catchment area -- significant ($F = 43.11$, $df = 4/162$).

All varieties produced tillers but local Kamboinse produced the greatest number of tillers followed by Ex-bornu with Souna-3 having the least number of tillers/plant. As expected, the average number of tillers/plant increased with an increase in size of catchment area. Number of tillers/plant for local Kamboinse changed at a greater rate, for size of catchment area, than Ex-bornu or Souna-3.

The means and LSDs of total plant height to size of catchment area and variety are shown in Table 30. These data were taken at 50% flowering which was 79 days for local Kamboinse followed by 62 days for Souna-3 and 60 days for Ex-bornu.

TABLE 30. Effect of Millet Variety and Size of Catchment Area (m^2) on Total Plant Height (cm)

MILLET VARIETY	SIZE OF CATCHMENT AREA (c) 0.50	0.75	1.00	1.25	1.50	VARIETY MEANS (b)
Local	320	333	337	345	326	332
Ex-bornu	253	250	258	253	260	255
Souna-3	256	250	261	260	256	256
MEANS (a)	276	278	286	286	280	

a: LSD, 5% = 7
b: LSD, 5% = 9
c: LSD, 5% among size of catchment area
for same variety = 26.2
among the same size of area
for different varieties = 26.9

The analysis of variance of the split-split plot design showed:

1. varieties -- significant (F = 236, df = 2/18);
2. size of catchment area -- significant (F = 2.67, df = 4/162).

Local Kamboinse was the tallest of the millet varieties averaging 332cm whereas Ex-bornu and Souna-3 had essentially the same height of 256cm. The relation of height to size of catchment area follows a similar pattern as grain yield in that the 1.00m^2 area produced the tallest plants on the average. However, by partitioning the sum of squares for the orthogonal comparison, the height relationship of local Kamboinse was not related to size of catchment area.

1983 Millet Studies

The millet research studies for 1983 followed the same pattern as developed for the 1983 sorghum studies. These studies were designed to evaluate the following treatments:

1. the effects of plant density; and,
2. the effects of quantity of mulch.

Soil surface treatments were determined from the results of 1981 and 1982 studies; ridges were spaced at 1.00m and tied at 1.00m. Main plot treatments were 3 varieties, local Kamboinse, Ex-bornu, and Souna-3, and subplots were the above treatments. A split plot statistical design was used with plots randomized into complete blocks of 8 replications for the plant density study and 6 replications for quantity of mulch study. Scarcity of available land limited the number of replications for the quantity of mulch study.

Millet Density Studies: For the plant density studies, all millet varieties were planted as follows:

1. 100,000 Plants/ha, 10cm between pockets,
2. 67,000 Plants/ha, 15cm between pockets,
3. 50,000 Plants/ha, 20cm between pockets, and
4. 40,000 Plants/ha, 25cm between pockets.

Each pocket was planted with 10 seeds following an adequate rainfall and ridges were tied or dammed. After germination, the pockets were thinned to 1 plant/pocket. No mulch was applied. Protocol for measurements and field plans were similar to examples in the Appendices.

The means and LSDs for height of millet are presented in Table 31 for measurements during September at 50% flowering. Local Kamboinse continued to grow for 97 days (time to 50% flowering) for the highest stand density. This is an extremely long period caused by irregular climatic conditions of the 1983 growing season. Maximum plant height was between the 67,000 and 50,000 plants/ha stand densities. However, there were no significant differences between the 3 higher stand densities. Other plant measurements show that local Kamboinse had the longest leaves (88.9cm versus 72.6cm for Ex-bornu and 71.7cm for Souna-3) and that Souna-3 had the widest leaves (4.0cm versus 3.7cm for Ex-bornu and 3.3cm for local Kamboinse). The stand density of 67,000 plants/ha was superior for these latter measurements.

TABLE 31. The Effect of Millet Variety and Stand Density (plant/ha) on Plant Heights (cm), 2/9/83

MILLET VARIETY	STAND DENSITY 100,000	67,000	50,000	40,000	VARIETY MEANS (b)
Local	224	240	237	236	234
Ex-bornu	237	237	222	238	234
Souna-3	251	256	262	234	251
MEANS (a)	238	244	241	236	

a: LSD, 5% = 7.4
b: LSD, 5% = 14.5
The analysis of variance for the split plot design showed:
1. varieties -- significant (F = 3.35, df = 3/3);
2. stand density -- significant (F = 4.43, df = 2/8).

Millet yields for the 1983 season were higher than those of the 1981 season but were somewhat lower than yields for the 1982 season. Table 32 presents the means and LSDs for grain weight for each millet variety and stand density. All grain weights have been adjusted to the 8% moisture content.

TABLE 32. Effect of Millet Variety and Stand Density (plants/ha) on Grain Yield (tons/ha)

MILLET VARIETY	STAND DENSITY (c) 100,000	67,000	50,000	40,000	VARIETY MEANS (b)
Local	0.47	0.48	0.51	0.50	0.49
Ex-bornu	1.73	1.90	2.01	2.16	1.95
Souna-3	1.68	1.91	2.38	2.34	2.08
MEANS (a)	1.21	1.33	1.50	1.53	

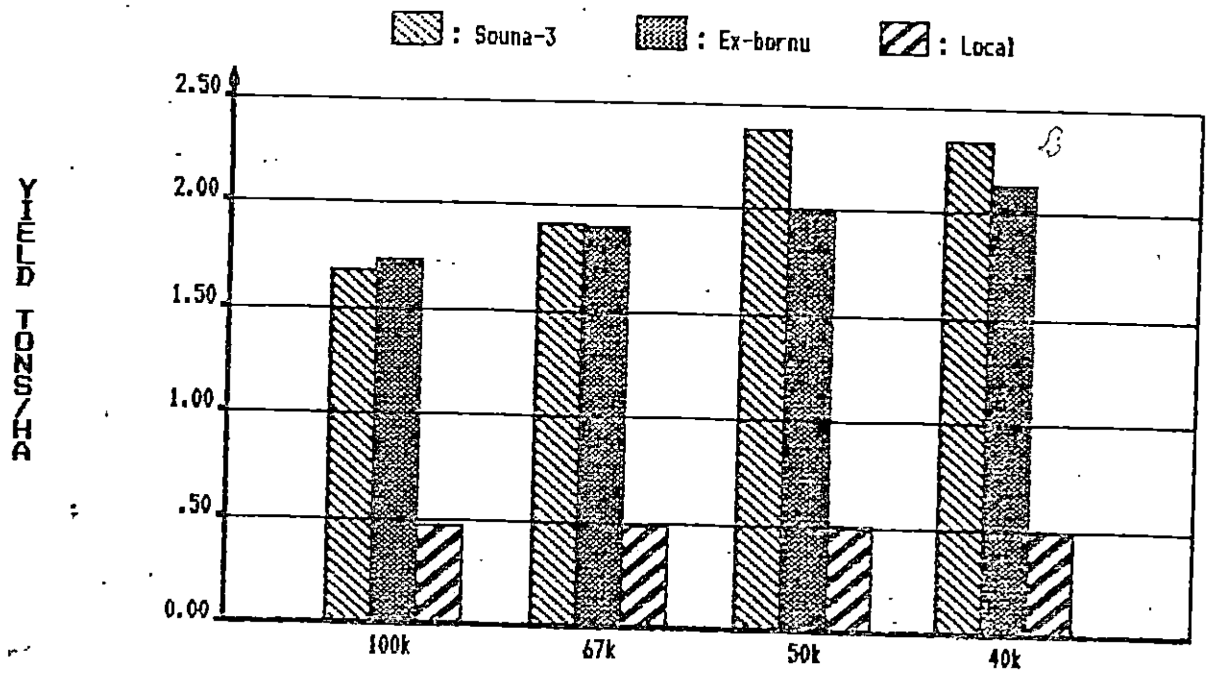
a: LSD, 5% = 0.19
b: LSD, 5% = 0.23
c: LSD, 5% among stand density treatments
for same variety = 0.31
among stand density treatments
for different varieties = 0.56

The analysis of variance for the split plot design showed:

1. varieties -- significant ($F = 70.3$, $df = 2/14$);
2. stand density -- significant ($F = 8.4$, $df = 3/63$).

Souna-3 produced the highest yield but not significantly higher than Ex-bornu. Nonetheless, both varieties produced significantly higher yields than local Kamboinse. Highest yields for all varieties was between stand densities of 50,000 and 40,000 plants/ha. A graphic display of these data is presented in Figure 13 which emphasizes that for local Kamboinse there was no significant effect of yield on stand density. Part of this can be attributed to climate and the long delay in flowering. This is further exemplified by date of harvest with Ex-bornu and Souna-3 harvested on 26/9/83, whereas local Kamboinse was harvested 12/11/83.

FIGURE 13. Stand Density on Grain Yield



STAND DENSITY x k = 1000, plants/ha

The relation between the means and LSDs for quantity of plant dry matter produced is presented in Table 33 for millet variety as a function of stand density.

TABLE 33. Effect of Millet Variety and Stand Density (plants/ha) on Quantity of Plant Dry Matter (tons/ha)

MILLET VARIETY	STAND DENSITY 100,000	67,000	50,000	40,000	VARIETY MEANS (b)
Local	5.68	5.50	5.43	5.27	5.74
Ex-bornu	7.00	7.11	6.73	7.57	7.09
Souna-3	5.78	6.02	7.16	6.40	6.34
MEANS	6.15	6.21	6.44	6.41	

b: LSD, 5% = 1.16

The analysis of variance for the total plant dry matter showed:
variety -- significant (F = 6.16, df = 2/14).

Quantity of dry matter was greatest for Ex-bornu although it was not significantly different from Souna-3. Both varieties had significantly more dry matter than local Kamboinse. The effect of stand density was not significant; nonetheless, trends were increasing towards lower stand densities. Yields of dry matter for 1983 were much greater than in previous years even though grain yields were slightly depressed.

Using the measurements of grain yield and total plant dry matter, the harvest index was calculated. Table 34 shows the harvest index, plant moisture content, and total wet weight of plant material.

TABLE 34. The Harvest Index (%), Plant Moisture Content (%), and Wet Weight of Plant Material (tons/ha)

MILLET VARIETY	HARVEST INDEX, %	PLANT MOISTURE, %	PLANT MATERIAL WET WEIGHT (tons/ha)
Local	8.6	43.8	8.8
Ex-bornu	27.4	38.1	12.9
Souna-3	32.8	37.5	11.5

Souna-3 had the highest harvest index but because of seasonal effects, the harvest index was lower than for the previous year (65.1% in 1982). The indices were much lower for 1983; however, trends and ratios of the magnitudes were essentially the same. During the 1983 season plant moisture contents at harvest time were also lower than for the 1982 season.

Effect of millet variety and stand density on number of days to 50% flowering can be seen in Table 35.

TABLE 35. Effect of Millet Variety and Stand Density (plant/ha) on Number of Days Until 50% Flowering

MILLET VARIETY	STAND DENSITY (plants/ha) (c) 100,000	67,000	50,000	40,000	VARIETY MEANS (b)
Local	97.5	92.9	91.1	90.8	93.0
Ex-bornu	52.1	52.6	53.9	52.0	52.7
Souna-3	57.3	56.5	56.8	55.5	56.5
MEANS (a)	69.0	67.3	67.3	66.1	

a: LSD, 5% = 1.3
b: LSD, 5% = 1.4
c: LSD, 5% = 2.4 for different stand densities and the same variety;
= 2.5 for the same stand densities and different varieties.

The analysis of variance for the split plot design showed:

1. varieties -- significant (F = 2194, df = 2/14);
2. stand density -- significant (F = 5.6, df = 3/63);
3. interaction between millet varieties and the stand density -- significant (F = 4.5, df = 6/63).

A period of 93 days to 50% flowering for local Kamboinse was longer than for previous years (average = 80 days). This extended time was attributed to the hotter growing season and the erratic distribution of rainfall. However, climate had little effect upon the non-photosensitive varieties of Ex-bornu and Souna-3, in that the normal time for 50% flowering is between 50 and 60 days for both varieties. This probably accounts for reduced yields of local Kamboinse and normal yields of Ex-bornu and Souna-3. The interaction was attributed to the large change in days for local Kamboinse from a stand density of 100,000 to 40,000 plants/ha (about 7 days) and the insensitiveness of the other 2 varieties over the same range (less than 2 days).

Additional results which may be of interest are plant measurements of plant node diameter, distance between nodes, leaf length and leaf width which varied by variety but were not affected by soil surface treatment. These results are the same as the sorghum varieties tested. Also, seed weight/1000 grains and % moisture of grain varied with variety but not with stand density: local = 6.66gm at 8.33%, Ex-bornu = 7.78gm at 9.17%, and Souna-3 = 5.73gm at 9.21%.

Data for total number of good heads/plot showed that Souna-3 = 290 heads, Ex-bornu = 283 heads, and local Kamboinse = 144 heads. This is in contrast to 1981 when pollen wash severely affected Ex-bornu. The percentage of bad heads followed a similar trend with Souna-3 = 24.1%, Ex-bornu = 38.1% and local Kamboinse = 61.4%. Total number of good heads/plot were significantly different for stand density ($F = 17.7$, $df = 3/63$) where 100,000 plants/ha = 277 heads/plot, 67,000 plants/ha = 240 heads/plot, 50,000 plants/ha = 227 heads/plot, and 40,000 plants/ha = 212 heads/plot. The highest stand density gave the highest number of good heads/plot.

Millet Mulch Studies: The millet studies on quantity of mulch followed the treatments used for the sorghum studies:

1. 0.0 tons/ha of millet stalks;
2. 7.5 tons/ha of millet stalks; and,
3. 15.0 tons/ha of millet stalks.

These plots were planted 20/06/83 following a good rainfall, cultivation and ridging at the 1.00m spacing. Ridges were tied at 1.00m down the row and millet stalk mulch was placed within the catchment basin of the tied-ridge. Later, plants were thinned to two plants/pocket for a stand density of 96,000 plants/ha.

Plant height, measured on 29/08/83, for variety and quantity of mulch applied is shown in Table 36. These values represent the means of 6 plant measurements/plot.

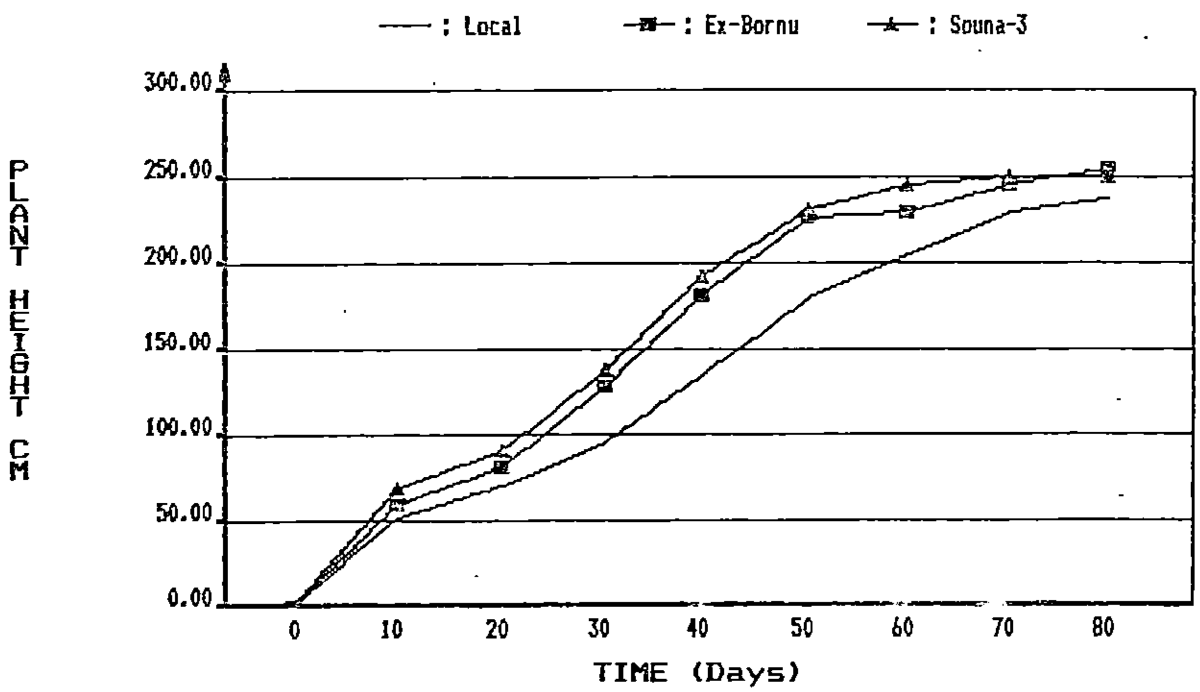
TABLE 36. Effect of Millet Variety and Quantity of Mulch Applied (tons/ha) on Plant Heights (cm), 29/08/83

MILLET VARIETY	QUANTITY OF MULCH (tons/ha) (c) 0.0	7.5	15.0	VARIETY MEANS (b)
Local	207	243	241	231
Ex-bornu	238	252	248	249
Souna-3	244	252	262	250
MEANS (a)	230	246	252	

a: LSD, 5% = 9
b: LSD, 5% = 11
c: LSD, 5% among mulch treatments for same variety = 20
among mulch treatments for different varieties = 19
The analysis of variance for the split plot design showed:
1. varieties -- significant (F = 12.4, df = 2/10);
2. quantity of mulch -- significant (F = 7.9, df = 2/30)

These data show effect of mulch on plant growth; however, 7.5 tons/ha of millet mulch was as satisfactory as 15.0 tons/ha. Similar results were found with height measurements of 18 August. Although varietal differences of millet plants were always significant, it was not until these height measurements that quantity of mulch was significant. Another aspect of growth characteristics of millet is displayed in Figure 14.

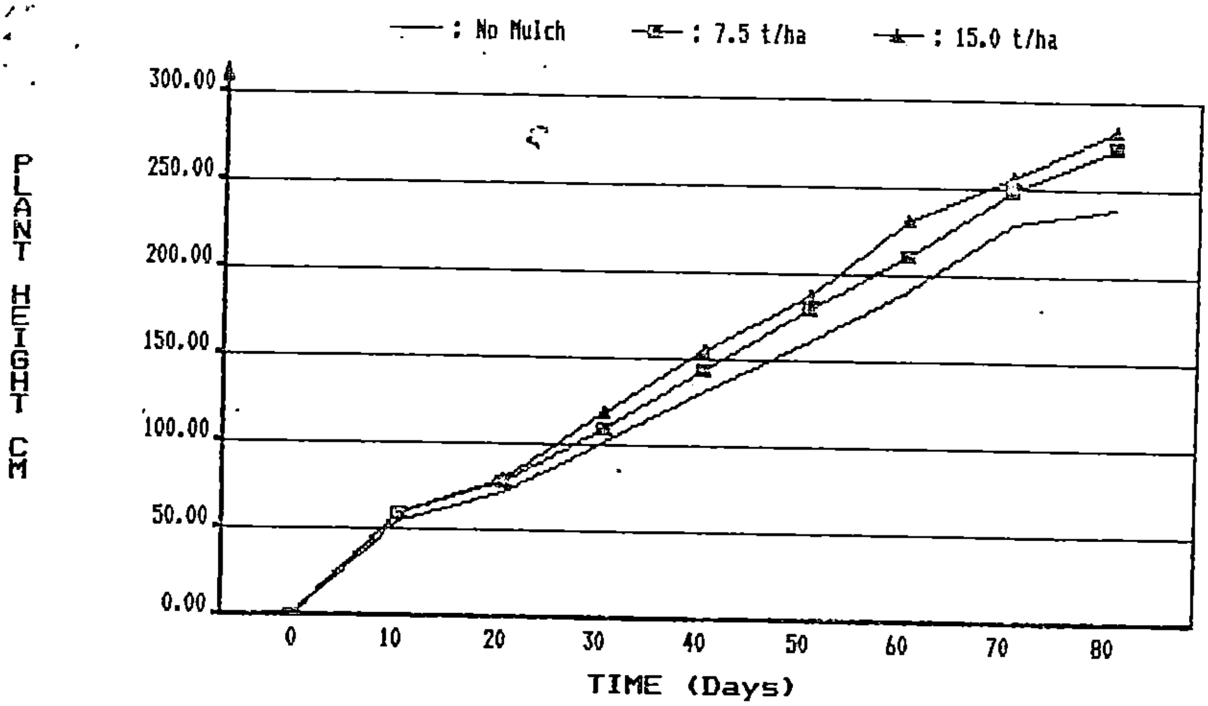
FIGURE 14. Millet Plant Height to Time.



Plant growth characteristics are similar for both Ex-bornu and Souna-3; whereas, local Kamboinse lags behind initially but exceeds the other 2 varieties towards the end of season. All 3 varieties have good seedling stand establishment qualities and the 2 exotics respond well to management. Height curves are a continuous function without steps which suggests that local climatic effects do not alter growth rate of millet. This effect is in contrast to the data for sorghum in Figure 8.

Response of these millets to quantity of mulch is shown in Figure 15. Here again, it must be remembered that mulch had been placed in the water catchment basin of the tied-ridges. Differences viewed here were attributed only to application of mulch. The effect of mulch was not statistically significant until the 20th day. After that time the effect of quantity of mulch on height of millet plants was significantly different for each addition of mulch.

FIGURE 15. Millet Plant Height to Time.



Millet yields for the 1983 season were less depressed than sorghum. Table 37 shows the mean and LSDs for millet grain yield to quantity of mulch applied. For these data, grain weights have been adjusted to a moisture content of 8%.

TABLE 37. Effect of Millet Variety and Quantity of Mulch (tons/ha) on Grain Yield (tons/ha)

MILLET VARIETY	QUANTITY OF MULCH (c) 0.0	7.5	15.0	VARIETY MEANS (b)
Local	0.25	0.25	0.30	0.27
Ex-bornu	0.95	0.94	1.05	0.98
Souna-3	0.93	0.97	1.22	1.04
MEANS (a)	0.67	0.68	0.81	

a: LSD, 5% = 0.10
b: LSD, 5% = 0.11
c: LSD, 5% among mulch treatments
for the same variety = 0.19
among mulch treatments
for different varieties = 0.44

The analysis of variance for the split plot design showed:

1. variety -- significant (F = 21.5, df = 2/10);
2. quantity of mulch -- significant (F = 3.9, df = 2/30).

Yield increased when quantity of mulch increased; however, a significant response did not occur until quantity of mulch = 15.0 tons/ha. A portion of this yield response was attributed to the coarse textured sandy soils of these plots. In this event, any increase in yield for the 0.0 and 7.5 tons/ha mulch treatments must have resulted from tied-ridges. Data for grain yield did not follow the same logic as that of plant height for these millets. Some clarification can be obtained by examining total plant dry matter.

The means and LSDs of the millet varieties and quantity of mulch applied is shown in Table 38 for total plant dry matter.

TABLE 38. Effect of Millet Variety and Quantity of Mulch Applied (tons/ha) on Total Plant Dry Matter (tons/ha)

MILLET VARIETY	QUANTITY OF MULCH (tons/ha) 0.0	7.5	15.0	VARIETY MEANS
Local	4.8	5.5	4.9	5.1
Ex-bornu	5.2	5.9	7.1	6.1
Souna-3	4.4	5.7	8.2	6.1
MEANS (a)	4.8	5.7	6.8	

a: LSD, 5% = 1.0

The analysis of variance for the split plot design showed:
quantity of mulch -- significant
(F = 6.4, df = 2/30).

Quantity of dry matter continued to increase for each level of mulch applied. However, the quantity produced for each variety was statistically the same even though the 2 exotic varieties produced slightly more. Once again data showed an apparent lack of response from local Kamboinse to increased management emphasizing this variety's adaptation to low levels of soil-water management. Souna-3 responded the best to increasing levels of soil-water management which was similar to results of the 1982 season.

These data can be seen differently by examining the harvest index, plant moisture content, and weight of wet plant material presented in Table 39.

TABLE 39. The Harvest Index (%), Plant Moisture Content (%), and Plant Material Wet Weight (tons/ha)

MILLET VARIETY	HARVEST INDEX, %	PLANT MOISTURE, %	PLANT MATERIAL WET WEIGHT (tons/ha)
Local	5.2	43.5	9.0
Ex-bornu	16.1	34.3	9.3
Souna-3	15.5	34.0	9.3

In this study, the harvest index was low for all varieties. Depressed yields and good plant growth combined to reduce magnitudes of the harvest index. However, the expected differences showed where the exotic varieties of Ex-bornu and Souna-3 were more efficient in using available energy than local Kamboinse. In addition, plants were somewhat drier at time of harvest than in previous years.

Effect of quantity of mulch showed that 7.5 tons/ha gave the major contribution to number of good heads/plot. Increasing mulch to 15.0 tons/ha had little or no effect upon number of good heads/plot but number of good heads/plot is related to variety. Local Kamboinse produced the least number of good heads/plot or 38.4% of the total heads. In comparison, 42.3% of the heads produced by Ex-bornu were good and 48.9% of the heads produced by Souna-3 were good. Other heads, not included in the count for good heads were either empty, bird damaged, or infected by disease.

Response to quantity of mulch is shown in Table 40 which presents the means and LSDs of number of good heads/plot at time of harvest.

TABLE 40. Effect of Millet Variety and Quantity of Mulch (tons/ha) on Number of Good Heads/Plot

MILLET VARIETY	QUANTITY OF MULCH (tons/ha) (c) 0.0	7.5	15.0	VARIETY MEANS (b)
Local	85	96	97	93
Ex-bornu	121	187	169	159
Souna-3	187	215	233	212
MEANS (a)	131	166	167	

a: LSD, 5% = 25
b: LSD, 5% = 39
c: LSD, 5% among mulch treatments for the same variety = 43
among mulch treatments for different varieties = 53
The analysis of variance for the split plot design showed:
1. variety -- significant (F = 22.2, df = 2/10);
2. quantity of mulch -- significant (F = 5.5, df = 2/30).

The means and LSDs are presented in Table 41 for effect of variety and quantity of mulch applied on number of days until 50% flowering.

TABLE 41. Effect of Millet Variety and Quantity of Mulch Applied (tons/ha) on Number of Days Until 50% Flowering

MILLET VARIETY	QUANTITY OF MULCH (tons/ha) 0.0	7.5	15.0	VARIETY MEANS (b)
Local	94	90	91	92
Ex-bornu	62	60	59	60
Souna-3	61	59	58	59
MEANS (a)	73	70	69	

a: LSD, 5% = 2
b: LSD, 5% = 1
The analysis of variance for the split plot design showed:
1. varieties -- significant (F = 852, df = 2/10);
2. quantity of mulch -- significant (F = 13, df = 2/30).

These data show a large variation in number of days until plants have produced 50% of their flowers. Photosensitive local Kamboinse required 92 days or 10 to 12 days more than was required during the previous 2 years. Partial photosensitive exotic varieties also required about 8 to 9 days more than was previously observed. These longer growing periods, attributed to climatic effects, permitted more time for plant head damage from disease, storm damage, and birds.

As quantity of mulch applied increased, number of days to 50% flowering decreased. Effect of quantity of mulch was greatest on local Kamboinse, and in consequence, length of growing season was shortened by a few days.

Village Studies, Djibo: Djibo is in the northwest corner of Burkina Faso at 14 degrees, 6 minutes north latitude, 1 degree, 37 minutes west longitude at an elevation of 274m. Average annual rainfall for Djibo is 567mm and potential evapotranspiration is 1972mm (Virmani, et. al., 1980). Actual rainfall of 1983 at the research site was only 479mm with a cloudburst of 100mm falling the 4th of August which caused considerable damage to soil surface treatments of the plots. Effectively, seasonal rainfall started the 26th of May and ended the 27th of September, a season of 125 days. However, only during the months of July, August and September did rainfall provide a favorable moisture balance.

Soils in this region are loamy fine sands on slopes varying from 0 to 3%. Many areas of this soil type have slopes less than 2% with steeper slopes up to 3% being short slopes associated with small hills. These soils are gently undulating with local relief being less than 0.5m. In general, the depth to laterite is estimated to be 2.5m to 4m based upon location. Reaction (pH) is generally neutral to slightly acid. Surface soils (A horizon) are made up of yellowish red loamy fine sand (91% sand, 6% silt and 3% clay) between 30cm to 40cm thick. This horizon is underlaid by a subsoil (B horizon) which is a red loamy fine sand (85% sand, 5% silt and 10% clay) that extends to depths greater than 2m. These soils are examples of typical alfisols used for millet production in the north of Burkina Faso.

The objective of this study was to evaluate, in the Djibo environment, soil surface treatments being used successfully on the Mossi Plateau in central Burkina Faso. In addition, measurement information was needed on plant management studies to serve as baseline data for future studies in the region. Soil surface treatments were as follows:

1. Tied-ridges,
2. Melon-beds, also tied,
3. Flat planting, traditional, and
4. Flat planting and tied-ridges made during the first weeding by animal traction.

Plot dimensions for these 32 plots with 8 replications were 10m by 15m. Millet variety was the short but rapid growing IKMV-8201, planted in pockets to a density of 40,000 plants/ha in rows 1.00m apart. The entire field was plowed by animal traction and, where needed, ridged before seeding with tieing of ridges 13-15/07/83. Plots were seeded 16 July and harvested 26 October, a total of 102 days. Before planting, an application of 100 kg/ha of cotton fertilizer was applied and, later, side dressed with 65 kg/ha of urea.

Table 42 presents the mean, standard deviation and percent coefficient of variation for grain yield produced on these plots. Grain moisture values were adjusted to an 8% moisture content.

TABLE 42. Effects of Soil Surface Treatment on Millet Yield (tons/ha) Production at Djibo, Burkina Faso

SOIL SURFACE TREATMENT	MILLET YIELD (tons/ha) MEAN	STD. DEV.	% COEF. VAR.
Tied-ridge	1.92	0.39	20.4
Melon beds	1.77	0.14	7.7
Flat	1.87	0.18	9.4
Flat/Tied-ridge	2.14	0.29	13.6

The analysis of variance for the randomized complete block design showed that the soil surface treatment was non-significant.

Effects of the storm which occurred on the 4th of August can be seen in yield data of the tied-ridge and melon-bed plots. Runoff from cultivated fields above the study area seriously eroded and totally leveled some of these plots. Growth on 2 treatments was setback and plants never fully recovered even though plots were completely rebuilt immediately following the storm. Runoff flowed over traditional flat plantings without any serious erosion or plant damage. This storm occurred before first weeding and the flat/tied-ridge treatment avoided damage. The magnitude of yields were similar or better than those reported at Kamboinse Experimental Station for 1983 signifying a good rainfall season for the Djibo area.

The means, standard deviation, and percent coefficient of variation for total plant dry matter produced are shown in Table 43.

TABLE 43. Effect of Soil Surface Treatment on Total Plant Dry Matter (tons/ha) Production at Djibo, Burkina Faso

SOIL SURFACE TREATMENT	TOTAL PLANT DRY MATTER (tons/ha) MEAN	STD. DEV.	% COEF. VAR.
Tied-ridge	2.49	0.48	19.5
Melon-bed	2.53	0.35	13.8
Flat	2.48	0.49	19.9
Flat/tied-ridge	2.53	0.45	17.8

The analysis of variance for the randomized complete block design showed that the soil surface treatment was non-significant.

Quantity of dry matter produced by this short variety was somewhat low when compared to quantity of dry matter produced at Kamboinse. Using these data for dry matter and grain yield, the harvest index was calculated and appears in Table 44.

TABLE 44. The Harvest Index (%), Plant Moisture Content (%), and Plant Material Wet Weight (tons/ha).

SOIL SURFACE TREATMENT	HARVEST INDEX, %	PLANT MOISTURE, %	PLANT MATERIAL WET WEIGHT (tons/ha)
Tied-ridge	77.1	42.3	4.30
Melon-bed	70.0	39.4	4.18
Flat	75.4	43.8	4.38
Flat/tied-ridge	84.5	43.2	4.44

Effect of soil surface treatment neither increased yield nor increased total dry matter production; however, this short fast growing millet is an extremely efficient energy user and responds well to management. Any differences in the harvest index were attributed to damage from the 4 August storm. Plant moisture contents and wet weight of plant material appear to be comparable for the region.

The relationship of soil surface treatment to seed weight/1000 grains is presented in Table 45. Seed weight has been adjusted to an 8% moisture content.

TABLE 45. Effect of Soil Surface Treatment on Seed Weight/1000 Grains (gm).

SOIL SURFACE TREATMENT	SEED WEIGHT/1000 GRAINS (gm) MEAN	STD. DEV.	% COEF. VAR.
Tied-ridge	7.82	0.56	7.12
Melon-bed	7.91	0.54	6.89
Flat	7.80	0.51	6.55
Flat/tied-ridge	8.50	0.32	3.72

LSD, 5% = 0.53
The analysis of variance for the randomized complete block design shows that soil surface treatments were significant ($F = 3.37$, $df = 3/21$).

Soil surface treatments which were planted flat and then, at time of weeding, ridged and tied, showed a significant increase in seed weight/1000 grains. Had the severe storm not damaged the tied-ridge and melon-bed plots, the effect of water catchment basins might have been observed in other plant measurements.

Additional measurements of interest showed that percentage of bad heads was only 1.17% and measurements of plant parameters, i.e., nodes and leaves, were not significant with soil surface treatments. Total number of good heads/plot = 528 heads/plot and the percent moisture of grain = 7.93%, both values, are comparable to Kamboinse Station data.

1984 Millet Studies

The 1984 millet studies for soil surface treatments followed the same patterns as in previous years and protocols for these study designs are in the Appendix. Planting and replanting times are similar to those discussed for the 1984 Sorghum studies. Table 46 shows effect of soil surface treatment on plant emergence for a short term variety, IKMV 8305, planted on 12/08/84 and for a long term variety, IKMV 8201, (see 1983 Djibo study) which was planted on 10/07/84.

TABLE 46. Effect of Millet Variety and Soil Surface Treatment on Plant Emergence Percentage

MILLET VARIETY	SOIL SURFACE TREATMENTS (c) Flat	Flat With Mulch	Ridges Tied	Ridges Tied/ Mulch	VARIETY MEANS (b)
IKMV 8305	68	76	68	54	66
IKMV 8201	60	70	0.3	1	33
MEANS (a)	64	73	34	28	

a: LSD, 5% = 17
b: LSD, 5% = 18
c: LSD, 5% among SST for same variety = 24
among SST for different varieties = 27

The analysis of variance showed:

1. varieties -- significant (F = 22.5, df = 1/5);
2. soil surface treatment -- significant (F = 13.6, df = 3/30);
3. interaction varieties versus SST -- significant (F = 6.7, df = 3/30).

Plant emergence percentage for IKMV 8201 when planted flat was significantly different from tied-ridges. The increased efficiency of using light rainfalls when soil surface treatment is flat and then planting dry is discernible. Results for millet differ from sorghum which were attributed to the millet being planted in a loam soil whereas sorghum was planted in a sandy soil. A better water holding capacity for the millet field was seen in the seedling emergence of IKMV 8305.

Table 47, for percentage of plant emergence, shows the added effect of plowing or not plowing on a loam soil. Effect of plow treatment was not significant but effect of soil surface treatment on plant emergence was significant. The best soil surface treatment was flat planting with mulch; whereas, flat and tied-ridge treatments were not significantly different from each other.

Although interactions were significant they were caused by the large effect of Souna-3 to the flat with mulch soil surface treatment and the low values obtained for tied-ridge with mulch. Termites were also active in mulch plots and the mulch was nearly half decomposed by 15 August.

TABLE 47. Effect of Plow Treatment, Millet Variety, and Soil Surface Treatment on Plant Emergence Percentage

PLOW TREATMENT	MILLET VARIETY	SOIL SURFACE TREATMENT (c) Flat	Flat With Mulch	Ridges, Tied/ Mulch	PLOW versus VARIETY MEANS
Plow	IKMV 8305	42.9	51.4	30.6	41.6
	Souna-3	58.6	69.0	29.4	52.3
No Plow	IKMV 8305	12.9	43.6	74.3	43.6
	Souna-3	42.9	47.9	32.0	40.9
MEANS (a)		39.3	53.0	41.6	

a: LSD, 5% = 10.2

c: LSD, 5% among SST for same variety = 14.4;
among same SST for same varieties and plow treatments = 20.4.

Analysis of variance showed:

1. soil surface treatment -- significant ($F = 4.2$, $df = 2/48$);
2. interaction plow treatment versus SST -- significant ($F = 11.6$, $df = 2/48$);
3. interaction varieties versus SST -- significant ($F = 10.3$, $df = 2/48$).

ROOT DISTRIBUTION STUDIES

The type of root system developed by a plant is fixed by heredity. Each species has its own characteristic growth habit. In general, sorghum roots penetrate an open soil of good tilth to a depth of about 2m. However, a continuous supply of available water is necessary for optimal root development. Size of the soil reservoir that holds available water for a plant is primarily determined by the plant's rooting characteristics; i.e., distribution of the root system determines the moisture extraction pattern. For sorghum, when grown in a uniform soil, the extraction pattern results in 40% of the moisture coming from the upper quarter of the root zone, 30% from the second quarter, 20% from the third quarter and 10% from the bottom quarter.

Root penetration can be seriously affected by dense soils and by compacted layers in the soils. Alfisols of Burkina Faso can have a density restricting layer which varies in depth from 30cm to 50cm with bulk densities greater than 1.50 gm/cm^3 which can severely limit plant root development. In shallow soils, roots are confined to a thin layer of soil irrespective of their normal growth pattern in an open soil. When soil moisture has been depleted to or below the permanent wilting point, then root growth is severely limited. At the beginning of the rainy season the upper portion of the soils are at or near field capacity when, at lower depths, soil may be dry. If rainfall does not provide a total soil profile at or near field capacity, then root growth will be restricted, therefore, limiting the plant's drought tolerance and yield.

The objective of this project was to consider root distribution of 4 sorghum varieties in the laboratory under conditions of aeroponics and in the field where cultivation was managed with and without plowing. Several varieties of sorghum do extremely well under experimental field plot conditions but fail or give reduced yields under traditional farming methods. In addition, seedlings of sorghum E 35-1, a high yielding variety, experience difficult development during emergence and the first month's growth. A part of these difficulties could be related to characteristic growth habits of the root systems of this variety. The following program was developed to measure the specific differences attributed to rooting characteristics of all 4 sorghum varieties.

1982 Sorghum Studies

The following studies were done in 2 parts:

1. Using aeroponic apparatus at IRAT Laboratories in Montpellier, France; and,
2. Using a village field for *in situ* measurements in Burkina Faso with the scintillation counting also performed at IRAT, France.

Aeroponic Culture: This technique used an intermittent vaporization of a nutrient solution as an aerosol spray or mist in a closed environment. The aerosol penetrated the root system and assured a constant and adequate supply of water and minerals to the roots. Consequently, plant roots were enclosed under a nutritive mist environment and could grow freely in the air without physical restraints. The root growth chamber was constructed to permit easy access and viewing of root elongation during the vegetative cycle of the plant. For this study, the root growth chamber consisted of a rectangular plastic box (PVC, 0.5cm wall thickness), 160cm in height by 110cm in length by 70cm in width. The cover of the box consisted of 10 plastic plates joined to the PVC which were 2cm thick by 10cm wide with holes to permit the insertion of the plants. Vaporization of the nutritive solution was assured by 3 environmental humidifiers (type DEFENSOR 505) placed at the bottom of the growth chamber.

The 4 varieties of sorghum (the seed was from the 1981 harvest season), used in this study were:

1. Local Kamboinse
2. E 35-1
3. 38-3
4. CSH-5 (hybrid)

These seeds were germinated in sand and after 7 days growth, the young plants were transferred to a growth chamber. The test consisted of 7 replications. Plant height (including leaves) and maximum root length was measured each week until 49 days after transplanting. At this stage, roots touched the bottom of the growth chamber.

Maximum height of plants for the 4 varieties at each vegetative stage of development is shown in Table 48 and maximum length of roots is presented in Table 49. In addition, these data are presented graphically in Figures 16 and 17.

Root growth was rapid for the duration of the study. The fastest mean growth rate of roots was 4.6 cm/day. Table 48 and Figure 16 show that the root development could be sectioned into 3 distinct stages. The first stage appeared during the first 7 days after transplanting. During this period, called the phase of adaptation, the mean growth rate for roots was about 2.2 cm/day. The second stage appeared between 7 to 21 days when the mean growth rate was rapid at 3.9 cm/day. During the second stage of development differences between varieties distinctly manifested itself. During the third stage of root development the mean growth rate leveled off and reduced to 1.7 cm/day.

TABLE 48. Effect of Sorghum Varieties With Time (days) on Mean Maximum and Standard Deviation of Plant Height (cm)

TIME (days)		SORGHUM VARIETIES Local	E 35-1	38-3	CSH-5
(transplant)					
0	mean	7.1	8.2	7.5	6.0
	st.dev.	0.9	1.4	0.7	0.8
7		21.3	25.8	19.2	20.4
		2.2	2.1	2.4	2.2
14		41.4	45.6	35.7	37.3
		4.2	5.2	9.0	3.8
21		70.1	73.6	60.9	63.7
		8.2	10.9	16.1	8.9
35		121.1	111.0	85.3	87.7
		25.2	16.8	15.7	15.9
49		146.0	130.6	95.4	102.1
		28.8	15.9	17.6	17.6

TABLE 49. The Mean and Standard Deviation of Maximum Length of Roots (cm) for Sorghum in the Aeroponic Environment

TIME (days)		SORGHUM VARIETIES Local	E 35-1	38-3	CSH-5
(transplant)					
0	mean	9.8	10.1	9.6	8.9
	st.dev.	0.9	1.2	0.6	0.9
7		28.2	27.0	22.1	25.6
		3.2	4.4	4.9	1.2
14		59.8	48.4	38.0	48.5
		8.0	8.5	10.1	3.5
21		110.2	82.4	58.8	75.4
		20.3	17.1	11.8	20.0
35		151.3	127.6	92.7	104.0
		26.5	27.8	26.6	23.3
49		163.0	152.6	99.4	107.6
		20.6	26.8	30.5	29.2

FIGURE 16. Aeroponics: Growth of Sorghum Roots

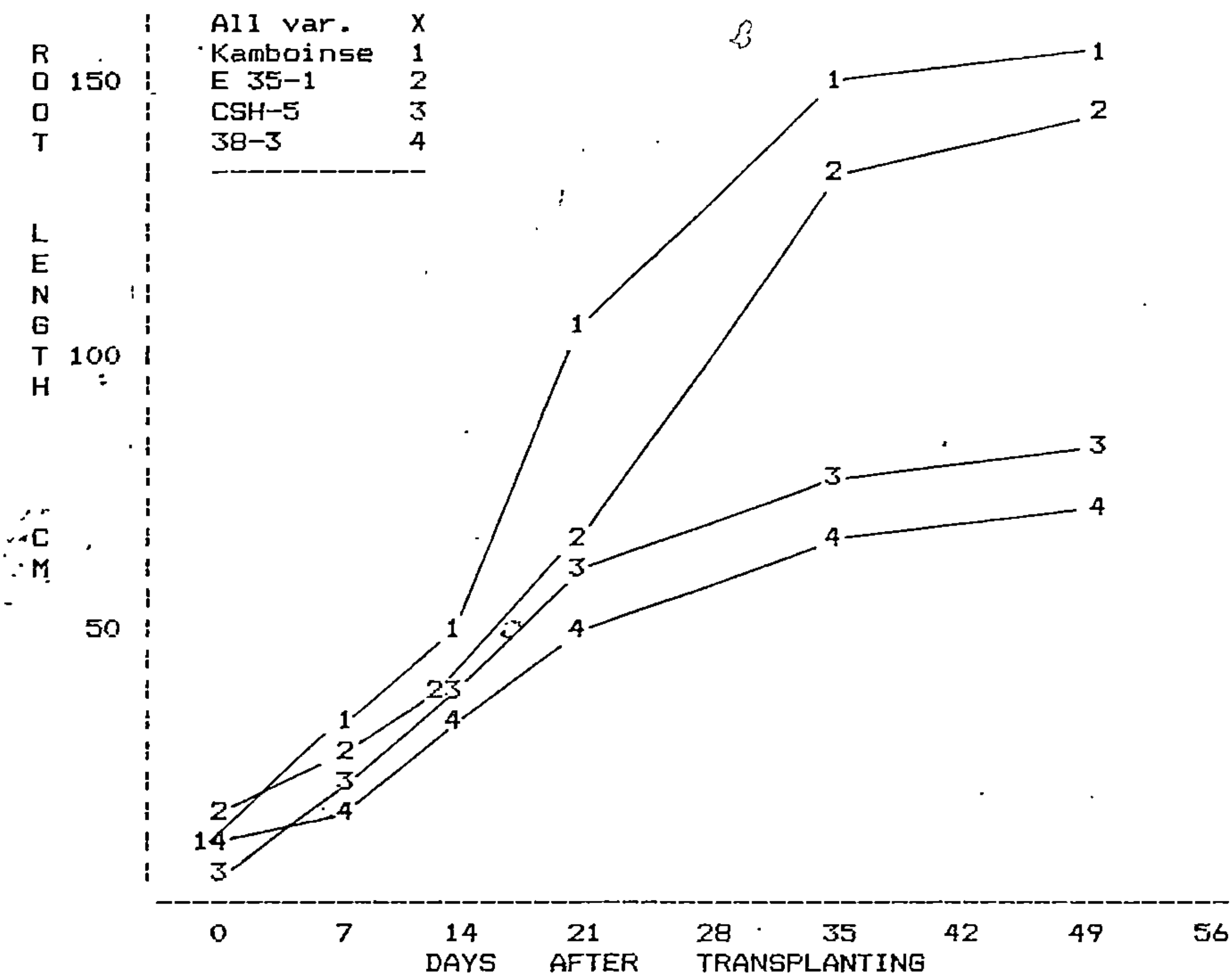
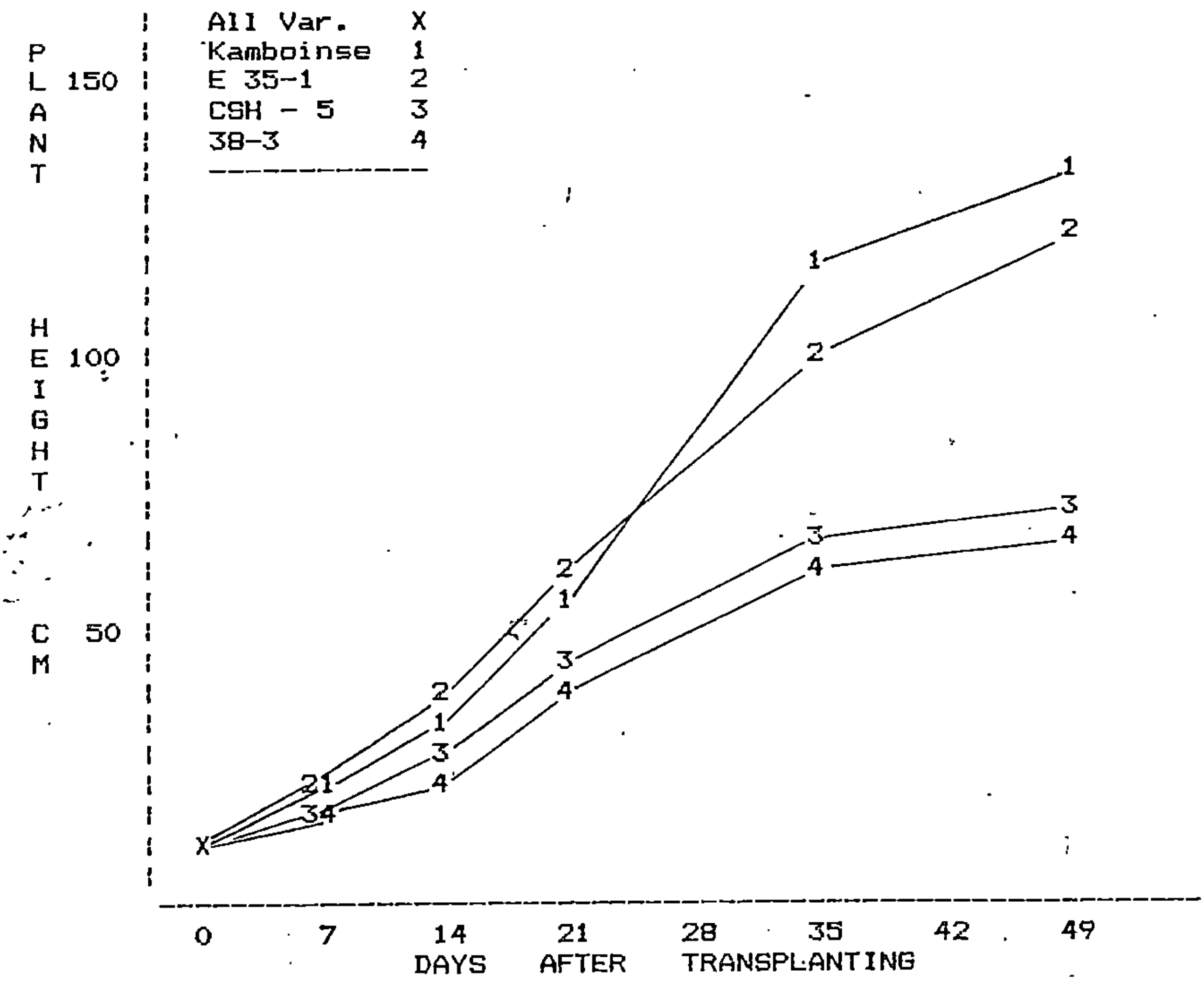


Table 49 and Figure 17 show plant development followed a similar growth pattern to that of roots. The most rapid period of plant development also occurred in the second stage and was about 2.2 cm/day. However, unlike the growth of roots, the plant growth continued at a modest rate up to the end of the study (49 days). Differences between varieties were not distinct until the 35th day which was somewhat later than indicated by root growth. Again, local Kamboinse had the tallest plants as well as the longest roots. The varieties, E 35-1, CSH-5, and 38-3 followed in that order of growth, respectively.

FIGURE 17. Aeroponics: Growth of Sorghum Plants.



In the aeroponic chamber, local Kamboinse and E 35-1 varieties had the most vigorous seedling growth. These data would suggest that E 35-1 should do well under field conditions; however, E 35-1 has a definite weakness during seedling emergence and, under most field conditions, required transplanting or reseeding to ensure an adequate stand establishment. In contrast, 38-3 and the hybrid CSH-5 showed the weakest development in the aeroponic chamber but under field conditions these varieties did not have emergence problems.

A good relationship is shown in Table 50 between plant height and root length when comparing the 4 sorghum varieties.

TABLE 50. Effect of Varieties on Comparable Measures of Plant Length (cm) and Root Length (cm)

SORGHUM VARIETIES	MEASUREMENT PARAMETERS PLANT HEIGHT (cm)	ROOT LENGTH (cm)
Local	146	163
E 35-1	130	150
38-3	95	99
CSH-5	102	107
Coef. of Variation, %	19.13	22.07
F-test	7.72 **	8.49 **

** significant at the 5% and 1% level

The statistic using Duncan's multiple range test shows that the data set can be divided into 2 parts which are significantly different at the 5% level. The first part combines the varieties of local Kamboinse and E 35-1 and the other part combines 38-3 and CSH-5 varieties for the 2 parameters considered.

The aeroponic technique permitted a simple examination of root growth and plant height as a function of time for 4 different sorghum varieties. In this system, roots can grow without restraints (unlike the alfisols of Burkina Faso) and the technique is suitable to give significant differences between varieties within the same growth environment.

Village Studies, Kamboinse: The objective of this phase was to measure distribution of roots in the soil profile *in situ* through introduction of a radioactive tracer at different depths in soil and, after a fixed time, measure level of radioactivity in the aerial parts of plants.

Radioactivity of phosphorus, P^{32}, was used because it is a major plant element and is taken up in large quantities by plants. P^{32} is easy and rapid to detect and the method uses small quantities of radioactive material. The technique has been thoroughly tested and verified in rice culture in Ivory Coast (Truong, 1977; and, Truong and Beunard, 1978) and with millet culture in Senegal (Truong, 1980). The technique was effectively carried out in 2 phases:

1. Piercing 5 holes in the soil around the base of the plant up to a predetermined depth.
2. Placing at the bottom of each hole a 2ml solution which contains 25 microcuries/ml of P^{32} and 0.5 mg/ml of P as monopotassium phosphate.

After adding the solution, test holes were backfilled with soil. The experiment was implemented in a farmer's field 7km from

Kamboinse Experiment Station. To determine if the soil in this field was adequate for the study, a soil pit of 1.5m depth was dug at each 50m distance around the periphery of the field. From this examination, the field was considered sufficiently uniform and had a soil depth of at least 1.0m needed for plant root evaluation.

On the average, the texture at the soil surface could be classified as a loam which had 32% sand, 28% silt, and 40% clay. The field was partitioned into 2 parts: the first part was plowed to a depth of 20cm with a tractor and disced before planting. The second part was cultivated only by hand with the "daba". There were 8 plots of $625m^2$ within the field. Some parts of the field could not be used because of trees and surface irregularities. The sorghum varieties, local Kamboinse, E 35-1, 38-3, and CSH-5, were not planted until 19 July 1982 because of a severe midseason drought. Ten seeds were sown in each pocket on a $1.0m^2$ grid and later thinned to 1 plant/pocket.

Problems of a midseason drought affected seedling emergence with variable plant emergence for all varieties. To reduce or manage field variability, plant height was measured for all plants in each plot to determine the variance. Then 60 plants, which approximated the mean height, were selected for continued study and the data presented in Table 51. These plants (Table 52) were marked or tagged on 16 August, 37 days after planting, and the radioactive P^{32} solution added at the following depths: 20cm, 40cm, 60cm, 80cm, and 100cm. These 5 depths were randomly positioned throughout the specific plot with 12 replications. They were harvested on 9 September, 51 days after planting, which permitted a 2 week period for absorption of P^{32}.

TABLE 51. The Mean (cm), Standard Deviation (cm), and Coefficient of Variation (%) of Height of All Sorghum Plants 37 Days After Planting

SORGHUM VARIETY	TOTAL NUMBER	MEAN (cm)	STANDARD DEVIATION (cm)	COEFFICIENT OF VARIATION (%)
FIELD PLOWED				
Local	577	54.9	19.6	35.7
E 35-1	620	65.0	17.2	26.5
38-3	545	50.1	18.0	36.0
CSH-1	592	57.1	21.0	36.7
FIELD NOT PLOWED				
Local	653	66.7	32.9	36.1
E 35-1	720	60.4	20.7	34.2
38-3	621	60.1	21.4	35.6
CSH-1	786	54.8	22.5	41.0

TABLE 52. The Mean (cm), Standard Deviation (cm), and Coefficient of Variation (%) of Heights of 60 Sorghum Plants Selected for Further Study

SORGHUM VARIETY	MEAN (cm)	STANDARD DEVIATION (cm)	COEFFICIENT OF VARIATION (%)
PLOWED FIELD			
Local	55.6	3.0	5.5
E 35-1	65.1	3.6	5.5
38-3	50.6	4.4	8.8
CSH-1	56.2	3.7	6.6
FIELD NOT PLOWED			
Local	64.4	5.7	8.8
E 35-1	60.5	4.0	6.7
38-3	60.8	6.5	10.8
CSH-1	55.0	2.9	5.3

After 2 weeks, sorghum plants were cut at the soil surface, chopped then dried in an oven at 75-80 degrees Celcius for 2 or 3 days depending on volume of sample. Oven-dried plant samples were then ground to a powder in a Wiley-Mill. A 1.0gm sample of this powder was then incinerated in a muffle furnace at 550 degrees Celcius for 2 hours and the residue placed in 50ml of a 2% solution of hydrochloric acid. The solution was filtered and a 20ml aliquot was put into plastic cups and placed in a liquid scintillation counter for measurement of the level of activity of P^{32}. Radioactivity was calculated from number of counts starting from time zero. The activity of P^{32} on day of placement, 26 August 1982, was 10^{8} counts/minute.

Mean plant height/plot at the start of the study (37 days after planting), at the end of the absorption study (51 days after planting), and mean weight/plant at the end of the study are given in Table 53 for each variety.

The choice of 60 plants from each variety reduced the coefficient of variation to 7.33%, but after a 2 week growing period it had climbed to 12.78%. The arrangement of the tallest varieties was somewhat different in the field than in the aeroponic study as local Kamboinse was significantly taller than E 35-1 followed by CSH-5 and then 38-3.

TABLE 53. Effect of Sorghum Varieties and Cultivation on Height of Plants (cm) at 37 and 51 Days After Planting and Weight of Dry Material (gm)

TREATMENT	PLANT HEIGHT AT 37 DAYS (cm)	PLANT HEIGHT AT 51 DAYS (cm)	WEIGHT OF DRY MATERIAL (gm)
PLOWED FIELD			
T1 = Local	T2 = 65	T5 = 176	T8 = 62
T2 = E 35-1	T5 = 64	T1 = 151	T5 = 59
T3 = CSH-5	T8 = 60	T2 = 137	T7 = 42
T4 = 38-3	T6 = 60	T3 = 122	T6 = 39
FIELD NOT PLOWED			
T5 = Local	T3 = 56	T6 = 121	T2 = 38
T6 = E 35-1	T1 = 55	T8 = 116	T3 = 36
T7 = CSH-5	T7 = 55	T7 = 108	T1 = 26
T8 = 38-3	T4 = 50	T4 = 102	T4 = 20
Coef. Variation	7.33%	12.78%	34.02%
F-test	76.6 **	111.5 **	59.5 **

** significant at the 5% and 1% level

Plowing did not have the same effect on all varieties. It had a positive effect for E 35-1 and CSH-5 but a negative effect for 38-3 and local Kamboinse. This is a different response than was reported in the 1981 sorghum studies where local Kamboinse grew satisfactorily whether plowed or not plowed; however, seedling emergence was better for E 35-1 in plowed soil. Effect of plowing was non-significant on weight of dry matter for the 4 varieties. Correlations (R) between plant height and dry weight for the 60 samples of plant material were reasonable: R = 0.60 for local Kamboinse; R = 0.38 for E 35-1; R = 0.54 for 38-3; and, R = 0.62 for CSH-5.

In general, distribution of measurements of radioactivity are non-symmetrical (skewed) and the means and standard deviations vary proportionally (Thomin and Reyniers, 1978). However, logarithmic transformation of these measurements gave a normal distribution which permit statistical comparison of the means. Statistical analyses were performed on transformed data and the tables represent geometric means. Quantity of P^{32} absorbed at different depths for the varieties is shown in Table 54. All plants had roots to a depth of 1.0m or more.

TABLE 54. Effect of Sorghum Variety and Cultivation on the Absorption of P^{32} (counts/min) at 5 Depths

TREATMENTS	SAMPLE DEPTHS (cm) 20	40	60	80	100
PLOWED FIELD					
T1 = Local	1,542,888	127,601	38,722	14,875	4,993
T2 = E 35-1	1,189,646	344,264	26,502	12,088	7,150
T3 = CSH-5	4,732,669	831,372	111,859	22,303	9,398
T4 = 38-3	2,465,551	451,350	30,920	7,319	4,337
FIELD NOT PLOWED					
T5 = Local	3,913,724	523,521	207,278	57,622	18,199
T6 = E 35-1	5,412,202	681,261	37,328	29,633	23,175
T7 = CSH-5	4,271,604	723,966	163,980	38,050	19,454
T8 = 38-3	3,385,458	918,043	127,814	52,095	28,471
Coef. Variation	6.61%	10.23%	12.97%	12.38%	8.21%
F-test	3.90 **	2.97 *	3.97 **	4.11 **	8.21 **
Duncan	T6	T8	T5	T5	T8
Multiple	T3	T3	T7	T8	T6
Range	T7	T7	T8	T7	T7
Test	T5	T6	T3	T6	T5
	T8	T5	T1	T3	T3
	T4	T4	T6	T1	T2
	T1	T2	T4	T2	T1
	T2	T1	T2	T4	T4

Classification of these varieties was difficult. However, in the plowed treatment, CSH-5 was able to absorb more of the P^{32} at all depths than did any other variety because it had the deepest roots. In the non-plowed treatment, all varieties absorbed the same amount of P^{32} but were not significantly different. Measurements in the non-plowed treatment were superior to those of the plowed treatment which were similar to observations made on plant dry matter.

Distribution of roots in the soil profile is shown in Table 55. These data represent the percentage of absorption at each depth divided by the total absorbed by the plant. These data show that 82% of the absorption of P^{32} was in the top 20cm of soil and, if the 40cm depth is included, it represents 96% of the absorption of P^{32}. This absorption is dependent upon quantity of roots at each depth but complications of data occur if some absorptive effects are obtained by soil moisture content and evaporative demand during time of measurement. These results are not uncommon in alfisols where root penetration is limited by depth. For loam soils, Table 2 shows that bulk density increased with depth and became restrictive between the 20cm to 50cm depths which would compare favorably to results from this field.

TABLE 55. Effect of Sorghum Variety and Cultivation on Percent of P^{32} Absorption by Depth

TREATMENTS	SAMPLE DEPTHS (cm) 20	40	60	80	100
FIELD PLOWED					
T1 = Local	89.23	7.37	2.23	0.86	0.28
T2 = E 35-1	75.31	21.79	1.67	0.76	0.45
T3 = CSH-5	82.91	14.56	1.95	0.39	0.16
T4 = 38-3	80.55	17.76	1.21	0.28	0.17
Mean	82.00	15.37	1.76	0.57	0.26
FIELD NOT PLOWED					
T5 = Local	82.91	11.09	4.39	1.22	0.38
T6 = E 35-1	87.95	10.58	0.60	0.48	0.37
T7 = CSH-5	81.87	13.87	3.14	0.72	0.37
T8 = 38-3	75.03	20.34	2.83	1.15	0.63
Mean	81.94	13.97	2.74	0.89	0.43

Sometimes where the plant is cut will determine amount of radioactivity absorbed and variability of measurement. To avoid the question: Does the plant stalk represent a uniform uptake of P^{32}?, a test was made of quantity of radioactive material in the leaves. A disk of 10cm in diameter was taken from 5 leaves on each plant of E 35-1, then dried, ground and analyzed in the same manner as the entire plant. The relation between radioactivity/gm of leaf (x) and total radioactivity of the stalk (y) showed:

$$y = 0.077\,x + 6.124, \quad R = 0.93$$

The relation between radioactivity/gm of leaf (x) and radioactivity/gm of stalk (y) showed:

$$y = 0.878\,x + 0.959, \quad R = 0.93$$

It was possible to estimate total radioactivity of the plant by measuring a sample from the leaves.

The relation between radioactivity/gm of stalks and total radioactivity of the stalks was good which showed that dry weight of plant material does not affect results. Table 56 shows the linear equations and the correlation coefficients for each sorghum variety.

TABLE 56. The Relation of Radioactivity/gm of Plant Material (counts/min/gm), x, Total Radioactivity of Plant Material (counts/min/gm), y, and Correlation Coefficient, R, for Each Sorghum Variety

SORGHUM VARIETY	LINEAR EQUATION	CORRELATION COEFFICIENT, R
Local	y = 1.00 x + 3.14	0.98
E 35-1	y = 0.99 x + 3.66	0.99
CSH-5	y = 0.96 x + 3.78	0.98
38-3	y = 0.94 x + 3.28	0.98

On 12/11/82, final plant height and total weight of plant dry matter were measured. Fields were separated into 4 plots for each variety to serve as replications where average plot size was $142m^2$ and the average number of plants/plot was 150. Table 57 presents average final height measurements of 10 plants/plot to cultivation treatment and sorghum variety.

TABLE 57. Effect of Cultivation Treatment and Sorghum Variety on Final Height Measurements (cm), 12/11/82

CULTIVATION TREATMENT	STATISTICAL PARAMETER MEAN (cm)	STD. DEV. (cm)	COEF. VAR. %	VARIETY MEANS (b)
FIELD PLOWED				
Local	244	18.0	7.4	
E 35-1	154	27.4	17.8	
CSH-5	146	19.0	13.0	
38-3	134	14.3	10.7	
MEAN (a)	170			
FIELD NOT PLOWED				
Local	229	16.1	7.0	237
E 35-1	127	4.8	3.8	140
CSH-5	111	5.6	5.0	129
38-3	121	6.6	5.5	127
MEAN (a)	147			

a: LSD, 5% = 19,
for difference between cultivation treatment means
b: LSD, 5% = 17,
for differences between variety means
The analysis of variance showed:
1. cultivation treatment -- significant (F = 6.0, df = 1/3);
2. varieties -- significant (F = 75.5, df = 3/18).

Final height measurements compared favorably to those presented in the 1981 data set when local Kamboinse was taller than E 35-1; however, unlike earlier height measurements for this study, final height measurements showed a significant increase in height for plowed versus non-plowed fields.

Seeding was completed late in the season. No yield data is presented because local Kamboinse produced only empty heads and the other varieties produced only partially filled heads. Weight of total plant dry matter was taken only on the plowed cultivation treatment because a stray herd of pigs ate and destroyed the non-plowed cultivation treatment just before sampling.

Table 58 presents total plant dry matter for each variety on the plowed cultivation treatment.

TABLE 58. Effect of Non-Plowed Cultivation Treatment and Sorghum Variety on Total Plant Dry Matter (tons/ha)

SORGHUM VARIETY	TOTAL PLANT DRY MATTER (tons/ha) MEANS	STD. DEV.	COEF. VAR. %
Local	1.28	0.23	17.9
E 35-1	2.12	0.52	24.5
CSH-5	1.24	0.23	18.7
38-3	1.09	0.34	31.4

LSD, 5% = 0.88 for differences between treatment means
The analysis of variance for randomized blocks showed:
varieties were significant (F = 7.8, df = 3/9).

These data compare favorably to data for local Kamboinse and E 35-1 collected during the 1982 and 1983 growing seasons in that E 35-1 generally produced the greater quantity of dry matter followed by local Kamboinse. Dry matter production of CSH-5 and 38-3 was lower. Unfortunately, no reliable statistical comparison could be made to the non-plowed cultivation treatment at end of season.

1983 Sorghum Root Studies: Plans had been made to continue the root distribution studies during the 1983 growing season but the studies were hampered by 2 dramatic events: 1. Burkina Faso suffered through another coup d'etat in August which made scheduled measurements of P^{32} uptake by Mr. Truong impossible; and, 2. Yield from the field designed for the study was ravaged by local thieves. However, some of the data was salvaged and is presented. It must be remembered that statistical comparisons presented for end of season data are open to question.

The objective of this study was to measure root distribution of 3 varieties of sorghum with the following treatments:

A. Method of Cultivation
   1. Field plowed
   2. By hand (daba)
B. Sorghum Varieties
   1. local Kamboinse
   2. E 35-1
   3. S-29 (IRAT)
C. Soil Surface Treatment
   1. Tied-ridges
      with 15 tons/ha of Sorghum mulch.
   2. Flat, traditional

S-29 is a photosensitive variety selected from local sorghums and is similar to local Kamboinse. Ridges were tied at 1.0m intervals immediately after planting, 28/06/83. All varieties were planted in pockets 20cm apart and, after a good rain 11/7/83, were thinned to 1 plant/pocket giving a stand density of 70,000 plants/ha. At that time, some transplanting of E 35-1 was necessary to ensure a full stand for each plot. Following planting and tieing of ridges, mulch was placed within the catchment basins. Subplot and sub-subplots were randomized into complete blocks of 7 replications.

The mean, standard deviation, percent coefficient of variation, and the LSDs of sorghum heights measured on 25 July are presented in Table 59. These values represent the means of 10 measurements/plot with 7 replications.

Early height data showed an immediate effect of plowing on growth of sorghum. Plants grown under plowed conditions were nearly 10cm taller than those grown under hand cultivation methods. E 35-1 benefited from plowing as did local Kamboinse but S-29 showed no growth advantage with plowing.

TABLE 59. Effect of Method of Cultivation, Sorghum Variety, and Soil Surface Treatment on Plant Height Measurements, 25/7/83, Presented as Means, Standard Deviations and Coefficients of Variation

CULTIVATION TREATMENT/ VARIETY	SOIL SURFACE TREATMENTS FLAT MEAN	STD	VAR	TIED-RIDGE/MULCH MEAN	STD	VAR	VARIETY MEANS	CULTIVATION /VARIETY (c) MEANS
PLOW								
Local	59.7	9.4	15.8	54.5	7.4	13.6	57.1	
E 35-1	60.1	8.3	13.9	56.1	3.4	6.0	58.1	
S-29	52.2	7.3	13.9	57.3	6.3	10.9	54.7	
MEAN							56.7	
HAND								
Local	44.6	5.5	12.3	43.4	7.0	12.3	43.9	50.6
E 35-1	45.8	8.0	17.5	52.3	5.6	10.8	49.0	53.6
S-29	53.8	5.6	10.5	53.3	6.8	12.8	53.7	54.1
MEAN (b)							48.8	
MEAN (a)	52.7			52.8				

a: LSD, 5% = 3.1
b: LSD, 5% = 1.7
c: LSD, 5% = 3.5
The analysis of variance showed:
method of cultivation -- significant
(F = 116.3, df = 1/6).

Table 60 shows sorghum height data of 3/8/83 at a different stage of development. These represent the same measurement parameters and number of samples/plot. At this stage of plant development (37 days after planting), varietal effects begin to show a significant difference. Effect of plowing still exists but effect of soil surface treatment was not significant even though a trend was beginning to appear. An interaction was obtained because height of S-29 was not affected by plowing; whereas, heights of both local Kamboinse and E 35-1 were increased because of plowing.

TABLE 60. Effect of Method of Cultivation, Sorghum Variety, and Soil Surface Treatment on Plant Height Measurements, 3/8/83, Presented as Means, Standard Deviations and Coefficients of Variation

CULTIVATION TREATMENT/ VARIETY	SOIL SURFACE TREATMENTS FLAT MEAN	STD	VAR	TIED-RIDGE/MULCH MEAN	STD	VAR	VARIETY MEANS	CULTIVATION /VARIETY (c) MEANS
PLOW								
Local	84.5	9.5	11.2	88.4	12.8	14.4	86.5	
E 35-1	84.1	9.6	11.4	87.1	10.1	11.6	85.6	
S-29	85.1	8.6	10.1	83.3	10.7	12.8	84.2	
MEAN							85.4	
HAND								
Local	67.5	10.3	15.3	71.0	10.8	15.3	69.2	77.8
E 35-1	66.3	14.0	21.2	79.5	6.5	8.2	72.9	79.3
S-29	85.1	5.1	6.0	86.2	6.9	8.0	85.6	84.9
MEAN (b)							75.9	
MEAN (a)	79.1			81.7				

a: LSD, 5% = 4.5
b: LSD, 5% = 5.3
c: LSD, 5% = 5.8

The analysis of variance showed:

1. method of cultivation -- significant (F = 19.1, df = 1/6);
2. varieties -- significant (F = 3.5, df = 2/25);
3. interaction between method of cultivation and variety -- significant (F = 5.8, df = 2/25).

A graphical presentation of 5 dates of measurement are presented in Figure 18 to show the effect of method of cultivation to plant height for days after planting. These data show that plowing increased plant height. The first 4 sets of data points were significantly different, however, the last height measurements were not. There was more variability within plant height measurements during the later stages of growth. On the 67th and 78th day after planting, statistical analysis for plant height showed an interaction between method of cultivation and soil surface treatment (SST) (67th day: F = 10.2, df = 1/37 and 78th day: F = 5.1, df = 1/37). In both cases interaction was caused by the greater growth response to the non-plowed treatment of tied-ridges with mulch than the lower growth response to the plowed treatment.

FIGURE 18. The Relation of Plant Height (cm) to Number of Days After Planting Where Method of Cultivation (Plow -- Hand) is the Parameter

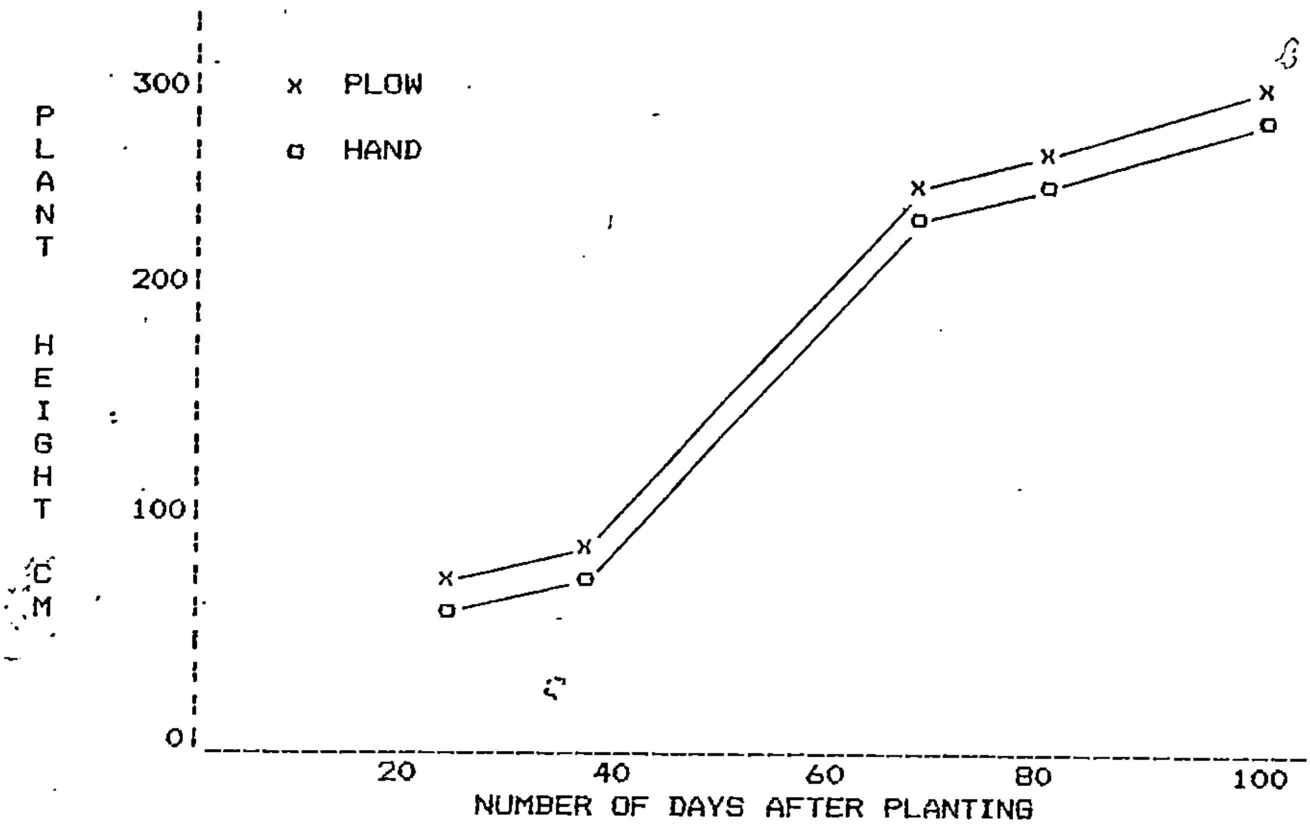
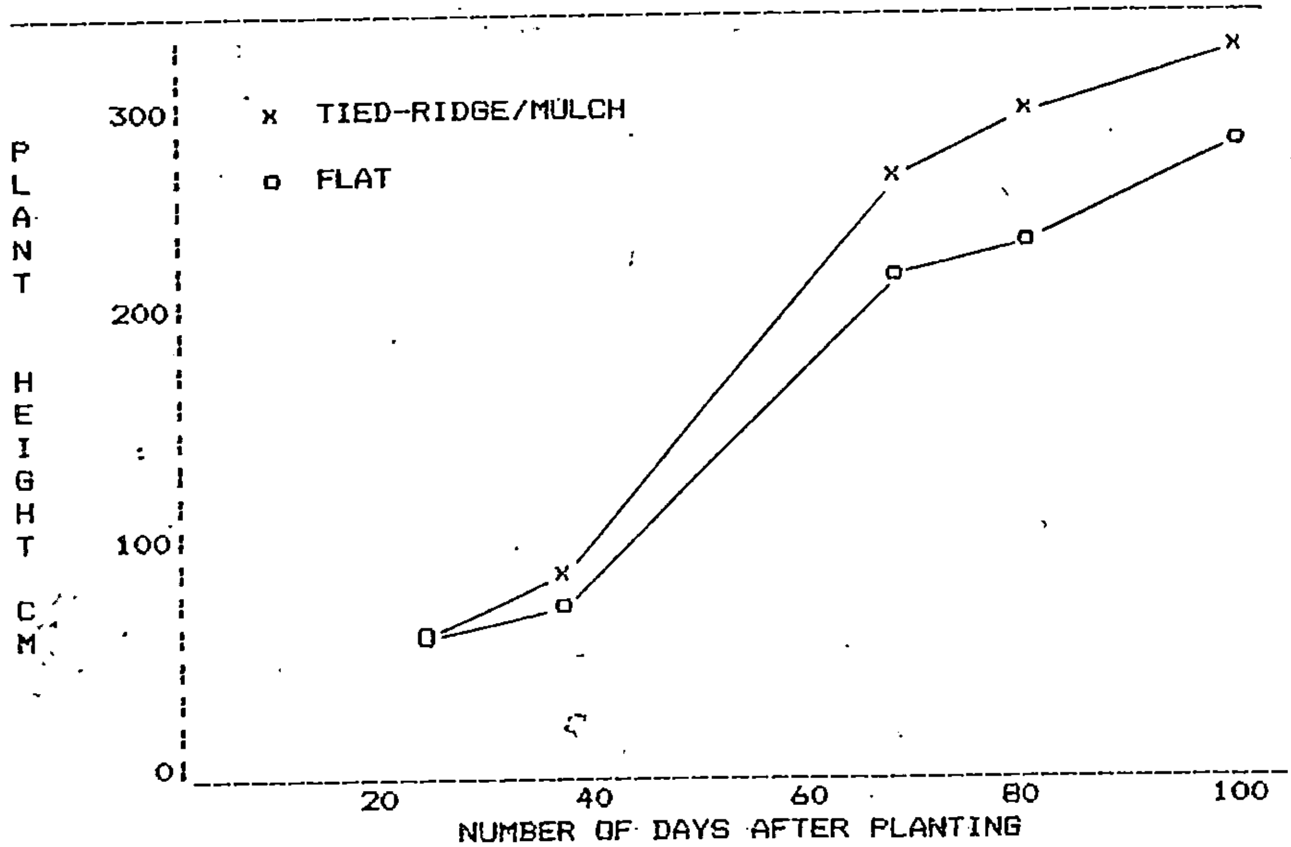


Figure 19 displays plant height to number of days after planting for effect of method of cultivation: flat (traditional) versus tied-ridges with mulch.

These data show that effect of tied-ridges with mulch was not significant until after the second plant height measurement. The major effect of soil surface management was observed during the rapid vegetative growth stage of plant development. This effect continued until end of season. Statistical analysis for the 100th day showed an interaction between variety and soil surface treatment ($F = 7.69$, $df = 2/37$) as S-29 did not respond to either tied-ridges with mulch or flat planting. Mean plant height for flat planting was 314.3cm and for tied-ridge with mulch was 412.8cm.

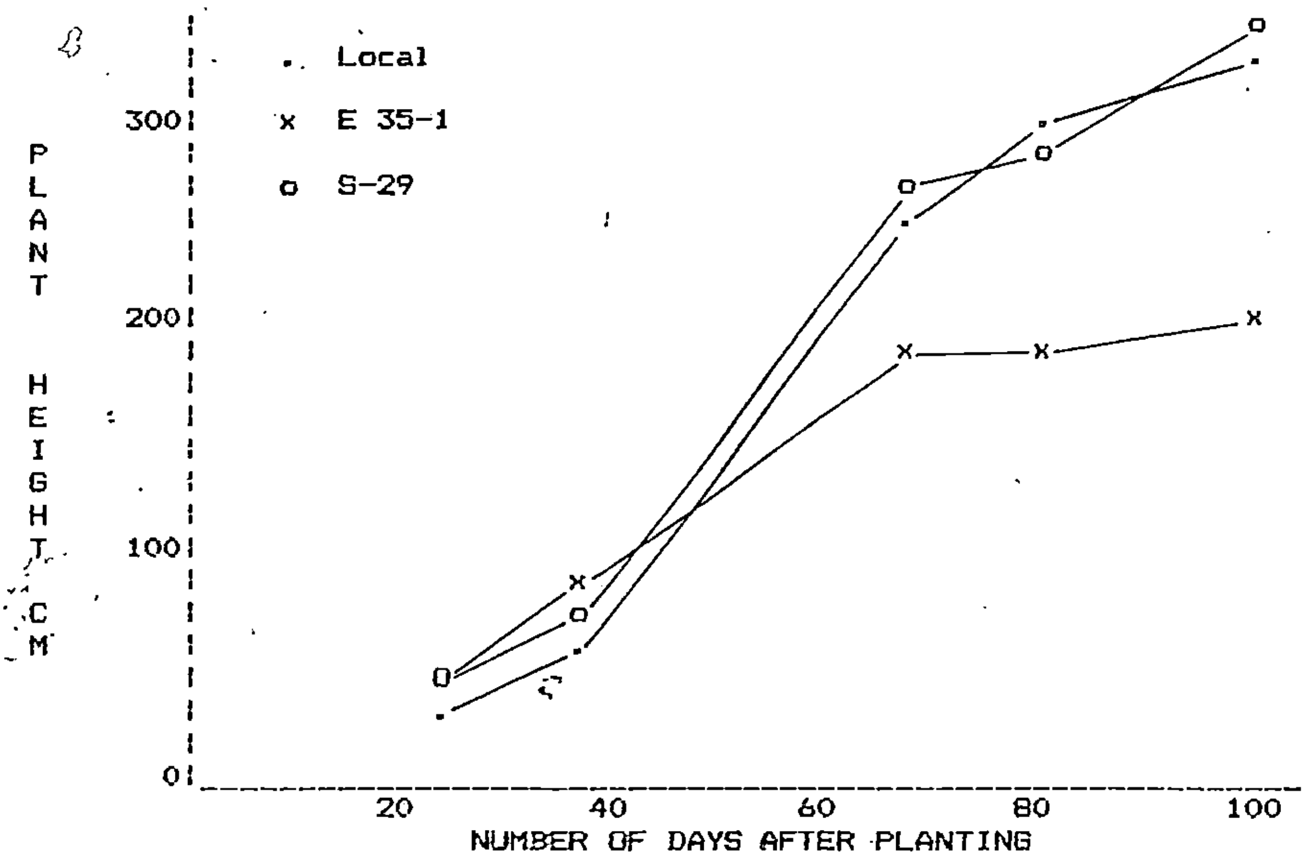
FIGURE 19. The Relation of Sorghum Plant Height (cm) to Number of Days After Planting for Soil Surface Treatment



Since both local Kamboinse and S-29 are physiologically similar, their plant growth rates reflect these similarities. Both continued their vegetative growth up to the end of season. The growth rate of E 35-1 was much less than the other 2 varieties following the 37th day of measurement. E 35-1 did not increase plant height after the 67th day.

Figure 20 shows the relationship of sorghum variety on plant height and number of days after planting.

FIGURE 20. The Relation of Sorghum Plant Height (cm) to Number of Days After Planting Where the Parameter is the Sorghum Variety



Yields of the 1983 growing season were much lower than for previous years because of reduced rainfall and a late August drought. Table 61 presents the means and LSDs for grain yield for each sorghum variety. However, in the plowed treatments, 3 plots were completely missing yield data and many plots had the good heads removed by thieves. The method of missing values (Li, 1964) was used to estimate data when all heads were lost. However, nothing could be done to estimate number of heads lost by selective stealing but it would force yields to be lowered. When making comparisons, the lost heads would add bias to the non-plowed treatment as the plowed treatment had the better heads before harvest. Grain weight for all varieties was adjusted to a moisture content of 8%.

There was a 3-fold increase in yield attributed to tied-ridges and mulch over the traditional flat planting treatment. However, there was no significant difference between plowing and non-plowing. This was not an expected result. The effect of plowing was feared lost with the stolen heads as thieves took only the best looking heads which happened to be in the plowed area of the field. Yield data was as expected with E 35-1 the highest followed by S-29 and then local Kamboinse.

TABLE 61. The Effect of Method of Cultivation, Sorghum Variety and Soil Surface Treatment on Grain Yield (tons/ha)

CULTIVATION TREATMENT	SORGHUM VARIETY	SOIL SURFACE TREATMENTS FLAT	TIED-RIDGE/MULCH	CULTIVATION MEANS (b)
PLOW	local	0.48	1.41	0.95
	E 35-1	0.62	2.40	1.51
	S-29	0.52	1.86	1.19
HAND	local	0.81	1.07	0.94
	E 35-1	0.92	1.84	1.38
	S-29	0.59	1.57	1.08
MEANS (a)		0.66	1.69	

a: LSD, 5% = 0.34
b: LSD, 5% = 0.25
The analysis of variance on grain yield showed:
1. varieties — significant (F = 30.2, df = 2/25);
2. soil surface treatment — significant; (F = 26.0, df = 1/37).

The means and LSDs of method of cultivation, sorghum varieties, and soil surface treatment compared to total dry matter is presented in Table 62.

TABLE 62. Effect of the Method of Cultivation, Sorghum Varieties and Soil Surface Treatment on Total Plant Dry Matter (tons/ha)

CULTIVATION TREATMENT	SORGHUM VARIETY	SOIL SURFACE TREATMENTS FLAT	TIED-RIDGE/MULCH	CULTIVATION MEANS (b)
PLOW	Local	3.63	6.31	4.97
	E 35-1	5.92	10.64	8.28
	S-29	5.05	8.02	6.53
HAND	Local	4.26	6.06	5.16
	E 35-1	6.53	8.31	7.42
	S-29	4.62	6.50	5.56
MEANS (a)		5.00	7.65	

a: LSD, 5% = 0.86
b: LSD, 5% = 2.92
The analysis of variance on total plant dry matter showed:
1. varieties — significant (F = 4.08, df = 2/25);
2. soil surface treatment — significant (F = 37.5, df = 1/37);
3. interactions — significant.

Quantity of plant dry matter was greatest for E 35-1, followed by S-29, and lastly local Kamboinse. Quantity of material was comparable to other sorghum studies for 1983. There was a large difference between soil surface treatments but there was no significant difference because of plowing. This data set was only slightly affected by the damage caused by thieves.

From these measurements it is possible to look at the harvest index, plant moisture content, and wet weight of plant material presented in Table 63.

TABLE 63. The Harvest Index (%), Plant Moisture Content (%), and Plant Material Wet Weight (tons/ha)

SORGHUM VARIETY	HARVEST INDEX, %	PLANT MOISTURE, %	PLANT MATERIAL WET WEIGHT (tons/ha)
Local	18.1	53.1	7.90
E 35-1	17.5	50.3	11.44
S-29	17.5	53.3	9.36

The harvest index is about the same for all sorghum varieties as is the data for plant moisture content. In general, the entire data set compares favorably to information obtained from other sorghum studies for 1983.

Additional results of interest showed average percent moisture of grain = 8.75%; but, there was a significant effect for soil surface treatment where flat = 8.59% and tied-ridge/mulch = 8.91%. Seed weight/1000 grains had similar effects with E 35-1 = 23.5gm, local Kamboinse = 20.6gm, and S-29 = 19.5gm and a significant effect to soil surface treatment with flat = 20.3gm and tied-ridge/mulch = 22.1gm.

Plant measurements in Table 64 for plant node diameter, distance between nodes, leaf length and leaf width had a significant effect for soil surface treatment and variety; however, no significant effect for method of cultivation. This was the only study during the 4 years that plant measurements were significantly different for soil surface treatment. In this study treatment differences were put at the extremes as the best consistent soil surface treatment was tied-ridges with mulch and the poorest was traditional flat planting. Always plants increased in volume and length at the highest level of soil-water management.

TABLE 64. The Relation of Sorghum Variety to Soil Surface Treatment for Node Diameter (cm), Distance Between Nodes (cm), Leaf Length (cm), and Leaf Width (cm).

SORGHUM VARIETY	PLANT MEASUREMENT (c)			
	NODE DIAMETER	DISTANCE BETWEEN NODES	LEAF LENGTH	LEAF WIDTH
FLAT				
Local	1.86	23.7	64.8	6.92
E 35-1	2.19	14.3	66.4	8.52
S-29	1.89	21.7	59.9	6.61
TIED-RIDGE/MULCH				
Local	2.04	27.9	69.4	7.42
E 35-1	2.49	15.4	69.3	9.53
S-29	2.15	24.9	66.2	6.86

ANIMAL TRACTION PROGRAM

Background

Use of domestic animals for draft power has had a major effect on the history of SAT (Semi-Arid Tropics) in French West Africa. Animal traction was introduced by the French in the early 1900's in West Africa and, by 1928, research on animal traction implements was started by French researchers at the Institut de Recherches Agronomiques Tropicales (IRAT) Station, Bambey, Senegal (Mason and Maule, 1960).

Although use of draft animals has been predominantly for cultivation throughout the remainder of the world, in Burkina Faso, cattle are traditionally reserved to animal husbandry. Herdsmen prepare the animals for human consumption. In most cases, cultivation of crops and animal husbandry are done by 2 separate groups of the rural population, i.e., farmers and stock-raisers. In general, the stock-raiser herds the animals but does not operate agricultural farm implements as does the farmer. In addition, not all farmers know what factors constitute needed body type and conformation to develop a breeding program for draft animals.

Problems which continue to plague development of animal traction include poor nutrition, lack of dry season fodder, disease, high mortality rates, uncertain supply of equipment, difficulties in consolidating and destumping fields, lack of reliable markets, and failure to establish intensive and continuous training programs for potential animal owners (Eicher and Baker, 1982). Lack of a reliable feed supply is a major constraint and, under these conditions, it is impossible to prevent animals from losing weight during the dry season without supplemental feeding.

In Burkina Faso, it is difficult to find good quality animals for draft purposes. By simple observation draft animals can be seen throughout the country in a weakened condition attempting to plow and cultivate land immediately after the first heavy rains of May and June. Even under light loads, the animals require frequent rest periods to finish a partial day's work. Occasionally, animals are in such a poor state of health that a full day's rest (24 hours) is needed for recuperation from the previous days meager workload. Normally, animals start the growing season in a weakened and somewhat untrained condition and finish the season in good health, in a well-trained and easily controllable condition.

Animal traction, in Burkina Faso, usually refers to cultivation with oxen; however, in recent years donkey cultivation has increased in importance. Although they cannot do heavier tasks, donkeys are less expensive to buy, good browsers, easier to train, and can be used for transport. A description of the types of draft animals found in Burkina Faso is given as follows:

Camel: The 1-humped camel or dromedary is found in northern areas of Burkina Faso. In most of this area, mean annual rainfall is less than 600mm. In reality, no specific breeds are recognized but camels are often named after the tribes which breed them. As these names have little meaning for classification purposes, they have been divided into, 1., working camels, or 2., riding camels.

1. Work camels are large and heavily built and may weigh up to 400kg. Typical color varies from off-whites to greys. Hair is short except at the top of the hump and on the shoulders where it may be several inches in length. These camels have a large head with a narrow nose, prominent eyes, large lips and a long neck so that the head is held high. Generally, the hump is large and well developed. There is a great variety of sizes and colors as the breeds are not well established.

2. Riding camels are smaller and lighter and are bred for speed and not to carry large loads. They are also light in color of off-white shades. They are somewhat taller than working camels being about 200cm at the withers; however, they are lighter and weigh from 300kg to 350kg. These camels have a light, fine head with a slender long neck and slender legs. Hair of these animals is usually of a softer texture than working camels and they have only a small hump.

Horse: Horses are found throughout Burkina Faso. However, there are not as many now as in the past. It is estimated that there are fewer than 2,000 horses in the entire country and most of these are used for riding and are owned by village chiefs or other high officials. Some horses are used for draft purposes but this is mostly in the lower half of the country.

Most horses in Burkina Faso are of the breed Dongola which takes it's name from the town and district of Dongola on the Nile. This type of horse is widespread throughout West Africa (Mason and Maule, 1960). These animals are of moderate size, 135cm to 145cm in height at the withers. Color is generally reddish bay to roan with white face-blaze and white stockings; however, blacks and whites are also seen. Generally, body conformation is poor with a heavy head, long large nose, small eyes, short thick neck, straight shoulders, flat sides, narrow weak loins, a goose-type rump and long sloping pasterns. They have poor action and a soft constitution. Their body conformation lacks strength needed for draft animals.

Donkey: Donkeys are distributed throughout the country although most are found in the central part (Mossi Plateau). Their numbers are increasing as traction equipment becomes available.

A characteristic donkey is usually moderate in size and grey in color. They have a conspicuous black shoulder cross and black back stripe with zebra type markings on the legs. There are white areas around muzzle and eyes, as well as on the stomach and inner-side of the thighs. These animals are used to ride, pack, and for draft purposes. Donkeys are generally from 100cm to 120cm in height at the withers and weigh up to 200kg. They are a healthy and hardy animal with a heavy, coffin shaped head and a convex profile. They have short hair and short manes with long ears. They make good pets and are easily trained for donkey carts and for draft purposes.

Oxen: Cattle of West Africa are usually classified according to presence or absence of a hump as well as the length of their horns. They are increasing in use as draft animals; however, they have not as yet displaced the donkey. Normally 2 oxen are used in plowing but as many as 8 oxen are not uncommon (Botswana). Most oxen draft animals are composed of indigenous Zebu with possible crosses of Sanga cattle of East and Central Africa. Zebu and Sanga cattle do not have the genetic potential of cattle in temperate zones but are well adapted to environmental conditions and low levels of management found in Burkina Faso. In general, Zebus have short horns whereas Sanga cattle have long, crescent shaped horns. There are a few long-horned Zebu cattle which are bred by the Fulani of the northern sahel.

Most cattle herds are found in the northern part of Burkina Faso (above the 600mm isohyet) but oxen draft animals are found throughout the country with heaviest concentrations in the southern half (higher rainfall area). Most farm work is done by castrates which do the best for draft purposes. The Zebus do especially well in the grass-acacia savannah of Burkina Faso but, as oxen, they do not survive as well in the deserts of the north. In general, these animals weigh from 250kg to 350kg and are from 150cm to 200cm in height at the withers. There is no characteristic color as this can vary over a broad range. The horns are generally short in length measuring from 15cm to 35cm and varying from 6cm to 10cm in diameter at the base for females and from 8cm to 12cm for males. Although loose horns are not common, breakage does occur.

Predominately, classification of Zebu depends upon variation of the hump. The hump is composed of fatty and muscular tissue (large thoracic) in various proportions. Their backs consist of 2 distinct parts (bifid) which are distinguished at the hump. Zebus with large humps have the best heat tolerance (as measured by rectal temperatures). Humps are large in males with a tendency to hang over at the side or rear. They are not so well developed in females and castrates.

Personnel Training, Kamboinse

Training of 6 animal traction operators for the soil-water management program has been carried out on a continuing basis. Five operators took a 2 week animal traction training program given by ARCOMA-FAO near Ouagadougou, Burkina Faso. In 1982, 2 operators went to Cinzano Experimental Station in Mali and worked in a 2 week training program presented by Mr. R. K. Bansal of ICRISAT, India, and Mr. Phil Serafini of ICRISAT, Mali. In addition, 5 operators participated in an 8 week animal traction training program presented by Mechanism Agricole/Helvetas in cooperation with ILCA and ICRISAT, Mali.

Several pairs of oxen and donkeys have been trained for work in experimental areas with traditional and drawbar equipment. Equipment for earth moving projects has been designed, manufactured and, purchased for constructing roads, terraces, field plot leveling, and contoured ridges (open and tied). Animal traction personnel were trained to design and implement field trials and build terraces at Kamboinse Experiment Station and on farmer's fields for the most efficient use of soil-water management techniques.

Developmental Projects, Kamboinse

Terrace, tied-ridge, and furrow systems of cultivation were introduced as major methods of increasing yields using soil-water management techniques. Construction of these systems by hand is difficult, if not impossible; therefore, soil-water management techniques were implemented using animal drawn tillage equipment. The team learned engineering surveying and land leveling techniques and constructed level bench terraces at Kamboinse Station. This project gave animal traction personnel knowledge and experience in the versatile use of animal traction earth moving equipment. Preliminary plans were drawn to do a bench terrace demonstration project north of Kongousse, Burkina Faso, on a loamy sand alfisol using information and skills learned at Kamboinse but constraints of transportation and equipment hindered implementation.

Variability Projects, Village Level

Working capacity and efficiency of animal traction depends upon such factors as animal breed, body size, draft capacity, duration of work (time), soil and field conditions, and climate. This information is a primary requirement in determining areas of research needed to improve and manage performance of draft animals. In addition, this information can be used to determine criteria needed to develop and modify equipment for use under the environmental conditions of Burkina Faso.

The objectives of this study were:

1. To determine performance of oxen and donkeys throughout the year when trained under village conditions; and,
2. To evaluate variability of draft animals to characterize their capacity for work.

The study sites and villages were:

A. Four villages with FSU/Purdue University;
   1. Diapangou/Fada N'Gourma,
   2. Dissankuy/Solenzo,
   3. Nedogo/Pabre,
   4. Poedogo/Manga,

B. Six villages with ICRISAT;
   1. Koho/Boromo,
   2. Kolbila/Yako,
   3. Ouonon/Yako,
   4. Sayero/Boromo,
   5. Silgey/Djibo,
   6. Woure/Djibo, and

C. Kamboinse Experimental Station, ICRISAT.

Certain fixed variables were measured for each animal to obtain an estimate of sample variability:

1. Breed,
2. Health,
3. Quality and quantity of feed,
4. Effects of fatigue,
5. Level of training,
6. Skill of operators,
7. Seasonal management,
8. Animal traction equipment,
9. Soil and field management, and
10. Barn and barnyard facilities.

An animal scientist from each ORD region with a selected village was asked to cooperate and assist in determining general health and age of the animals to be tested. Nutritional balance and quantity of feed was estimated for each animal according to it's body weight. Animals selected for testing had been used in all types of farming operations specific to a particular farmer's need. Level and type of training for each animal was estimated for a particular farming operation.

Donkeys and oxen tend to tire at the end of a 6 to 8 hour working day, particularly if they have worked under a heavy load during the day. It is not unusual that a night's rest may not be enough for an animal to recover from effects of the previous day's fatigue. Animals must have had a rest period of 24 hours before each experimental test period.

Before the start of each test period as well as before each rest break, the physiological state of animals was observed. The following measurements were made where possible:

a. Respiration rate -- usually measured by visual observations of movement of the flanks. The number of movements of the flank/minute gives the animal's respiration rate.

b. Pulse rate -- the pulse rate is recorded by feeling the coccygeal vein.

c. Rectal temperature -- this measurement is not a problem for donkeys and horses but to make these measurements on oxen it was necessary to build a double "stock" to rigidly confine the animal as most oxen do not allow anyone to touch their tail or anus.

To determine draft, a sled was built to be pulled over a bare soil surface. It was designed to be transported behind a motorcycle and filled with necessary equipment to complete tests in the "bush". "Draft" is the pull multiplied by the cosine of the angle of pull: a constant angle of 12.5 degrees for all experimental loads was used where possible or measured if changing animals changed the angle. Angle of pull had a direct bearing on draft capacity and work load efficiency of each animal.

The pull of animals was observed on a mechanical dynamometer (2000kg limit) by continuous visual readings because a battery operated chart recorder was not available. A chart recorder would have proven beneficial as it could have provided information on variation in pull as an animal moved down the course. During each testing period, the weight of animals was measured using a dynamometer with a box or sling, a tall tree, and a block & tackle to hoist the animal. The sling did not function for weighing oxen therefore a box needed to be built which could be dismantled and transported to the test site in the sled.

Maximum loads (kg of pull) that an oxen could pull on the sled ranged from 50kg to 200kg over a 100m course. Single oxen could pull about 1/2 of this load. Maximum loads for donkeys on the sled ranged from 0kg to 100kg over a 50m course. The time required to complete the course was used to determine draft. The first measurements were started in June and were continued monthly thereafter. However, the actual time increment of data collection followed availability of transport and equipment.

A smooth, level, earth track, 100m in length was used at each site for draft measurements. Distance markers were placed at each 10m interval along the track. Velocity of the animals, time of day, air temperature, and humidity were recorded for each test. Time and dynamometer load for each animal were observed and recorded as it passed each 10m mark.

From this data set the following computations were made:

1. Velocity, v, is obtained from:

$$v = x/t$$

where v = velocity, km/hr,
x = distance (100 or 50m at 10m intervals), and
t = time (converted to hours) for the animal to traverse the interval.

2. Draft is calculated from:

$$D = P \cos(12.5 \text{ degrees})$$

where D = draft, kg, and
P = pull, kg, which is measured with a dynamometer.

3. Draft power or horsepower is calculated from:

$$HP = v * D/270$$

where HP = horsepower, kg-km/hr,
v = velocity of animals/sled, km/hr,
D = draft, kg, and
270 = correction factor to obtain horsepower.

4. Work output for the animal in horsepower is computed from:

$$W = T * HP,$$

where W = work output, HP-hrs,
T = time expended/measurement, hrs, and
HP = horsepower, kg-km/hr (usually averaged).

An open-ended questionnaire and animal history sheet were prepared which asked the farmer for specific information about each animal tested. Data was collected describing an animal's current state of health, current feeding procedure, conditions of habitation, etc. Each animal was tagged (ear) and its general health and work capacity recorded for the duration of the study.

Preliminary Results: Use of draft animals varied in each village tested. Table 65 shows number of farmers and animals which were registered and participated in the preliminary test program.

TABLE 65. Number of Farmers and Types of Animal Registered at Each Village

SPONSOR/ VILLAGE	FARMERS	HORSES	OXEN (SINGLE)	OXEN (PAIRS)	DONKEYS
FSU/PURDUE UNIV.					
Nedogo/PABRE	26	2	2		34
Diapangou/FADA N'GOURMA	33			18	32
Poedogo/MANGA	27	4	3		35
Dissankuy/SOLENZO	19			17	8
ICRISAT					
Koho/BOROMO	10			8	11
Sayero/BOROMO	19			12	15
Kolbila/YAKO	8			2	6
Ouonon/YAKO	10	4			8
Silgey/DJIBO	6			6	
Woure/DJIBO	7			7	

Oftentimes participation was erratic because either animals were sick, farmers were otherwise occupied, or notification was not received of the testing team's arrival on a particular day and place. Nonetheless, at least 2 visits, and sometimes 3, were made to each village.

The weighing of horses and donkeys with a sling suspended from a stout branch of a tree presented little problem. However, when the first ox was weighed, the sling equipment was destroyed and had to be repaired. Further weighing of oxen with the sling were met with similar disastrous results so collection of these data was abandoned. A portable walk-in animal scale (balance) was needed but was not available in Burkina Faso. Also, the staff required some time before they were confident to take respiration and pulse measurements accurately, therefore, some of this data is missing. Recording of anal temperatures was abandoned as a stock and crush (chute) was not available at each village to restrain animals securely during measurement.

Table 66 presents means on characteristics of the animals and the percent coefficient of variation for determination of horsepower together with an animal's capacity to do work assignments at specific dates of measurements. The bulk of the data is for donkeys then oxen-pairs with least data for single oxen and horses (see Table 65). Before each run, weight and respiration measurements were made; however, it was not uncommon for animals to become upset with these initial measurements and uncontrollable before a run could be made. After each run, some animals were flighty and taking respiration measurements was difficult. Tests tended to become a race between village competitors and with ensuing crowds animals became nervous before tests could start. Sometimes because of the cheering, hollering and coaxing animals would bolt, leave the track, and runaway. During these occurrences, equipment would be damaged and all measurements would be suspended until repairs could be made.

If the animals were tamed, trained and cared for properly, few difficulties of management were encountered. Amount and quality of training was the keynote in animal control. If animals were allowed to "run with the herd" during the off-season period, they would return to work in an unmanageable condition but as the season progressed their control improved. However, the best trained animals tested remained within the farmer's care and supervision throughout the year.

TABLE 66. Mean Measurements for Draft Animals

VILLAGE	DATE	ANIMAL WEIGHT kg	WORK UNIT hp-hr	HORSE POWER kg-km/hr	%CV	VELOCITY km/hr	RESPIRATION Start	End	Diff
							breaths/min		
DONKEY									
Diapangou	02/07	116	11.3	0.91	26.0	4.27	70	85	15
	03/08	127	11.5	0.92	35.8	4.30	59	97	38
	05/10	148	12.1	0.76	26.6	3.33	65	82	16
Dissankuy	16/07	139	12.7	0.97	21.9	3.99	31	47	16
	19/10	185	16.4	1.59	52.9	6.16	46	50	5
Koho	12/10	172	13.2	1.67	29.5	6.32	44	52	9
	24/11	181	14.3	2.56	28.1	9.48	46	58	12
Kolbila	14/09	150	12.5	1.34	23.4	5.52	32	39	7
	16/11	180	15.0	1.92	24.7	7.09	25	32	7
Nedogo	30/06	125	8.5	0.56	30.7	3.51	41	61	13
	25/08	131	9.9	0.58	29.1	3.32			
	31/10	158	12.1	1.02	21.0	4.36	42	51	9
Ouonon	14/09	138	12.0	1.02	35.2	4.82	52	74	22
	18/11	169	13.7	1.43	25.5	5.59	48	70	22
Poedogo	16/08	134	14.0	1.05	31.7	4.41			
	09/09	139	12.3	1.16	34.8	5.00			
	04/11	168	12.2	1.21	22.2	5.10	53	65	11
Sayero	13/10	155	12.4	1.07	30.1	4.66	37	51	14
	25/11	150	12.3	0.88	37.7	3.99	36	57	21
OXEN-pair									
Diapangou	02/07		24.2	1.34	86.7	3.69	74	94	20
	03/08		23.1	1.28	80.1	3.69	74	98	24
	05/10		24.0	2.88	24.9	6.37	64	80	16
Dissankuy	16/07		67.8	2.57	37.9	4.93			
	19/10		54.1	2.65	35.5	5.50	41	49	8
Koho	12/10		57.8	3.15	61.3	7.38	36	43	7
	24/11		52.8	3.58	34.3	7.41	42	59	17
Kolbila	14/09		47.7	2.46	34.7	5.78			
	16/11		57.1	2.56	58.3	5.42	43	61	18
Sayero	13/10		45.4	2.19	32.2	5.15	43	50	8
	25/11		48.3	2.82	44.8	6.10	43	65	22
Silgey	28/09		52.1	3.79	48.0	8.30	47	60	13
Woure	12/08		57.7	3.05	47.6	6.37	44	59	15
	27/09		44.5	2.61	40.1	6.44	45	58	13
	09/12		46.0	2.48	32.7	6.01	43	59	17
OXEN-one									
Dissankuy	16/07		29.6	2.74	67.5	5.73			
Nedogo	25/08		27.5	1.59	27.8	6.03			
	31/10		43.0	1.63	24.6	4.01	39	46	7
Poedogo	16/08		52.3	1.93	77.3	5.86			

TABLE 66. cont.

VILLAGE	DATE	ANIMAL WEIGHT kg	WORK UNIT hp-hr	HORSE POWER kg-km/hr	%CV	VELOCITY km/hr	RESPIRATION Start	End	Diff breaths/min
HORSE-one									
Nedogo	30/06	210	21.8	0.99	28.1	4.70			
	25/08	280	20.3	1.05	35.1	5.45			
Dounon	14/09	262	36.8	1.83	42.2	5.80	96	136	40
	18/11	329	46.7	3.28	30.2	7.68	92	124	32
Poedogo	16/08	186	43.2	2.16	31.9	6.00			
	09/09	200	54.8	5.62	63.8	13.30			
	04/11	262	32.3	1.55	36.5	5.34			

Early in the season when forage was lacking, animals were in poor health. For example, at Diapangou on 2/7/83 an average donkey weighed 116kg with a range of 107kg to 125kg. However, 95 days later, 5/10/83, an average donkey weighed 148kg with a range of 135kg to 161kg or a mean difference of 32kg. This amount of bulk added to the donkeys in such a short period is not beneficial to their health because they lack muscle tone and endurance. This is exemplified by the amount of work performed in pulling the sled which changed little from test to test.

During measurements at Diapangou on 3/8/83, early morning temperatures were 35°C and climbing which had an immediate effect on respiration rates which increased on the average by 38 breaths/min resulting in greater physical stress for the donkeys. This same temperature and physical stress effect can be observed for Oxen-pairs at Diapangou on the same date.

At the village of Sayero near Boromo, in the 1000mm rainfall zone, donkeys (15 donkeys in sample) lost weight which infers natural forage was already diminishing in this area by 25/11/83. Farmers, in general, do not feed and care for donkeys as well as oxen or horses.

Even though it was not possible to weigh oxen, visual observations of weight gains by end of season were similar to those measured for horses and donkeys; however, there were notable exceptions which will be discussed later. There was a large variation in respiration measurements; nonetheless, they do present an indication of an animal's capacity to work under load. Oxen-pairs produced the most work with the least effort and traveled at a faster pace than donkeys: on an overage of 6 km/hr versus 4 km/hr for the donkey. Also, amount of work output was much greater for oxen as a 75kg load was added to the sled to increase the work effort. Frequently, this load did not tax oxen-pairs. Single oxen performed nearly 2/3rds the work of an oxen-pair at the same velocity of travel.

Horses gained about 100kg during 79 days from 16/8/83 to 4/11/83. This high weight gain without a comparable gain in work or horsepower output shows that the horse was not an efficient energy user. There was a disproportionate weight gain for horses tested at Ouonon, with a mean weight of 329kg, when compared to horses at Nedogo or Poedogo. Breeding of horses in Burkina Faso, in general, does not cross bloodlines, therefore, body conformation and the general state of animals has continued to decline. Horses require better care and feed than oxen; but, they have one redeeming feature in ease of control and manageability. In general, farmers do not fear horses but they do hold a healthy respect for the unpredictability of oxen.

High percent coefficients of variation show the difficulties experienced by animals. These high coefficients were caused by 3 factors: first, an animal trainer's ability to move the animal down the track at a steady pace, second, the fatigue experienced by an animal under load and in a possible weakened condition, and third, the surface condition of the track itself. The first was a reflection of quality of training for both operators and animals and the second was a consequence of the state of health of the animal.

To illustrate the general state of a specific donkey, Figure 21 shows horsepower measured for each 10m of travel down a 50m course. The high energy outburst (HP = 4.65 kg-km/hr) on 16/8/83 between the 30m and 40m posts was caused by the farmer applying a whip because he thought the donkey was pulling too slowly. However, additional runs on 9/9/83 and 4/11/83 showed that this donkey could be stimulated initially but quickly adjusted to its standard slow pace.

Measurements taken on this donkey for each date are shown in Table 67. Although there was a weight loss of 5kg between the first and second trial there was a large difference in respiration which is attributed to improved physical conditioning. However, by the third date of measurement the animal had gained 60kg, was noted to be fat but performed a 50m track with less exertion than before. Velocity of travel showed that the animal walked slower each trip as exemplified in horsepower output shown in Figure 21.

TABLE 67. Measurements Taken for One Donkey at Poedogo/Manga

DATE	WEIGHT kg	MEAN VELOCITY km/hr	WORK OUTPUT hp-hrs	RESPIRATION START	END breaths/min	DIFFERENCE
16/8	140	7.6	18.5	36	60	24
9/9	135	6.3	13.4	40	54	14
4/11	185	5.3	11.5	56	60	4

FIGURE 21. Donkey Horsepower/10m Increment.

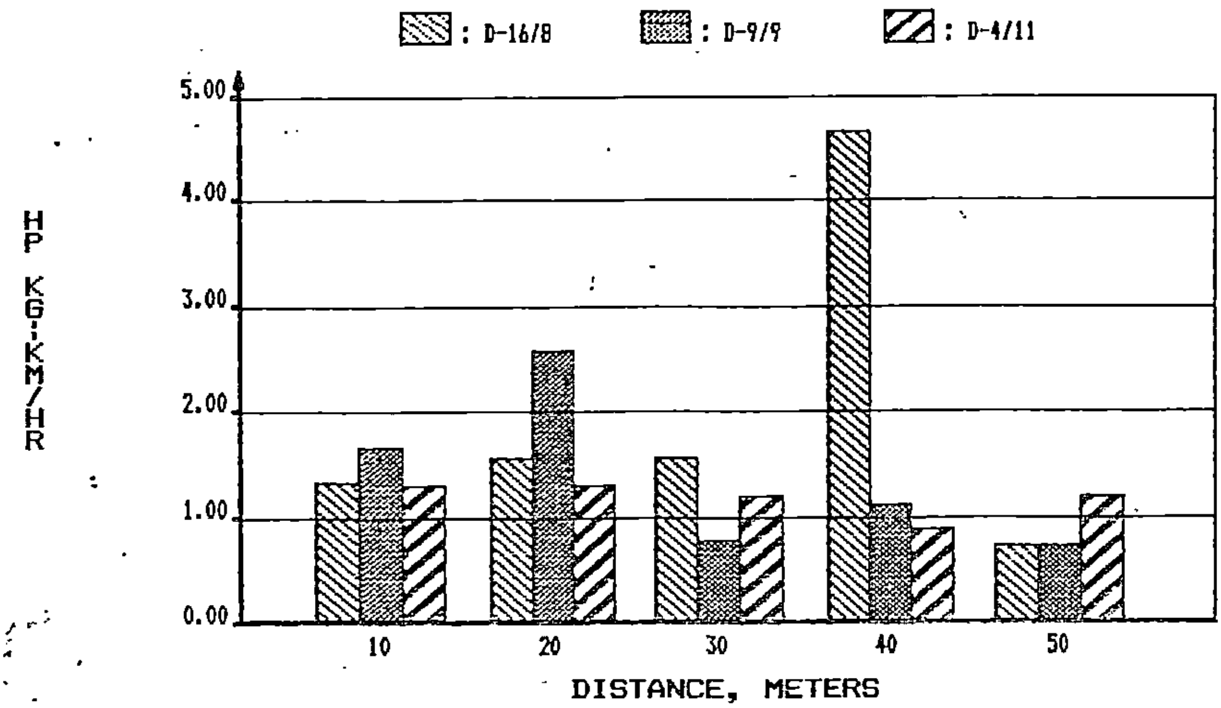


Figure 22 graphically displays data of a donkey in poor condition at time of first measurements. It pulled at a steady pace but was exhausted at the end of a 50m run. On the second measurement its condition had improved as well as its horsepower output. And on the last run the animal appeared to be in an excellent state of health and breezed through the course. Data shown in Table 68 support the findings and observations at the time of trials. This donkey also has 1 pace but amount of exertion decreased as body weight increased. Amount of work output paralleled the increase in body weight.

TABLE 68. Measurements Taken for One Donkey at Nedogo/Pabre

DATE	WEIGHT kg	MEAN VELOCITY km/hr	WORK OUTPUT hp-hrs	RESPIRATION START breaths/min	RESPIRATION END breaths/min	RESPIRATION DIFFERENCE breaths/min
30/6	110	4.05	6.7	48	78	30
25/8	120	4.05	8.8	42	60	18
31/10	150	4.53	12.9	46	56	10

FIGURE 22. Donkey Horsepower/10m Increment.

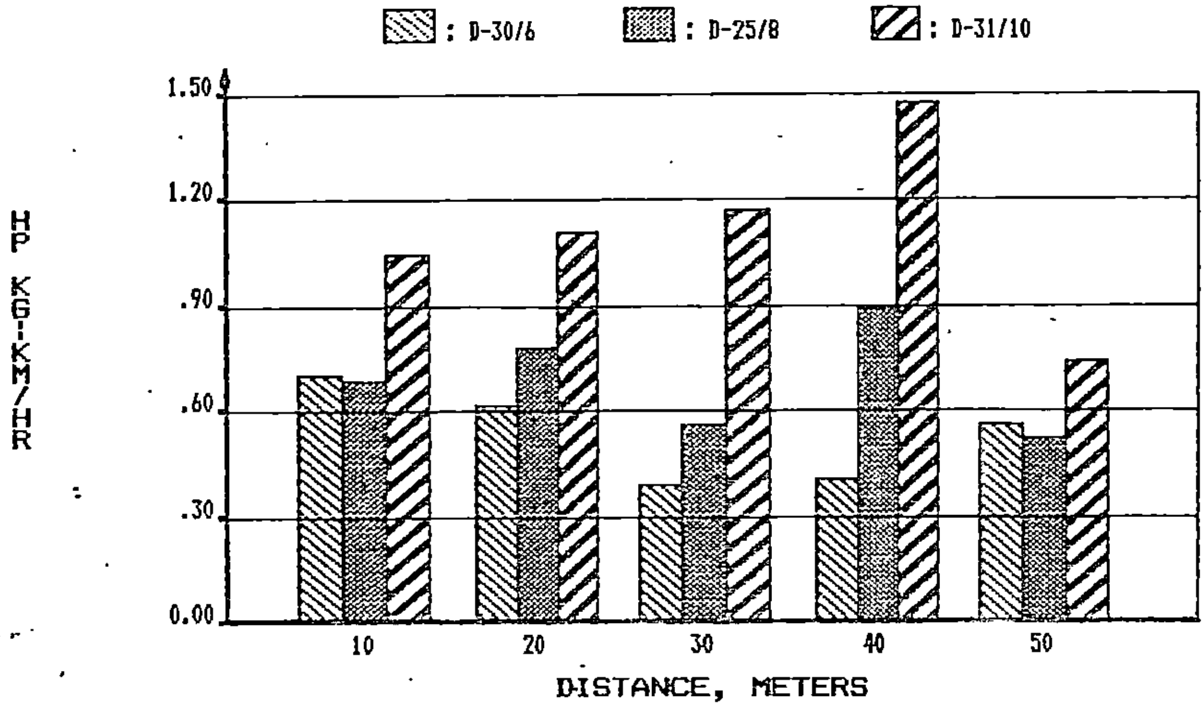


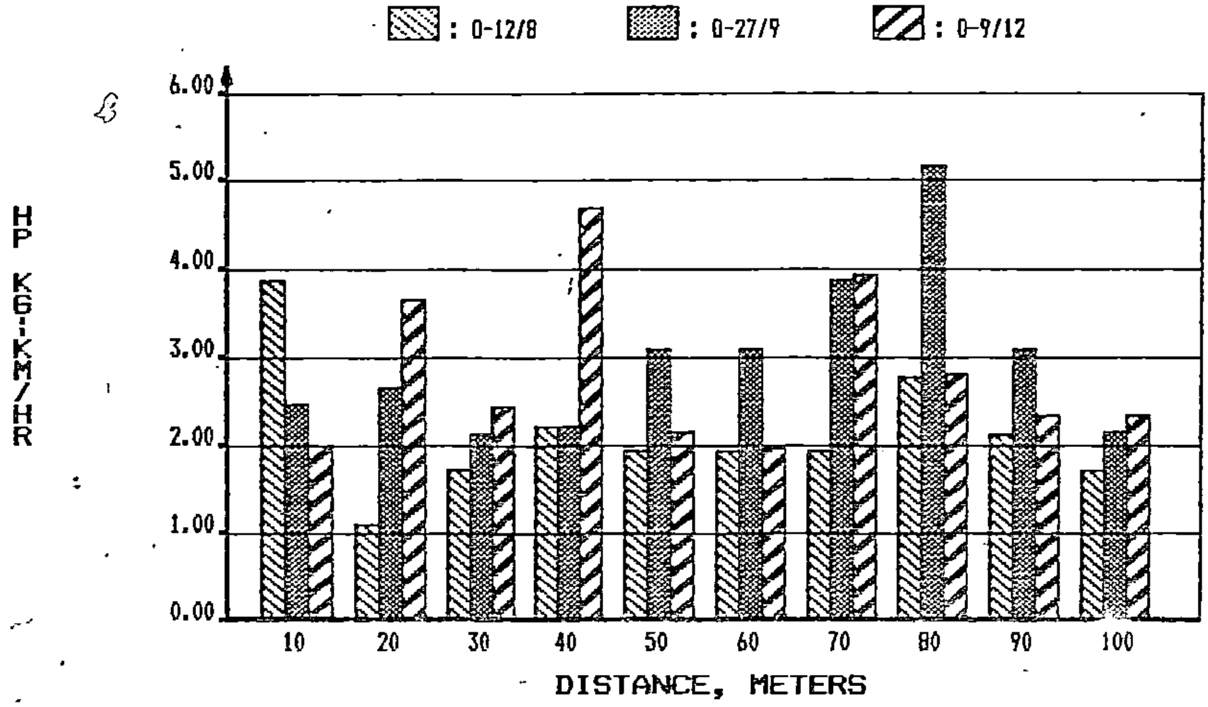
Figure 23 shows horsepower output over a 100m course for an oxen-pair from the village of Woure/Djibo which is in the 400mm rainfall zone. Although it was not possible to take the animals' body weight, respiration rates of the lead oxen were taken. Also, general state of health for the animals was observed to diminish with time. Here, changes of horsepower with distance reflects the trainer's whipping and coaxing of the animals instead of fatigue.

Table 69 shows measurements made for each trial. During the runs for these animals the sled was loaded with 80kg of material to put the oxen under strain. The increases in difference of respiration rates compare with observed effects of the state of health of the animals.

TABLE 69. Measurements for an Oxen-Pair at Woure/Djibo

DATE	MEAN VELOCITY km/hr	WORK OUTPUT hp-hrs	RESPIRATION breaths/min START	END	DIFFERENCE
12/8	4.90	48.6	45	54	9
27/9	7.90	45.8	44	64	20
9/12	7.00	44.1	36	59	23

FIGURE 23. Oxen-Pair Horsepower/10m Increment



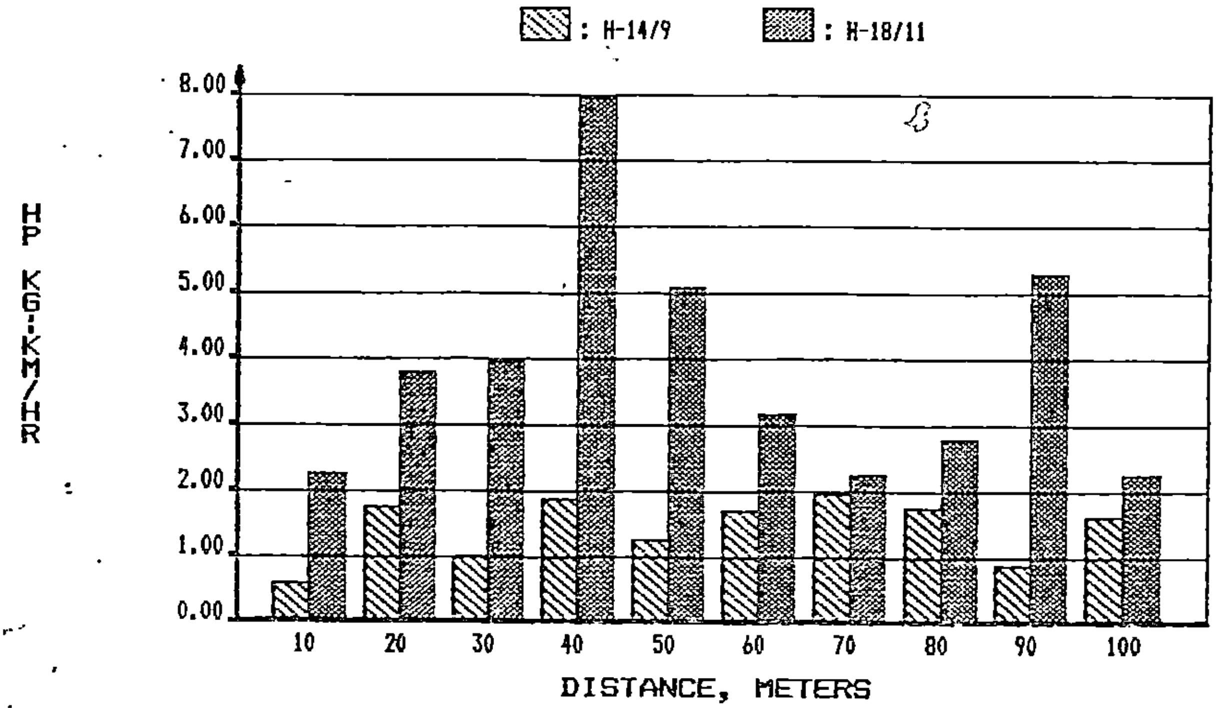
Horses measured in this study were easily managed and physical handling of the animals did not unduly upset them because they were well trained to work. No working teams of horses or mules of any type have been observed in Burkina Faso.

Figure 24 shows horsepower measurements made of a horse for 2 dates at the village of Ouonon/Yako. During the first test this animal pulled very steady at a velocity = 8.98 km/hr with an added weight of 40kg. During the second test some shouting and whipping occurred which spurred the animal forward. At the owner's request the sled weight had been increased to 70kg for the second run and the animal pulled in spurts. This is reflected in the coefficient of variation for horsepower for 2 runs where CV = 23.1% for the first run and increased to 46.5% for the second run. Table 70 shows measurements for 2 runs by this horse. Although this horse had gained 65kg it apparently did not affect its ability to work. The velocity and work output increased without an increase in respiration rate.

TABLE 70. Measurements of a Horse From Ouonon/Yako

DATE	WEIGHT kg	SLED LOAD kg	MEAN VELOCITY km/hr	WORK OUTPUT hp-hrs	RESPIRATION START breaths/min	END	DIFFERENCE
14/9	275	40	4.93	33.3	48	84	36
18/11	340	70	8.98	50.8	50	87	37

FIGURE 24. Horse-1 Horsepower/10m Increment



General Observations: Farmers constantly asked questions about animal health, feeding, and care. When possible general questions were answered but technical questions were first discussed with the Veterinary Officer in Ouagadougou and responses relayed to the farmer. In general, questions were if we could do vaccinations, do worm and fluke drenching, provide tick and fly control, and give medical care for injuries. In addition, we were asked to do such veterinary functions as castration by the bloodless Burdizzo, removal of horn tips, and the punching of a hole in the nose septum for a ring or nylon cord. Since the staff were ill-equipped to perform these tasks or give recommendations to solve these problems, we tried to refer the farmers to a trained local Veterinary Officer.

In the dry season, animals are allowed to forage unsupervised when there are few crops to damage. In general, horses remain under supervision as they are considered a valuable investment and a prestigious animal. For supplementary feeding of working oxen (proportionally adjusted to body weight for the other animals) the following standard allowances were given (Starkey, 1981):

For maintenance of each animal:
Grazing plus sorghum or millet stalks,
Salt and minerals at 200gm/day.

Supplemental portions for working animals:
Light work: 1500gm of cereals/day,
Medium work: 500gm of cereals/hour of work, and
Heavy work: 750gm of cereals/hour of work.

The cereal mixture can be made from 1/3 measure each of corn, sorghum and millet or similar feed mix. In general, farmers have shown that they do work animals without feeding grain but veterinarians recommended that salt and mineral mixture should be given to working animals. Farmers were cautioned that if no supplementary feeds were given then they should reduce workloads as the animals lose physical conditioning. Feeding of supplements to animals may be nutritionally and economically justified agriculturally but there are social barriers to feeding corn, sorghum and millet to animals when scarcity exists and the grain is destined for human consumption.

Most farmers move working animals close to their homes at night. Occasionally, they have a cattle shed and some farmers place their working animals within the compound for protection and security from theft. A well ventilated shed provides an excellent place to give shelter as well as groundnut or cowpea hay for supplemental feeding. The animals are tied to posts with a rope halter or with a rope attached to their horns. The collection and use of animal manure was well understood by farmers but daily removal from shed areas was encouraged to reduce the insidious fly and insect problem.

In Burkina Faso, the main power source for field cultivation is the use of hand tools for plowing and harrowing, seeding, and weeding. In the villages tested, animal traction was used primarily for plowing and harrowing and, secondarily, for weeding. Seeding was always done by hand and no animal-drawn seeders were visible or used. Oxen-drawn toolbars were not found in villages tested. Oftentimes, donkeys were used only for marking the rows for hand seeding and occasionally a houemanga was used for cultivation.

WATER HARVESTING PROGRAM

A team of technicians has been trained to survey and layout rainfall-runoff plots. Additional training is currently underway to explain methods of measuring effect of soil surface treatment on slope, evapotranspiration, chemical losses, seepage losses and erosion losses. An interactive computer program has been completed (The USDA CREAMS model) which is written in BASIC for the small desk top computer, TRS80-Model III, and this program can be used for simulating hydrologic characteristics of various sized watersheds. This program will be calibrated and verified using data from runoff plots. The model is able to simulate daily, monthly, and annual runoff, deep percolation, soil erosion, soil chemical losses, temperature, soil-water, and evapotranspiration. This information could be used in the design and layout of hydrologic agricultural management systems and water harvesting projects at the village level.

RAINFALL-RUNOFF PLOTS

A study was designed in 1981 to measure rainfall/runoff processes on several small plots at Kamboinse Agricultural Experiment Station. During 1982 and with the cooperation of Mr. TROUNG, Binh, Ingenieur Agronome (IRAT), Montpelier, France, the concept was expanded to include chemical evaluation of surface runoff and soil percolation losses. However, equipment purchases were delayed therefore only a design has been completed and is presented as follows:

Goal

To estimate and measure water and chemical balance on alfisols at Kamboinse Experiment Station.

Objectives

1. To precisely measure precipitation and surface water runoff from controlled research plots under various soil surface treatments.
2. To measure soil and chemical losses in surface runoff.
3. To measure the soil moisture profile, deep percolation, and soil chemical losses because of leaching.
4. To use this information for calibration and verification of the simulation model.

At Kamboinse, 22 plots (10m x 20m) were positioned in parts of fields numbered C5 and C4. Eight of these plots have slopes of 0.4% and 14 have slopes of 1.0% with catchment basins located on the down slope. An evaporation pan with anemometer and a recording, tipping-bucket type raingage were centrally located among runoff plots. Three half-barrels (55 gallon type), 2 with sample splitters, were calibrated for each plot and are ready for installation. Other types of soil-water catchment devices were constructed and tested for the possibility of greater accuracy of runoff measurement. Soil-water samplers were to have been installed to measure nutrients lost by leaching; for example, Calcium, Magnesium and Potassium. The following apparatus were to have been installed in duplicate sets within each plot for measurement of soil-water parameters:

1. Soil moisture tensiometers, placed at 4 depths (30, 50, 100, and 150 cm).
2. Soil moisture Neutron measurements, placed at the 200 cm depth.
3. Soil-water samplers, placed at 4 depths (30, 50, 100, and 150 cm).

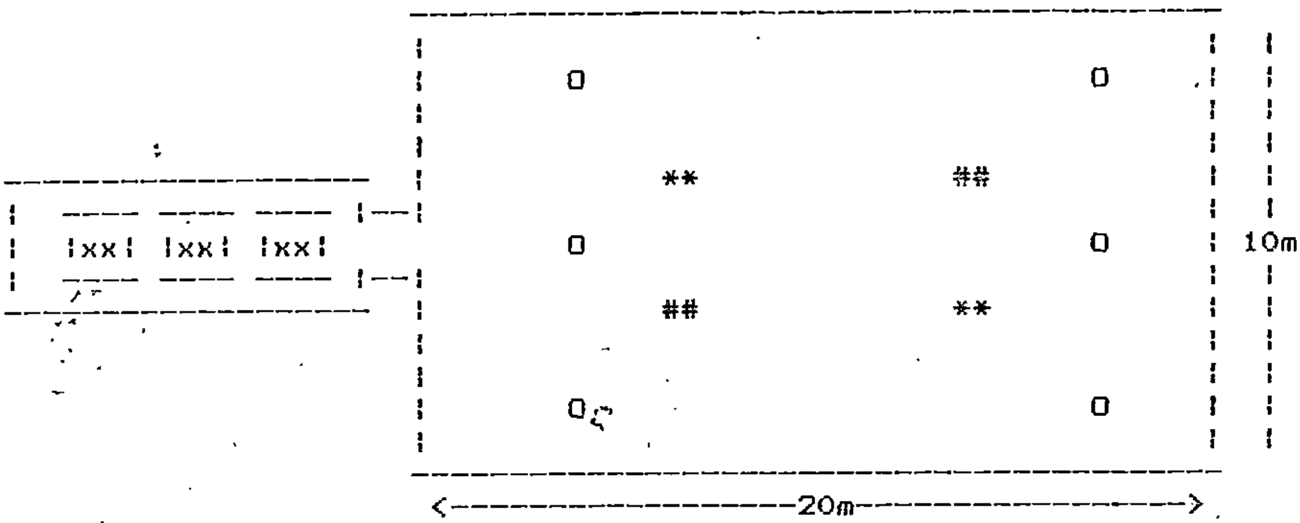
The general field plan for each runoff plot is shown in the schematic drawing presented in Figure 25.

FIGURE 25. Schematic Representation of Equipment Locations for Soil-Water Runoff Plots

Slopes of 0.4 or 1.0%

O.......Soil-water samplers
**......Soil moisture neutron tubes
##......Soil-water tensiometers

|xx|....Catchment barrels



These soil surface treatments were proposed for the first study:

1. Flat, traditional; and,
2. Tied-ridges with 8.0 tons/ha of mulch added.

Each treatment would have had 11 plots: 4 with 0.4% slopes and 7 with 1.0% slopes.

Planned Methodology of Implementation

1. Each plot will be plowed and, where needed, ridged using animal traction equipment.
2. Souna-3 millet variety will be seeded in rows 1.0m apart (9 lines x 19m long), 20cm between pockets with 10 seeds/pocket and later thinned to 1 plant/pocket giving a stand density of 50,000 plants/ha.
3. At time of seeding, 100 kg/ha of cotton fertilizer will be added to all runoff plots and 30 days later plots will be side dressed with 65 kg/ha of Urea.

4. Immediately following seeding, ridges will be tied and mulch (8.0 tons/ha) will be added into micro-catchment basins.
5. Following plot construction, soil-water samplers, neutron tubes and soil moisture tensiometers will be installed at designated depths.
6. Weeding, tied-ridge maintenance and plot maintenance will be made immediately as needed.

Proposed Data To Collect

1. Record dates of field operations and maintenance.
2. Daily record and service of pan evaporation, and service of soil-water samplers and soil moisture tensiometers.
3. Record soil moisture profile by neutron readings and tensiometer readings early in the morning at least 3 times/week.
4. After each rainfall, measure all soil and water collected in the catchment barrels and take a 100ml aliquot sample for chemical analysis.
5. Determine germination percentage of the millet.
6. Measure plant height of 20 plants/plot (includes length of top leaves pulled upwards) at 10 day intervals immediately following emergence.
7. Measure number of days to 50% flowering for each plot.
8. Count number of plants, number of lodged plants, and number of tillers/plant in harvest area for each plot.
9. Measure the harvested area for each plot.
10. Count number of heads at harvest times for each plot and determine the following:
    a. number of good heads/plot,
    b. number of bad and empty heads/plot,
    c. count number of bad heads for each type of disease, bird damage, storm damage, drought damage, etc., and;
    d. total number of heads/plot.
11. Record total weight of heads/plot and weight of good heads/plot.
12. Record weight of threshed grain/plot and weight/1000 grains/plot.
13. Take a sample of grain to determine moisture content/plot.
14. Determine weight of total plant material/plot.
15. Take a sample of total plant material/plot and determine plant moisture content.
16. Store all plant material and grain for use by animal traction or next year's mulch studies.

DISCUSSION AND CONCLUSIONS

Soil surface management of alfisols studied the effectiveness of different quantities of crop residues for mulching; effects of tied-ridges; and, size of catchment area using tied-ridges on several varieties of both sorghum and millet. Yield data was used as the major statistic for evaluation; however, other plant characteristics such as height, number of heads, number of good heads, total dry matter, etc., were measured and analyzed to aid in data interpretation. Plant characteristics and yield data for these crops were used to indicate soil-water management techniques to which these types of alfisols would respond. The water harvesting project examined the most effective way to use water conservation techniques at the village level. The zero runoff concept can be installed at the farmer's level so that efficient use of the hydrologic cycle is both implementable and manageable. Integration of soil-water management projects with draft power, provided by animal traction, points the way to an effective and economical increase in agronomic production.

Sorghum Studies

The results showed that by use of a no-till with mulch treatment, yields could be significantly increased over traditional plantings irrespective of the method chosen for water catchment: flat, ridged, or with tied-ridges. During an extended drought period in 1984, the no-till plots with mulch had the best seedling emergence. However, except for this extended 1984 drought, the best soil surface treatment was use of tied-ridges with mulch. Tied-ridge treatments had the most satisfactory yields when mulch was not used. This was particularly noticeable for the sorghum variety, E 35-1. By plowing before planting, the yield of E 35-1 increased by 236%, and by using tied-ridges and mulch, the yield increased by 493%.

During mid-season droughts, plants showed much less stress, as observed by color and curling of leaves, on soil surface treatments using mulch than those on other treatments. When no plowing was done, E 35-1 had a severe seedling loss and a significant yield reduction; however, this loss by poor emergence was circumvented with the application of mulch. The effect of cultivating the soil surface after each rain increased the means of various measurements above that of flat plantings without cultivation but these measurements were not statistically significant. Tillering was negligible for E 35-1 and less than 1 tiller/plant for local Kamboinse.

Highest yields for sorghum were with tied-ridges spaced at a 50cm distance, at a stand density of 88,000 plants/ha, and with mulch added at a rate of 15.0 tons/ha. However, after 2 years of experience with a 50cm row width, it was found that this row width was difficult to manage using the daba and animal traction cultivation techniques. Therefore, it was more convenient to use a 75cm row width at a stand density of 88,000 plants/ha even though E 35-1 increased yield by nearly 1 ton/ha at the 50cm row width. Maybe with increased use of tractor power, more efficient, higher yielding row widths will become a productive standard under rainfed agriculture.

The Framida (red) variety of sorghum responded to increased soil-water management better than either E 35-1 or local Kamboinse; nevertheless, E 35-1 responded much better than local Kamboinse. Local Kamboinse did not respond to variations in stand density but it did respond to mulch and tied-ridges. Local varieties are well adapted to low levels of management usually found in Burkina Faso.

Because of the lack of soil moisture measurement equipment, data of plant growth characteristics were used to evaluate soil-water management treatments together with production parameters of growth rate (height), yield, and quantity of dry material. Occasionally, seed weight/1000 grains varied with increased management; however, the response was usually noted at the extremes of plowed versus non-plowed treatments or flat plantings versus tied-ridges with mulch. Measurements of node diameter, distance between nodes, leaf length, and leaf width did not respond satisfactorily to soil surface treatments and are not recommended as a measurement for evaluation. These measurements, however, were specific to variety and early in the period of plant development a significant positive response was attributed to soil surface treatment and the plow versus no plow treatment.

Moisture content of grain was dependent upon variety and, occasionally, upon increased management. Therefore, all measurements of yield and seed weight/1000 grains were adjusted to the 8% seed moisture content before statistical comparisons were made. Measurements of number of good heads and weight of good heads were directly related to yield production terms. Therefore, only for specific examples or clarification were these measurements used to explain yield variance or differences.

Millet Studies

The principle conclusion supported by study results for millet is that yield is improved significantly when mulch is applied as a surface treatment. The traditional method of planting on flat bare surfaces without mulch limits yield. Although the yield of Ex-bornu was depressed by pollen wash, other growth characteristics (including less disease) were greatly improved using mulch. Highest millet yields were obtained with Souna-3 on tied-ridges spaced at 1.0m apart, at a stand density of 40,000 plants/ha and with mulch added to the catchment basin at a rate of 15 tons/ha. In addition, Souna-3 responded to improved soil-water management practices better than either Ex-bornu or local Kamboinse. Yields and dry matter production of local Kamboinse did not respond significantly to treatments of stand density, levels of mulch, or size of catchment area. However, yield of local Kamboinse did respond significantly to tied-ridges and tied-ridges with mulch.

The harvest index was highest for Souna-3 and Ex-bornu (2 year average = 37.8% and 31.7%, respectively) but, at the Djibo village study, a fast growing variety of moderate height, IKMV-8201, had a harvest index of 77%. The harvest index shows a wide variation by type of study and by climatic factors for a given year. Effect of climatic variation was also shown on local Kamboinse for number of days to 50% flowering. It was 80 and 79 days for the 1981 and 1982 seasons, respectively, but it increased to 93 days during the 1983 growing season. The exotic millet varieties, Souna-3 and Ex-bornu, remained essentially constant for all 3 years averaging 59 days and 57 days until 50% flowering, respectively.

Root Distribution Studies

The aeroponic technique for examining root growth without physical restraint of soil permitted examination of root growth and plant height as a function of time. Sorghum varieties, E 35-1 and local Kamboinse, responded better than 38-3 or CSH-5; however, under field conditions E 35-1 has serious emergence problems whereas emergence was not a problem for the other varieties. The seedling emergence or root growth problem for E 35-1 was not detected by this technique.

A village study showed that 85% of the roots were in the top 20cm of soil and that 96% of the roots were included in the top 40cm of soil. These results confirm conditions for alfisols in this region where a compacted layer starts between the 20cm to 50cm depths and continues to the ferralitic or gravel layer. The bulk densities for this compacted layer are greater than 1.5 gm/cm^3 which is the upper limit for viable root penetration. However, data did not show a seedling emergence problem associated with E 35-1 which was a stated objective. On the contrary, once E 35-1 was established, as was insured in these studies, vigorous root growth ensued. The difficulties experienced when attempting a controlled study on a village field were somewhat overwhelming. The follow-up study at Kamboinse Experimental Station was also met with problems beyond reasonable control. Further attempts at cooperative research were abandoned.

Animal Traction

Although an intensive continuous training program has been required to develop a group of skilled operators, the animal traction program was beginning to produce results. The team, with properly trained oxen, was able to show acceptable work levels to:

1. Plow and ridge research fields and plots;
2. Use various types of weeding equipment;
3. Use a seed and fertilizer drill effectively;

4. Build and maintain water conveyance systems (bunds);
5. Maintain farm roads;
6. Survey and use land leveling/earth moving equipment and techniques; and,
7. Build bench terraces.

This experience was to have been used to demonstrate the most efficient soil-water conservation techniques in the water harvesting program.

The variability and village level projects showed that draft animals in Burkina Faso were in a thin, weakened condition early in the season. There was a cyclic variation of weight related to forage availability. Donkeys could weigh as little as 110kg in June and by October or November weigh as much as 185kg and by the following June weigh as little as 110kg again. They could develop about 1.0 kg-km/hr of horsepower over a 50m track and generate a work output of 11.0 kg-hr when pulling a loaded sled. Donkeys traveled about 4 km/hr when working under load. Their respiratory rate and work output were affected by high temperatures.

Oxen required special apparatus to measure body weight. The usual sling method which worked so well for horses and donkeys could not be used with them. It was impossible to weigh and determine the body temperature of oxen used in this study with the equipment available in Burkina Faso. The work output by oxen-pairs of 48.0 hp-hr over a 100m track was 2 to 3 times that of donkeys. Horsepower developed by oxen-pairs was about 2.8 kg-km/hr which was more than double the output for donkeys. Generally, oxen traveled about 7 km/hr when working under load which was a faster pace than set by the donkey. A single ox could work about 2/3rds that of oxen-pairs when pulling the sled down a 100m track. Some oxen presented control problems and the farmer or trainer were constantly conscious of their tendency to bolt, kick or run.

Horses gained weight throughout the season from about 200kg in June to as much as 350kg in November. This large change in body weight was exhibited as excess fat on the animals; however, their ability to do work was not limited. Horsepower developed, work output achieved, and velocity of travel were in the same range as oxen-pairs over a 100m course. Although horses appear to be non energy efficient, sometimes, 1 horse could do the work of an oxen-pair. The disposition and control of a horse was a dramatic change from that of an ox. No mules were found at any village used in the program.

GENERAL CONCLUSIONS

Yields of all sorghum and millet varieties used in these studies were sensitive to variations in climate. Minor changes in rainfall distribution patterns could cause either increased yields or depressed yields. This sensitivity to the stochastic nature of climate did not permit investigators total control over production variables of yield or dry matter but installed an esoteric risk parameter which was itself an illusive stochastic variable. Explaining losses or gains in yields after the fact does not lend credence to logical research processes of futuristic scientific development. Obviously, the search for varieties and management techniques which lend themselves to yield stability will be a never ending quest.

The best soil surface treatment found in these studies from 1980 to 1984 was the no-till condition of flat planting with mulch. This system supported optimal yields with the least amount of labor input. However, management of plant residues was not a simple problem at the village level. These studies showed that additional use of plowing could provide only a marginal benefit for weed control and that mulching could provide an equal benefit. Fear that mulching would increase infestation by insects and disease was not substantiated by the results of this series of studies. In addition, flat planting was a benefit to plant emergence during extended periods of drought by taking advantage of light rainfalls (less than 10mm).

During heavy rainfall, water puddled on all plots without mulch. Puddling was observed on millet plots without mulch which were located on sandy loams as well as sorghum plots which were usually located on loams. Standing water remained in tied-ridge plots without mulch up to 3 days after rainfall ceased. Algal blooms formed in the bottom of tied-ridge basins attesting to water stagnation. No standing water was observed to remain after rainfall on plots with mulch. However, some runoff does occur from flat mulched plots. Nearly all mulch was decomposed by harvest time and did not interfere with post harvest operations.

Rice straw applied at a rate of 6 tons/ha was superior to both chopped sorghum or millet stalks when used as a mulch material. The matting of rice straw in the catchment basin of tied-ridges provided a complete cover from raindrop impact and a better environment for decomposition by termites and biological activity as well as a significant reduction in weed growth. Sorghum and millet stalks applied at 15 tons/ha approached the level of production improvement demonstrated by the application of 6 tons/ha of rice straw.

For sorghum, a tied-ridge row width of 50cm and a stand density of 88,000 plants/ha was significantly better than any other tied-ridge arrangement. Whereas, for millet, a tied-ridge row width of 100cm and a stand density of 50,000 plants/ha was significantly better. The exotic varieties of sorghum and millet responded favorably to mulch and flat planting. However, the most effective time for application of mulch was immediately following planting. Late application of mulch (mid-August) was neither beneficial nor detrimental to growth and yield responses of either sorghum or millet.

The sorghum varieties, Framida (red) and E 35-1, responded to soil-water management techniques at a greater rate than did local Kamboinse or S-29. For millet, Souna-3 responded to water management significantly better than either Ex-bornu or local Kamboinse varieties. However, Ex-bornu responded to water management better than local Kamboinse. Local varieties were well adapted to environmental conditions and the low level of management usually found in most parts of Burkina Faso on alfisols. The exotic varieties provided a much greater yield response for an equivalent increase in work effort; whereas, more work did not necessarily mean a greater yield response for local varieties.

Use of mulch and tied-ridges on these alfisols reduced the percentage of disease infestation and the amount of weeding necessary. During rainfall, these soils puddle and surface seal readily. Within the catchment area of tied-ridges where water could pond for 2 to 3 days after rainfall, the environment for seedling growth and development was extremely poor and weed control was easier. When mulch was used the work of weeding was further reduced without the resultant ponding and puddling associated with tied-ridges without mulch. Mulch shades the soil surface which, in turn, creates a poor environment for weed development.

Harvest indices for Framida and E 35-1 sorghum varieties and for Souna-3 millet variety show that these varieties were capable of producing more grain per amount of dry matter and were more energy efficient than local varieties. E 35-1, produced the greatest amount of dry matter (12.8 tons/ha on the average) and, generally, the highest grain yield averaging 3.2 tons/ha. Souna-3 produced the greatest amount of dry matter (6.5 tons/ha on the average) and the highest grain yield averaging 2.1 tons/ha.

Alfisols in Burkina Faso occur under unfavorable climatic conditions of the ustic environment. Even though physical and chemical characteristics of these soils are not particularly favorable, the interacting combination of soil-water management, fertilization, and the use of sorghum and millet varieties which respond well to increased management can, and will more than repay the farmer for his work effort expended and his costs invested.

ADDITIONAL COMMENTS AND OBSERVATIONS

Termites and Biological Activity

During rainfall, it was observed that mulch improved infiltration on alfisols by 2 distinct methods: one, by reducing raindrop impact; and the other, by increasing termite and biological activity. By using mulch, the material absorbed the impact of raindrops and no puddling or muddy water was observed in the microcatchment area.

As surface water infiltrates into soil, puddled soil particles are filtered out in the surface layer (see section on crust formation). When this process is permitted to continue it causes surface sealing and compaction which reduces water absorption and may increase surface runoff. Tied-ridges or microcatchment basins store water; however,if puddling and surface sealing is severe, then this stored water is effectively lost through evaporation.

Mulch encouraged termite and biological activity at the soil surface. Field termites started to consume plant material immediately after it was placed on the soil surface. Therefore, surface water, collected from rainfall, could enter the soil through micro-holes made by termites. Termites consumed the mulch material at a slow rate but by the end of August only a small amount of debris remained. Rainfall was never observed to accumulate and runoff from the tied-ridge plots which were protected by mulch. Also, termites consumed only the rice, sorghum and millet dry mulch material and did not attack growing sorghum or millet plants used in these studies. During the height of termite activity, large amounts of clay materials were transported from deeper horizons to the surface which should benefit upper layers of these sandy alfisols if surface erosion is inhibited. Mound building termites with large bore tubes were observed in the field consuming mulch during the excessive drought of 1984.

Biological decomposition also started immediately after the first rainfall. As these materials were decomposed and digested by soil organisms, their by-products became a part of the underlying soil horizons by infiltration. Biological activity increased micro-pores in the soil profile providing another pathway for increasing entry of water into the root zone where it was needed. Soil or angle worms were not a part of the soil matrix on fields used for these studies.

Soil Surface Crusting On Alfisols

Soil surface crusting, which is a major concern to soil-water conservation, is a function of raindrop impact and intensity, rainfall duration, soil surface condition, soil surface texture, quantity of organic matter, soil and air temperature, wind movement, and iron and aluminum compounds. Interacting combinations of these factors in soil solution determines the extent of compaction which can form at the soil surface. Alfisols of West Africa, including Burkina Faso, have all the necessary ingredients to insure soil surface crusting. The following discussion delineates a proposed cause for soil surface crusting on alfisols. Because of the interrelation of crusting to surface water runoff, further study should be implemented.

Crusting: The process can be described as follows: raindrops strike a dry bare soil surface under the force of a squall or wind driven storm front. A typical rainfall in Burkina Faso can have an intensity of about 1000 mm/hour (for a short period of time) where raindrops fall at a velocity of about 60 cm/second. This force is absorbed by the bare soil surface and these falling raindrops break down and disperse soil aggregates. However, with high rainfall intensities and soil surfaces of gentle microrelief, water stacks creating a micro-ponding effect. When the surface is wet and micro-ponded, the force of the raindrops striking the surface causes a water film to become puddled or muddy. These dispersed particles entrained in a water film tend to move downward by gravity and infiltration. They clog soil pores immediately at or near the surface and form a thin dense layer.

This layer has a much lower infiltration rate which has been estimated to be reduced by more than 2000 times the initial infiltration rate (McIntyre, 1958; Wischmeier and Smith, 1958). If the soil surface is not cultivated or managed through some method of conservation then this process continues with each rainfall and can cause surface sealing and compaction which reduces water absorption and increases surface water runoff.

If both the size of raindrops and their velocity on impact are maximized for a sufficiently long time, this process could release a large amount of fine particles from deeper soil depths to become crusted at the surface. If the force of driving rains continued without excessive surface runoff then the depth of the surface crust would increase with time. This process, of course, would be limited by the possibility of erosion which would remove the finer particles from the surface. However, if surface erosion is negligible then the depth of crust formation would be predictable. With each additional rainfall the process could continue and would increase the depth of the compacted zone. This thin surface compacted zone consists of oriented clay and organic particles with a few isolated air pores (Evans and Boul, 1968). Clay and organic particles can become totally disassociated by the energy and absorptive capacity of falling raindrops.

Chemical Relations For Crusting: A micro-ponded layer of entrained particles can have a rapid rise in pH, for example, from a pH of 4.2 to 7.0, and an immediate increase in number of negative charges associated with a parallel increase in cation exchange capacity, CEC (de Villiers and Jackson, 1967). Therefore, if sufficient amounts of iron and aluminum compounds are available they may be deposited within interlayers of clay minerals bonding the particles together with a concurrent raising of the CEC in a thin compact zone. With a rapid rise in pH, and an accompanying increase in net charge/particle there is an attendant increase in the bulk density of this surface layer.

This process is greatly assisted by high soil surface temperatures which increase ion activity and accelerate ion exchange processes. When the surface crust dries out rapidly, charges on the soil particles become fixed by cations, i.e., the soil surface sets-up as cement. Interactions within the process create an environment whereby thin surface layers become dense and inflexible to all but the strongest forces. During the rainy season, soil surface temperatures as high as 65 degrees Celcius (Chase, 1983) have been measured on sandy soils at the ICRISAT Center, Niamey, Niger. When rainfall occurs on soils at this high temperature, soil-water is heated and chemical reactions are accelerated. As these sandy soils wet, thermal conductivity increases to as much as 0.005 cal/cm/sec/degree Celcius. There would be a continuous passage of heat, therefore, from the soil body to the wetted soil surface during rainfall which would further accelerate chemical processes and crusting.

An addition of chemically pure water (pH 7.0) by rainfall, would rapidly increase the pH of a micro-ponded soil surface (initially pH 4.2) and release negative charges which affect a sizable pH-dependent CEC. These negative charges would require a high specific surface of positive edges of hydroxy aluminum on any mineral with a net negative permanent charge. These negative charges could be satisfied with cations in the system, e.g., iron and/or aluminum compounds. Further, adsorption of ferric hydroxide becomes irreversible upon dehydration and this irreversibility of colloidal ferric hydroxide is an important factor to produce stable aggregates in certain soils; especially alfisols. When this ferric hydroxide is in a micro-ponded solution it can act as a flocculating agent and upon rapid dehydration becomes more gelatinous and exerts a cementation action which binds flocculated particles together (Arca and Weed, 1966). When hydrated colloidal ferric hydroxide adheres to clay minerals it cannot be removed mechanically but only chemically. This cementation process works on both iron and aluminum compounds, bonding to form stable aggregates in acid soils.

The effects of organic matter can be demonstrated by the importance of sesquioxide-humus reactions in the formation of stable aggregates. Humic acid is adsorbed in relation to the quantity of ferric oxide gels. This results in the formation of organic mineral compounds by interaction of humic acids and free sesquioxides. Organic matter, a cementing agent, is conducive to the formation of large stable aggregates (Baver, 1956). If soils contain low amounts of clay, then organic matter content, however small, contributes heavily to the stabilization of soil aggregates. Therefore, for surface crusts on alfisols, the presence of only small quantities of colloidal humus and colloidal clay particles are necessary to aggregate crust formation with rapid dehydration.

Personnel Training

In addition to specific training of an Animal Traction Team, the soil-water management team has participated in a 3 month, twice a week, gas welding-burning course to construct, maintain, and repair field equipment. Ms. Sophie Ouedraogo is continuing her education by attending night classes. In 1981, Mr. Paul Ouedraogo was the first to take a 9 month training program at

ICRISAT Center, India, with emphasis on Farming Systems and rainfall-runoff plot designs. Mr. Mamane Toure attended a 9 month training program during 1983 with emphasis on animal traction at ICRISAT Center, India. Mr. Paul Kafando has left the team to pursue a course in agricultural economics at the bachelor degree level at the University of Abidjan, Ivory Coast. Also, Mr. Christophe Zaongo, student trainee who completed his thesis with the soil-water management program, was awarded a scholarship at Texas A & M University, USA, where he has been enrolled in the Ph.D. program of Soil-Water Science. When he has completed the course requirements, Mr. Zaongo will return to Burkina Faso for field research as a partial fulfillment of his Ph.D. thesis.

On-the-job-training was a continuous process with the soil-water management team. Lectures were given throughout the year on subjects concerned with soil physics, chemistry, soil survey, and hydrology. Instruction was given in the use and care of the TRS-80, Model III computer. This class included discussions of the compiler and the computer language BASIC. The objective of this instruction was to inform each team member about the intricacies of data analysis and statistics of field data.

Personnel Management

After viewing a women's field labor program which was instigated by Mr. Phil Serafini, ICRISAT, Mali, in 1981, it was decided that a similar program could be started here by the soil-water management program at Kamboinse Experimental Station. During the 1982 growing season, a group of 8 women were hired for temporary field labor work. This program started slowly with only young girls applying for field work. They were hired but it became immediately evident that the universal flaw in all human organizations was deep-seated and at work in Burkina Faso. The work force became lackadaisical with a tendency by both sexes to glance, stare, and chat. To overcome this problem, a strong effort was required by field managers to complete the work.

However, word spread throughout Kamboinse village and during the following growing season of 1983, it was possible to hire older, more mature women. It is not uncommon now to observe young family groups sitting under a shady tree when mothers are working in a nearby field. In addition, older women have changed the working atmosphere completely and for the better. At first, men felt challenged by older women and worked at breakneck speed. However, as the days passed, competition changed from that of challenge to that of pleasant sharing of the workload and competitive fun. It has become a shared experience.

Beyond any doubt, use of women on the temporary field labor force has not only improved the quality and volume of work but there has been a noticeable improvement in the morale of the crew. Field work with a daba is drudgery but now there is more smiling, joking, and a definite improvement in the level of language. During the 1983 season, the composition of the field labor crew was 50/50 and it continues to be 50/50 during the 1984 growing season. In addition, many of the women working on the labor crew had husbands who were also employed as laborers at Kamboinse station.

Publications and Reports

The Soil-Water Management Program has produced the following information:

1. Annual Reports: Soil-Water Management Sections, 1980, 1981, 1982 and 1983, ICRISAT, Kamboinse, Burkina Faso.
2. Perrier, E. R. and W. K. Jaeger, 1982. "Probabilistic Strategies for Determining Yield from Rainfall Data", Prepared for Publication in the American Society of Agronomy.
3. Perrier, E. R., L. P. Wilding, and B. Gilliver, 1983. "Statistical Measures of Field Plot Uniformity", Prepared for ICRISAT, Farm Development Committee, Niamey, Niger.
4. Perrier, E. R., 1983. "An Evaluation of Soil-Water Management on an Alfisol in the Semi-Arid Tropics of Upper Volta", Prepared for an ICRISAT publication in Consultant's Workshop on the State-of-the-Art an Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils.
5. Perrier, E. R., 1984. "The Soil-Water Management Program of Upper Volta", Technical Paper prepared for the SAFGRAD Technical Advisory Committee.
6. Perrier, E. R., 1984. "BASIC Statistical and Data Processing Programs for Mini-Computers", written for SAFGRAD/ICRISAT personnel.
7. Perrier, E. R., Wilding, L. P., and Gilliver, B., 1984, "An Evaluation of Computational Methods For Field Plot Uniformity Studies," Paper prepared for Advances in Agronomy Series.

RECOMMENDATIONS

SAFGRAD Phase I Results

Recommendations for implementation at the farmer's level based on analyses of these studies can be summarized as follows:

1. Mulching with crop residues is extremely effective, especially under no-till conditions.
2. Tied-ridges reduce water and erosion losses by surface runoff and increase yield (zero runoff concept). Tied-ridges can be improved by placing mulch in the catchment basin.
3. Mulching and tied-ridges reduce weeds and percentage of disease infestation.
4. Higher yield results from better surface water management, better varieties, more fertilizer; and, unfortunately, more actual hours of labor.
5. The use of animal traction as a source of draft power can be used to build terraces, contour ridges, drainage ditches, and many other water conveyance and storage projects for better farm and soil-water management.
6. There is a need for a program to instruct farmers on the rudiments of health, feed and care of draft animals.

SAFGRAD Phase II Proposals

Short Range Plans: Controlled field plot studies should be implemented employing water harvesting technology and soil conservation practices for rainfed agriculture to continue development and improvement of techniques of water use efficiency. The following areas of concern should be studied:

1. The inclusion of no-till studies in the 400mm zone of the Sahel should be implemented to evaluate management needs for use of mulching materials.
2. The design and construction of terraces should be used as a demonstration project. The use of terraces is the best method for control of erosion and management of water.
3. Tied-ridges, contour ridges, and water conveyance systems should be implemented using small integrated projects at the village level. These designs should be based upon controlled research results obtained from local research reports.
4. Controlled research studies should be continued to further evaluate tied-ridge techniques, effects of anti-transpirants, mulches, supplemental irrigation, micro-irrigation, and crop varieties on reducing risk of drought. In Burkina Faso, the effect of

drought can occur any time before and during the rainy season, and if it extends for more than 15 days it is considered severe.

5. The animal traction program at Kamboinse should be continued to aid in the establishment of soil-water management and conservation programs. The personnel need to be trained to excellence to serve as examples for farmers in control and management of animals. Because most of the energy for agriculture is produced by human labor, few conservation programs have been started. Oxen and donkeys should be employed as the source of energy and trained to use equipment for earth moving projects.

Long Range Plans: The focus of research in this project phase should be to coordinate an integrated program of soil-water management with national scientists taking an increased role in it's implementation and development. Research trials should be based on findings from Phase I studies and these findings translated into a technology at the farmer's level which can be readily adopted. Water harvesting farm layout designs should incorporate all necessary soil-water-engineering information available to develop a comprehensive system to insure a complete evaluation of techniques of soil-water conservation. Reports should be written about each element of the hydrologic farming system, delineating specific items which are supportive of technological transfer. Information from these studies should serve to increase baseline data sources for the Sahel. The adoption of these findings at the farmer's level may require extension activities and should be monitored to promote feedback for evaluation of problem areas.

No-Till Studies

Research studies using mulch should be continued at the village level with cooperative farmer input. The need to save and store various plant residues should be evaluated at each rainfall zone as each zone has problems peculiar to the region. The no-till concept can reduce weed growth, labor for seedbed preparation and improve yields where no fertilization is used. It is essential that the methods for management of mulch be exploited for the Sahel and implementation start immediately.

Water Conservation Studies

Basic research studies should be continued at an Experimental Station where variables can be controlled and techniques using micro-catchment of water can be evaluated. These studies should emphasize construction of terraces, tied-ridges, contour ridges, and tillage operations. In Phase II, greater emphasis should be placed on drought tolerance of various crops and their ability to adjust to different forms of soil-water management techniques. In addition, new methods involving anti-transpirants, types of mulches, seedbed shapes, methods of cultivation, supplemental irrigation and the Chase method of micro-irrigation should be examined and evaluated for their effectiveness in each rainfall zone for increasing crop production and decreasing the risk of crop failure. Often, these studies involve the measurement of soil-water *in situ* (this includes moisture content, soil-water conductivity, and soil-water suction), soil and plant temperatures, plant growth characteristics, climatic characteristics and crop use studies. Under no conditions should lack of equipment be permitted to limit exploitation of known technology of soil-water management.

Animal Traction Program

Animal traction is playing an increasingly important role in the agriculture of the Sahel and sale of animal traction equipment is increasing at an exponential rate. During Phase I, it was demonstrated at Kamboinse Experimental Station that improved animal traction equipment and management techniques are available which can reduce operation time and human power requirements for growing crops. Four row planters and seeders for use with drawbar equipment are available for oxen and could be modified for use by horses. All techniques for animal traction should be used towards improving production agronomy and not as a supplement to subsistence agriculture.

The effectiveness of animal traction studies of the Soil-Water Management Program in Burkina Faso would be greatly improved with the addition of an Agricultural Engineer and a Soil Chemist. The agricultural engineer should have a PhD with a specialty in power and machinery and an avid interest in animal traction. The soil chemist should have a PhD and be provided with a laboratory facility for analytical work. These scientists should cooperate with plant breeders, agronomists, and soil physicists in soil and fertility problems on management of alfisols. These staff members must be well established in research and development to maintain on-going cooperative research with international and national scientists, develop and implement new research efforts, help with on-the-job training programs, and direct the work loads of national supervisory staff and field managers.

Draft Animal Judging Contests

Contest Objectives:

1. To determine the best performance of draft animals within each ORD region and at the national level; and,
2. To determine the best draft animal body conformation for breeding purposes in each ORD region and at the national level.

Need for Contests: Local farmers have shown an intense interest in a recent research program developed by ICRISAT/SAFGRAD scientists which was entitled "The Variability of Animal Traction at the Village Level". The objective was to evaluate variability of draft animals and to characterize their capacity for work by measuring their performance throughout the year. A dynamometer was attached between an animal and a sled to measure the pulling force through a 50m or 100m course. The competitive nature of the study became obvious immediately to farmers, even before measurements had begun.

It is a simple observation to see draft animals throughout Burkina Faso in a weakened condition attempting to plow and cultivate soil immediately after the first heavy rains of May and June. To help farmers in solving this apparent dilemma, an "Animal Traction Pull Contest" is proposed for each ORD region in early spring, before arrival of normal rainfall, during the first part of April. In addition, another contest would be held at the national level at a stadium in Ouagadougou ending on the 1st of May. To compete in the contest, to win prizes and gain in public stature, the farmer would be required to bring his draft animals to at least a "good" state of health and trained condition before contest date. Therefore, animals would be in better condition when field work starts during the oncoming growing season.

In Burkina Faso, it is difficult to find good quality animals for draft purposes. Most herdsman prepare their animals for human consumption. In addition, not all farmers know what the factors are that constitute needed body types and conformation to develop a breeding program for draft animals. Therefore, a "Draft Animal Judging Contest" is proposed to run concurrently with a Pull Contest which will outline in detail those features which identify the best proportional shape and contour of an animal for draft power. Here, the farmer can be a participant in observing the body conformation most desirable in selecting his animals. Draft animal judging contests would be equally important for information transfer on a national basis. The contest would identify local and national farmers with the best available animals and eventually provide a source of breeding stock for upgrading existing draft animals.

At the national level, contests could be used as an opportunity to display and sell other equipment currently available for animal traction. For example, drawbar equipment, ridgers, tied-ridgers, graders, mowers, levelers, plows, harrows, seeders, weeders, blades, fertilizer and pesticide equipment, harness, chains, ropes, carts, wagons, harvesting equipment, etc. Breeding stock, imported from other countries, could be displayed so that potential breeders of draft animals could see possibilities for upgrading their own livestock.

The status level of a farmer in Burkina Faso is not very high. Even the connotation of the word "paysan" is somewhat derogatorily used in the language. There is an important need to help the farmer elevate his status level. The advantage of being a contest winner or owner of the "best" breeding stock offers an opportunity of regional and national prominence when publicity is supportive. Prize money or prizes must be adequate to provide added incentives for competition at the start of local phases of the program. Opportunities for increasing status levels should grow slowly and eventually both contest levels (regional and national) should give necessary inducements to compete.

Contest Development and Implementation: It is anticipated that 1 year would be required after funding to locate national scientists and engineers in each of the ORD regions who would be available to cooperate in development of the contests. To aid in training of these selected individuals for the contests, an instructional workshop or short course would be organized and presented within the first year by requesting a representative from Future Farmers of America (FFA) or the Amish Community of the United States (Illinois or Indiana) to participate or serve as advisors for the program agenda. Although there are judging contests held in Sierra Leone, Kenya, Sudan, South Africa, Zimbabwe, Ethiopia, Uganda, and other places in Africa, they do not include the "Animal Traction Pull" as an integral part of their program. The suggested organizations have experience and could be asked to present a workshop delineating planning and implementation requirements for animal draft power pulls and techniques involved in draft animal judging contests.

This period of organization, the first year, would also be used to locate areas and arrange facilities where local contests could be held within each ORD region. In reality, only a small level arena (about 1 hectare) would be necessary. A fenced-in area would be needed for individual judging of animals. Some office facilities would have to be provided locally for an official contest headquarters at each ORD where registry of animals and their owners could be done. An area adjacent to the contest arena would have to be made available for temporary bedding and feeding of animals during the contest period. In addition, some type of temporary housing should be provided for animal handlers and officials.

Farmers would bring their draft animals to each ORD contest area station at least 2 to 3 days before the scheduled traction pull and judging contests. This time would permit animals to rest and adjust to environmental changes and increased attention received by animals from strangers. During this period, farmers could schedule time to make inspections and familiarize themselves with the track and arena.

Contest judges at the national level could be selected by ORD representatives after regional contests. It would be anticipated that the top 5 winners of the draft power and stock judging contests from each ORD region would be eligible to compete at Ouagadougou. Because of the possibility of transport problems, it may be necessary to aid farmers who come from long distances. Facilities at Ouagadougou for contestants and animals must be planned for at least 3 to 5 days before the actual traction pull and judging shows, possibly for a total of 10 days. Each farmer must be permitted time to practice and prepare his animals for the appropriate contest.

As this would be a new program, many unforeseen emergencies will undoubtedly occur. The program leaders should have flexible decisional authority to resolve the unplanned events and problems as well as a budgetary category to support these contingencies. Financial support should come from some outside agency for the first and possibly second year. However, local support from banks and merchants should be solicited for financial support and to offer prizes. Within 3 years contests should have local support and national cooperation.

After each year's operation, a review of contest methods and rules should be made to update existing and solvable problems. A corrected set of instructions and regulations which have been agreed upon by contest officials and representatives from ORD regions could then be printed and distributed in anticipation of next year's contests.

Rainfall-Runoff and Water Harvesting Techniques

Water is the single most important resource limiting crop production in the Sahel. Its conservation and efficient use is therefore critical to the farming system. Efforts to manage rainfall-runoff and soil erosion which exploits these resources is fundamental to the farming systems approach. The erratic distribution of rainfall which manifests itself with extended droughts and rain storms of high intensity is potentially disastrous to the region.

The success of farming under rainfed conditions depends not only on the effective collection of runoff (water harvesting), but also upon efficient use of water by agricultural crops. Uncertainties of rainfall-runoff events are difficult to reconcile with crop requirements. It is crucial to choose a crop and management system that can make the best use of long term water storage in soil. Optimal water storage in soil requires that an adequate amount of rainfall infiltrate to the depth of roots with the remainder of the water stored in a catchment area or aquifer recharge for later distribution and use.

Water harvesting techniques can be used to develop local water supplies in remote areas for domestic use, livestock, farming, and supplemental irrigation projects. The design and construction of rainfall collection systems in isolated areas could be developed by an animal traction program. Demonstration projects should be implemented at the village level in areas representing rainfall patterns within ecological regions of the Sahel.

Training of Scientists and Technicians

Phase II needs to provide university training for undergraduates as well as university training for selected students at the graduate level. For most countries within the Sahel, it is difficult to find qualified students for graduate level programs in soil-water management. In addition, 5th year thesis students in Burkina Faso should be actively recruited to prepare dissertation problems in Soil-Water Management research areas. The ICRISAT Center in Hyderabad, India, and the IITA Center in Ibadan, Nigeria can provide additional technical training in agricultural research to those staff members who have completed their secondary education.

An additional effort should be made to aid and provide opportunities for staff to complete their primary and secondary schooling certification. Short courses on specific topics of soil-water management should be made available for attendance by all staff members. On-the-job training programs should be a continuing and on-going effort throughout the Phase II program.

Publications and Reports

An evaluational procedure throughout Phase II should monitor associated progress and development of implemented research studies. Report and manuscript writing is the principle method of technological transfer and time and facilities must be budgeted within the contract. Other forms of information transfer such as workshops, lectures, and tours are supportive of program goals. Reports should be written about each element of the soil-water management system delineating items such as animal traction and equipment, design and construction of terraces and contour ridges, microcatchment techniques, use of mulch and anti-transpirants; and, water harvesting and supplemental irrigation systems.

Research results should be prepared for publication in organizational pamphlets and brochures as well as for professional journals. Instruction manuals should be written focusing on information for immediate technological transfer. Detailed graphic designs and displays of on-going and completed project activities should be prepared for use as visual aids and instructional packages.

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APPENDICES

Characteristics of Sorghum Varieties (SORGHUM bicolor)

CATEGORY	E 35-1	LOCAL KAMBOINSE	FRAMIDA
Origin	Ethiopia	Burkina Faso	Nigeria
Soils	Adapted to Deep Soils (75-100cm)	Moderate to Deep Soils (40-100cm)	Adapted to most soils
Rainfall Zone of Adaptation	650mm to 850mm	650mm to 850mm	700mm to 1200mm
Growth Cycle	125 days	130 days	120 days
Photosensitivity	Partial	Total	Partial
Number of Days to 50% Flowering	80 days	82 days	80 days
Mean Height	2 meters	4 meters	2 meters
Type of Panicle	Compact	Loose (Guinea)	Semi-compact
Grains	Large hard endosperms Pearly white	Small endosperms Chalky; Speckled white	Medium endosperms Brown; soft ends
Disease Resistance	Leaf; Parasite; not striga	Susceptible; not striga	Striga
Seeding Date	After 15 June	After 1 June	After 1 June
Planting Density (Plants/ha)	60,000	75,000	80,000
Potential Yield	4.0 tons/ha	2.2 tons/ha	4.0 tons/ha
Field Preparation	Plowing, lacks seedling establishment	With or without plowing	With or without plowing

Characteristics of Millet Varieties (PENNISETUM Typhoides)

CATEGORY	SOUNA-3	EX-BORNU	LOCAL KAMBOINSE
Origin	Mali	Nigeria	Burkina Faso
Soils	Light Sands (30-40cm)	Sandy (30-40cm)	Sandy (30-40cm)
Rainfall Zone of Adaptation	500-800mm	600-900mm	650-800mm
Growth Cycle	75 days	75 days	120 days
Photosensitivity	None (Gero)	None (Gero)	Total (Maiwa)
Number of Days To 50% Flowering	55 days	55 days	80 days
Tillering	Many	Many	Many
Mean Height	2 meters	1.8 meters	2.9 meters
Length of Head	45cm	30cm	22cm
Grains	Large Slightly hard	Medium size	Little; Hard
Disease Resistance	good	Good	Poor
Seeding Date	20 June to 10 July	20 June to 10 July	After 1 June
Planting Density (Plants/ha)	65,000	65,000	70,000
Potential Yield	3.0 tons/ha	2.5 tons/ha	1.2 tons/ha
Field Preparation	With or without Plowing	With or without Plowing	With or without Plowing

ETUDE: Les Effets des Traitements Faits a la Surface du Sol Avec ou Sans Labour de Deux Varietes de Petit Mil.

OBJECTIF: L'alimentation eau constitue un des plus importants facteurs en culture pluviale. Les effets escomptes sont: la conservation du sol, l'accroissement du rendement, la reduction du ruissellement et de l'erosion sur les cultures de petit mil.

CHAMPS: L7 avec la triangle.

TRAITEMENTS: A. Methode de cultivation
- C1. Par main avec la daba
- C2. Avec la charrue

B. Varieties du sorgho
- V1. IKMV 8305
- V2. Souna-3

C . Gestion de surface du sol
- S1. Billons cloissones avec paillis
- S2. Plat sans paillis
- S3. Plat avec paillis

PLAN AU CHAMP:

a. 7 repetitions

b. Dimension des parcelles, 5m X 10m, avec 1 metre par allee, 2 lignes de bordure (voir le plan).

c. Population en plants: 50,000 plants/ha, 20 cm/poquet.

d. 100 cm entre les lignes pour les petit mil (10 lignes x 10 m).

e. 20 cm entre les poquets sur les lignes.

f. le petit mil a un plant/poquet.

g. les billons sont cloisonnes a un metre au semis.

h. adjoindre le paillis immediatement apres le semis.

i. 150 kg/ha d'engrais coton pendant le semis
65 kg/ha uree 30 jours apres, sous surface du sol.

METHODOLOGIE:

1. Mesurer et piqueter les parcelles immediatement apres avoir fait les billons du tracteur ou de la main.

2. Construire les parcelles plat manuellement a la daba pour des dimensions exactes.

DONNEES A COLLECTER:

1. Enregistrer toutes les dates des operations

2. Calculer le pourcentage de germination

3. Faire l'hauteur (10 plants/parcelle), longuer de l'avant 3e derniere feuille des plants (enregistrer la date):

    a. au sarclage (au moins quatre fois)
    b. a 50% floraison

4. Enregistrer la date a laquelle on a 50% floraison pour chaque parcelle.

5. Mesure la surface de la parcelle de recolte.

6. Compter le nombre d'epis au moment de la recolte:
    a. bons au rendement,
    b. mauvais ou vides,
    c. malades (type de maladie - charbon, mildiou, ergot, moisissure et insectes), et
    d. total pour chaque parcelle.

7. Enregistrer le poids des epis bons/parcelle

8. Enregistrer le poids en grains (battu) recoltee.

9. Enregistrer le poids pour 1000 grains

10. Enregistrer le poids des stockage pour chaque parcelle

11. Garder un echantillon de matiere seche et de grains pour la determination du taux d'humidite.

Champ L7

Sans Labour						Avec Labour			
R7 V1 S3 61	R7 V1 S1 62	R7 V1 S2 63	R7 V2 S1 64	R7 V2 S2 65	R7 V2 S3 66				
R6 V2 S3 51	R6 V2 S1 52	R6 V2 S2 53	R6 V1 S3 56	R6 V1 S2 57	R6 V1 S1 58	R4 V1 S1 54	R4 V2 S3 55	R4 V2 S1 59	R4 V2 S2 60
R5 V2 S2 41	R5 V2 S3 42	R5 V2 S1 43	R5 V1 S2 46	R5 V1 S3 47	R5 V1 S1 48	R3 V2 S1 44	R3 V2 S2 45	R4 V1 S3 49	R4 V1 S2 50
R4 V1 S1 31	R4 V1 S2 32	R4 V1 S3 33	R4 V2 S3 34	R4 V2 S2 35	R4 V2 S1 36	R3 V1 S3 37	R3 V1 S2 38	R3 V1 S1 39	R3 V2 S3 40
R3 V2 S1 21	R3 V2 S3 22	R3 V2 S2 23	R3 V1 S1 24	R3 V1 S2 25	R3 V1 S3 26	R2 V2 S1 27	R2 V1 S2 28	R2 V1 S3 29	R2 V1 S1 30
R2 V1 S2 11	R2 V1 S1 12	R2 V1 S3 13	R2 V2 S1 14	R2 V2 S3 15	R2 V2 S2 16	R1 V2 S3 17	R1 V2 S1 18	R2 V2 S2 19	R2 V2 S3 20
R1 V1 S1 1	R1 V1 S3 2	R1 V1 S2 3	R1 V2 S1 4	R1 V2 S3 5	R1 V2 S2 6	R1 V1 S3 7	R1 V1 S2 8	R1 V1 S1 9	R1 V2 S2 10

La triangle, Avec Labour

R7 V1 S2 81	R7 V2 S3 82	R7 V2 S2 83	R7 V2 S1 84
R6 V1 S2 78	R7 V1 S1 79	R7 V1 S3 80	
R6 V2 S3 75	R6 V1 S3 76	R6 V1 S1 77	
R5 V1 S3 72	R6 V2 S1 73	R6 V2 S2 74	
R5 V1 S1 70	R5 V1 S2 71		
R5 V2 S1 68	R5 V2 S2 69		
R5 V2 S3 67			

ETUDE: Traitement de Surface du Sol avec Paillage sur Sorgho et Petit Mill

OBJECTIF: Determiner l'effect du paillis avec la surface plat, billonnage cloisonne sur la production du sorgho et petit mil.

CHAMPS: Sorgho C4 (a1,a2,a3)
Petit Mil (c2)

TRAITEMENTS: A. Varieties du sorgho
V1. 82-S 104
V2. 82 S 50

Varieties du Petit Mil
V1. IKMV 8305
V2. IKMV 8201

B. Gestion de surface du sol
S1. Billons cloissones avec paillis (7.5 tonnes/ha - seche)
S2. Billons cloissones sans paillis
S3. Plat avec paillis (7.5 tonnes/ha - seche)
S4. Plat sans paillis

PLAN AU CHAMP:

a. 6 repetitions

b. Dimension des parcelles, 5.25m X 10m, avec 1 metre par allee, 2 lignes de bordure (voir le plan).

c. Population en plants:
Sorgho - 67,000 plants/ha
Petit Mil - 106,000 plants/ha

d. 75 cm entre les lignes
(7 lignes x 10 m).

e. 20 cm entre les poquets sur les lignes pour le sorgho.
25 cm entre les poquets sur les lignes pour le petit mil.

f. le petit mil a deux plants/poquet.
le sorgho a un plant/poquet.

g. les billons sont cloisonnes a un metre au semis.

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h. adjoindre le paillis immediatement apres le semis.

i. 150 kg/ha d'engrais coton pendant le semis
65 kg/ha uree 30 jours apres, sous surface du sol.

METHODOLOGIE:

1. Mesurer et piqueter les parcelles immediatement apres avoir fait les billons au tracteur ou a la main.

2. Construire les parcelles plates manuellement a la daba pour des dimensions exactes.

DONNEES A COLLECTER:

1. Enregistrer toutes les dates des operations

2. Calculer le pourcentage de germination

3. Faire l'hauteur (10 plants/parcelle), longueur de l'avant 3e derniere feuille des plants (enregistrer la date):

   a. au sarclage (au moins quatre fois)
   b. a 50% floraison

4. Enregistrer la date a laquelle on a 50% floraison pour chaque parcelle.

5. Mesure la surface de la parcelle de recolte.

6. Compter le nombre d'epis au moment de la recolte:
   a. bons au rendement,
   b. mauvais ou vides,
   c. malades (type de maladie - charbon, mildiou, ergot, moisissure et insectes), et
   d. total pour chaque parcelle.

7. Enregistrer le poids des epis bons/parcelle

8. Enregistrer le poids en grains (battu) recoltee.

9. Enregistrer le poids pour 1000 grains

10. Enregistrer le poids des stockage pour chaque parcelle

11. Garder un echantillon de matiere seche et de grains pour la determination du taux d'humidite.

Champ C4 (a1,a2,a3)

<--- Station Road --->

R1 V2 S4 4	R1 V2 S3 3	R1 V2 S2 2	R1 V2 S1 1
R1 V1 S4 5	R1 V1 S3 6	R1 V1 S2 7	R1 V1 S1 8
R2 V1 S4 12	R2 V1 S2 11	R2 V1 S3 10	R2 V1 S1 9
R2 V2 S1 13	R2 V2 S2 14	R2 V2 S3 15	R2 V2 S4 16
R3 V1 S3 20	R3 V1 S1 19	R3 V1 S4 18	R3 V1 S2 17
R3 V2 S2 21	R3 V2 S3 22	R3 V2 S4 23	R3 V2 S1 24
R4 V2 S1 27	R4 V2 S3 26	R4 V2 S4 25	
R4 V2 S2 28	R4 V1 S2 29		
R4 V1 S3 30			

X Pleuviometre

<--- Digette --->

R5 V1 S3 34	R5 V1 S1 33	R4 V1 S1 32	R4 V1 S4 31
R5 V1 S2 35	R5 V1 S4 36	R5 V2 S2 37	R5 V2 S1 38
R6 V1 S2 42	R6 V1 S1 41	R5 V2 S4 40	R5 V2 S3 39
R6 V1 S4 43	R6 V1 S3 44	R6 V2 S4 45	R6 V2 S2 46
R6 V2 S1 48	R6 V2 S3 47		

Champ C4 (c2)

R1 V1 S4 6	R1 V1 S3 5	R1 V2 S4 4	R1 V2 S2 3	R1 V2 S3 2	R1 V2 S1 1
R1 V1 S2 7	R1 V1 S1 8	R2 V2 S4 9	R2 V2 S3 10	R2 V2 S1 11	R2 V2 S2 12

<--- Digette --->

R3 V1 S4 18	R3 V1 S1 17	R2 V1 S1 16	R2 V1 S3 15	R2 V1 S2 14	R2 V1 S4 13
R3 V1 S3 19	R3 V1 S2 20	R3 V2 S2 21	R3 V2 S1 22	R3 V2 S3 23	R3 V2 S4 24
R4 V1 S1 30	R4 V1 S3 29	R4 V2 S2 28	R4 V2 S3 27	R4 V2 S4 26	R4 V2 S1 25
R4 V1 S4 31	R4 V1 S2 32	R5 V2 S4 33	R5 V2 S3 34	R5 V2 S2 35	R5 V2 S1 36
	R6 V1 S1 41	R5 V1 S1 40	R5 V1 S3 39	R5 V1 S2 38	R5 V1 S1 37
	R6 V1 S2 42	R6 V1 S3 43	R6 V1 S4 44	R6 V2 S1 45	R6 V2 S2 46
		R6 V2 S4 48	R6 V2 S3 47		

1984-09

SOIL-WATER MANAGEMENT PROGRAM FOR THE 1981,1982,1383 .AND 1984 GROWING SEASONS

Perrier, Eugene

AU-SAFGRAD