

THE SOIL-WATER MANAGEMENT PROGRAM OF UPPER VOLTA

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THE SOIL-WATER MANAGEMENT PROGRAM OF UPPER VOLTA

PROJECT BACKGROUND

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 in terms of the most efficient use of human resources. Generally, the conceptual understanding of water supply is that it is a natural resource to agriculture which is seen as uncontrollable; whereas, it should be considered a resource which can be modified, conserved, and managed. The semi-arid tropics of Upper Volta in West Africa is characterized by its two season climate: a dry season that lasts roughly from October to May followed by 4 to 6 months of rain. The average annual rainfall is highly erratic and varies from 400 mm in the North to 1500 mm in the South. The storms are convectional in nature and seasonally balanced by the high pressure ridges of the Sahara Desert and the lows of the Bight of Benin. However, 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 half of the rainfall that reaches their plot of earth.

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 potential of the implementation of soil-water management is challenging. Through the employment of soil-water conservation techniques, the soil can replenish its's storage reservoir for better plant growth and reduce the damaging effects of erosion.

To complete the project objectives, animal traction is needed to construct the facilities necessary for water harvesting, contour terraces, contour furrows and ridges, conveyance systems, and grass waterways. Construction of the necessary embankments, structures and field designs, as well as soil tillage, by animal traction can have an important impact on farmers with limited machinery and draft power.

Goal:

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

Objectives:

1. Design and construct terraces, contour ridges and conveyance systems for the most efficient use of soil-water management employing animal traction.
2. To measure, using controlled studies, the effect of soil surface management techniques on yield in relation to the use of tied-ridges anti-transpirants, mulches and crops.
3. To develop and evaluate rainfall-runoff and water harvesting techniques to restrict surface water losses, prevent soil erosion and increase the soil water available for improved crop production.

RESEARCH PROGRAM

West Africa is made up of ancient crystalline rocks that have been above sea level long enough to be worn to plateau surfaces of highly indurated sediments of pre-Cambrium age which form the substrate. West Africa has no true fold mountains like the Alps of Europe. The alfisols south of the Sahara Desert consist mainly of Ustalfs. On the upper parts of the slopes, these soils have a loamy sand to sandy loam surface followed by a clayey horizon that contains a few iron nodules (ferric luvisols). Further down the slopes the surface soils tend to loams with restricted internal drainage. These alfisols have surface crusting problems and have rather poor structural properties because of lower clay and organic matter contents in the surface layers. However, iron concretions increase in abundance with depth which progressively impedes the internal drainage.

The alfisols at the Kamboinse Agricultural Experimental Station in Upper Volta for sorghum and millet production 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 the position in the toposequence. The 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 nitrogen and phosphorus.

Soil-Surface Management

The Kamboinse Station is situated 14 kilometers north of Ouagadougou. The climate at Kamboinse is very similar to Ouagadougou where the 60 year mean annual rainfall for Ouagadougou is 860 mm whereas it is only 762 mm for the 11 year mean annual rainfall at Kamboinse. The rainfall for 1981 was 700 mm and 717 mm for 1982. Therefore, for the 2 years of data presented in this report there has been a deficit in the annual rainfall. Periods of drought put a severe stress on the plants and if the soil surface has been puddled and crusted from previous rainfall, then the opportunity for infiltration with the oncoming rains is limited.

Soil Characteristics

The alfisols which were used throughout the study period, have the general characteristics as presented in Table 1.

Table 1. Average characteristics of alfisols for a loam (sorghum soil) and a sandy loam (millet soil) showing the percentage particle size fraction, bulk densities gm/cm³, hydraulic conductivity (K) cm/h, pH, percent base saturation (BS), and cation exchange capacity (CEC) me/100 gm of soil by depth.

Soil Depth (cm)	Particle Size Distribution			Bulk Density	K	pH	BS	CEC
	sand	silt	clay					
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

The water relationships for these alfisols can be summarized as:

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, the bulk density increases which is caused by either compaction or by the ferralitic gravelly materials that are formed at the lower soil depths. In addition, for these alfisols on the upper portions of the colluvium, the clay content increases with depth. Two factors which may govern this effect 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 the eventual loss of these fine particles due to erosion. Thus, as the clay content and the bulk density increase with depth, the rate of percolation is restricted. These relations can be put in perspective by reviewing the *in situ* lysimetric data for an alfisol in Upper Volta 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.

Basic Soil Physics of Tied-Ridges

The concept of zero-runoff implies that all of the precipitation remains on the soil surface until it infiltrates into the soil or is collected for future use. One of the techniques to have been used throughout Africa for retaining the rainfall in place is called tied-ridges or a slight modification termed micro-catchment basins. Tied-ridges consist of covering the soil surface with closely spaced ridges in two directions at right angles, so that the ground is formed into a series of rectangular depressions. In Upper Volta, ridges may be formed by tractor or oxen with ridgers; however, the ridges and ties are usually constructed by hand with the aid of the "daba", a short-handled hoe. Ridges should be constructed on grade with the ties lower than the ridges so failure and the sudden release of runoff will be along each contoured ridge and not down the slope.

Tied-ridges (10 to 20 cm deep) can be constructed as micro-catchment basins. That is, the ridges can be deep (30 to 40 cm) so that all of the water that falls or runs into them will be captured. In general, the differences between the two systems involves soil type and slope as well as maintenance and the amount of hand labor required to maintain the ties and dams after storms.

The ridges and depressions increase the potential for the storage of water on the surface and provide for runoff trapping, thus increasing the potential for infiltration and the storage of water in the soil profile. Tied-ridges can be a very effective system but they help to produce increased yields only when surface runoff occurs at a greater rate than infiltration; that is, when water is lost which is needed to refill the soil profile in the root zone. If the infiltration rate of the soil is adequate to replenish the soil moisture in the root zone during rainfall or within a day after rainfall then whether or not surface water is captured or permitted to runoff is 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 in the soil-air-water relation plus the eventual loss of plant nutrients by leaching. Also, when ponding occurs for an extended period of time, say 2 to 3 days after rainfall, 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 quite common to see algal blooms when ponding occurs for more than one day; that is, infiltration can be limited because of puddling and crusting of the surface soil. The puddling and crusting caused by raindrop impact and ponding necessitates cultivation to increase, or restart, infiltration.

Sorghum Production On Alfisols

In 1981, the sorghum research fields were designed to evaluate the effects of soil surface treatments as sub-subplots, and with and without plowing treatments as subplots, on the yield and growth characteristics of two varieties of sorghum (E 35-1 and local Kamboinse) as main plots. The soil surface treatments were as follows: flat planting; flat planting with rice straw mulch (6 t/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.

After the arrival of the rains, these alfisols were planted as soon as possible when the soil was at or near field capacity. On all of the studies presented in this report an application of 100 kg/ha of cotton fertilizer (14-23-15) was made just prior to seeding and a side dressing of 65 kg/ha of urea was applied about a month later. All plots were 5 m x 10 m with each variety planted in rows spaced 80 cm apart. The E 35-1 was seeded in pockets 30 cm apart within the row with two plants per pocket at a rate of 90,000 plants/ha. The local Kamboinse variety was planted in pockets 45 cm apart within the row with two plants per pocket at a rate of 60,000 plants/ha.

The ridges were tied or dammed immediately after germination followed by the addition of the rice straw mulch. The tied-ridges had to have some maintenance on the ties twice during the growing season. Severe storms tend to wash and erode the ties which eventually leak and, without maintenance, they will not function properly as a water catchment device.

Table 2. Effect of plow treatment, sorghum variety and soil surface treatment on yield of grain (t/ha).

Flow Treatment	Sorghum Variety	Soil Surface Treatment (c)							Flow Versus Variety Means (b)
		Flat	Flat With Mulch	Flat Cult.	Ridges Open	Ridges Open/Mulch	Ridges Tied	Ridges Tied/Mulch	
Flow	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 Sorghum 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).

Table 2 shows the plot yield of the sorghum expressed as grain weight (t/ha). The yield more than doubled by using mulch over the traditional flat planting method for the E 35-1 and the local Kamboinse varieties on the plowed treatment. Similar trends in yield were found for the non-plowed treatment except that, in general, yields tended to be lower. There were no significant differences in yield between the open and the tied-ridges for the same treatment level, that is, mulch versus no mulch. The 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 the local Kamboinse for similar treatments. When the flat planting was cultivated after each rain, a slight but not significant increase in yield occurred when compared with the flat planting without cultivation.

The design for the 1982 sorghum experiments have the main plots with the same two varieties of sorghum as in 1981. The levels of rice straw mulch applied were at the rates of 0 t, 10 t, 15 t, and 20 t of dry material/ha and the row spacings of the ridges were 0.50 m, 0.75 m, 1.00 m, 1.25 m, and 1.50 m with all ties at the 1.00 m spacing and about 15 cm in depth. These plots were randomized into complete blocks of six replications.

During this season, both sorghum varieties were planted at a spacing of 0.22 m between pockets and thinned to one plant per pocket. The planting rate varied as to the spacing of the ridges; that is, at a spacing of 0.50 m the planting rate was 105,000 plants/ha, at 0.75 m spacing the rate was 66,000 plants/ha, at 1.00 m spacing the rate was 40,000 plants/ha, and at both the 1.25 m and the 1.50 m spacing the planting rate was 27,000 plants/ha.

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Table 3. Effect of size of catchment area (m) and sorghum variety on grain yield (t/ha).

Sorghum Variety	Size of Catchment Area (c)					Variety Means (b)
	0.50	0.75	1.00	1.25	1.50	
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 areas 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).

Table 3 presents the mean grain yield in t/ha for each sorghum variety in relation to the size of the catchment area. As the rice straw mulch was added late in the growing season, the effect of mulching was statistically non-significant on all collected data sets and; thus, 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 the middle of August.)

The yield at the 0.50 m row spacing is nearly double to that at the 1.50 m row spacing. The E 35-1 responded to the size of the catchment area at a greater rate than did the local Kamboinse variety. The relatively low yield of the local variety is partly attributable to the late date of planting. In addition, the yield response to the size of catchment area is complicated because of the variable stand density which ranged from 105,000 plants/ha at the 0.50 m spacing to 27,000 plants/ha at the 1.25 and 1.50 m spacing. These data suggest that the smallest catchment area significantly increased yield for both varieties.

2

Table 4. Effect of size of the catchment area (m) and sorghum variety on the total plant dry matter (t/ha).

Sorghum Variety	Size of Catchment Area (c)					Variety Means (b)
	0.50	0.75	1.00	1.25	1.50	
E 35-1	14.3	10.3	9.6	7.8	6.6	9.7
Local	14.8	11.8	10.7	10.0	7.8	11.0
Means (a)	14.5	11.2	10.2	8.9	7.3	

a: LSD, 5% = 1.3

b: LSD, 5% = 0.5

c: LSD, 5% among size of the catchment area for same variety = 3.8
among same size of catchment area for different varieties = 1.4

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

1. varieties -- significant (F = 25, df = 1/23);
2. size of catchment area -- significant (F = 33, df = 4/99).

The means of the total dry matter per plant (t/ha) as related to the size of the catchment area and sorghum variety is shown in Table 4. There was a significant increase in dry matter production at the 0.50 m plots for E 35-1 and for the local Kamboinse variety at both the 0.50 m and 0.75 m plots. Both varieties increased in quantity of dry matter at nearly the same rate as the catchment area was reduced. Although, the production of grain was greater for E 35-1 as the catchment area decreased than for the local Kamboinse variety, the production of dry matter was the same for both varieties as the catchment area decreased.

The plant index was determined which showed that E 35-1 with 38.5% was a more efficient grain producer than local Kamboinse which had a plant index of 20.8%. Therefore, as the plant index is a comparative efficiency rating, it shows that E 35-1 is more energy efficient than local Kamboinse.

Millet Production On Alfisols

In 1981, the effect of soil surface treatments for water conservation on the subsequent production of two varieties of millet (Ex-bornu and local Kamboinse) were compared to the following soil surface treatments: (1) flat planting; (2) open-ridges; (3) tied-ridges; and, (4) tied-ridges with rice straw mulch (at a rate of 6 t/ha).

The field was seeded 2 days after a rainstorm with rows spaced 80 cm apart. The Ex-bornu variety was planted with one plant per pocket spaced every 30 cm and at a rate of 45,000 plants/ha. The local Kamboinse variety was planted with one plant per pocket spaced every 45 cm and at a rate of 30,000 plants/ha.

The sandy loam was easier to manage than the loam while constructing the tied-ridges; however, these sandy loams tend to "melt" easily under driving rainstorms and maintenance is increased. During this study, the tied-ridges were reformed 3 times throughout the growing season.

Table 5. Effect of millet variety and soil surface treatment on yield by grain weight (t/ha).

Millet Variety	Soil Surface Treatment (b)			
	Flat	Ridge Open	Ridge Tied	Ridge Tied/Mulch
Ex-bornu	0.24	0.30	1.15	0.62
Local	0.14	0.12	0.36	0.65
Means (a)	0.19	0.21	0.75	0.63

a: LSD, 5% = 0.15

b: LSD, 5% for different SST's and the same millet variety = 0.22;
for the same SST and the different millet varieties = 0.23.

The analysis of variance showed:

1. varieties were significantly different (F = 18.42, df = 1/16);
2. soil surface treatments were significantly different (F = 23.77, df = 3/16);
3. interaction between soil surface treatments and variety was significantly different (F = 12.72, df = 3/12).

The yield of millet expressed as grain weight (t/ha) for millet variety and soil surface treatment is shown in Table 5. 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.

The 1982 millet study tested the effect of the size of the catchment area in relation to the quantity of mulch on three varieties of millet (Ex-bornu, Souna-3, and local Kamboinse) which were arranged in randomized complete blocks. There were four levels of rice straw mulch (0 t, 10 t, 15 t, and 20 t/ha) and five levels of tied-ridges with rows spaced at 0.50 m, 0.75 m, 1.00 m, 1.25 m, and 1.50 m with all ties at the 1-meter length.

All three varieties were planted at the same spacing of 0.22 m between pockets and thinned to one plant per pocket at a rate of 105,000 plants/ha at the 0.50 m row spacing; 66,000 plants/ha at the 0.75 m row spacing; 40,000 plants/ha at the 1.00 m row spacing; and, 27,000 plants/ha at both 1.25 m and 1.50 m row spacing.

Table 6. Effect of size of catchment area ² and millet variety on grain yield (t/ha)

Millet Variety	Size of Catchment Area (c)					Variety Means (b)
	0.50	0.75	1.00	1.25	1.50	
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 same variety = 0.40

among same size of catchment area for different variety = 0.64

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).

The means of the grain yield (t/ha) are presented in Table 6 for each millet variety in relation to the size of the catchment area. As previously mentioned, the effect of mulching was non-significant and these data will not be presented.

The millet yield was affected by downy mildew especially in the 0.50 m and 0.75 m row spacings with the local Kamboinse variety the most severely affected throughout all treatments. The plot yields ranged from a high of 3.22 t/ha for the Souna-3 to a minimum of 0.81 t/ha for the local Kamboinse variety. These data suggest that the 1.00 m spacing was the most satisfactory for millet production. In addition, Souna-3 produced significantly more grain than Ex-bornu and both of these varieties produced significantly more grain than the local Kamboinse. Unlike the sorghum data, there appears to be little, if any, evidence of plant density affecting the relationship of grain yield to the size of the catchment area.

2

Table 7. Effect of size of catchment area (m) and millet variety on total plant dry matter (t/ha).

Millet Variety	Size of Catchment Area (c)					Variety Means (b)
	0.50	0.75	1.00	1.25	1.50	
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 same variety = 1.06

among 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).

Table 7 shows the relation of the means for the total plant dry matter (t/ha) to the size of the catchment area and the millet variety. The local Kamboinse variety produces the greatest amount of dry matter at

5.26 t/ha followed by the Ex-bornu with 4.25 t/ha and lastly Souna-3 with 3.61 t/ha. Also, the closer row spacings produced significantly more dry matter for the Ex-bornu and Souna-3 varieties than the 1.25 m or 1.50 m row spacings.

Souna-3 had the highest plant index of 62.5% and was the most efficient grain producer; that is, less energy was used in the production of dry matter. Ex-bornu had 50% and the local Kamboinse had a plant index of 16.2%. However, at harvest, the stalks of Souna-3 contained the highest moisture content at 68.7% followed by Ex-bornu at 61.3% and the local with 61.0%.

Animal Traction Program

The use of domestic animals for draft power has had a major impact on the history of the SAT (Semi-Arid Tropics) in French West Africa. The terrace, tied-ridge, and furrow systems of cultivation have been introduced as the major methods of increasing yields using soil-water management techniques. Construction by hand is difficult, if not impossible; nevertheless, these systems could be implemented with the use of animal drawn tillage equipment.

Whereas the use of draft animals has been predominantly for cultivation throughout the remainder of the world, here in Upper Volta, cattle are traditionally limited to animal husbandry. In most cases, cultivation of crops and animal husbandry are performed by two separate groups of the rural population, e.g., the farmers and the stock-raisers. In general, the stock-raiser herds the animals but does not operate agricultural farm implements as the farmer does.

Oxen (zebu breeds) and donkeys are the main source of animal power in Upper Volta. Studies in Upper Volta, which delineate productive capacity when the farmers use animal traction tend to separate animals only according to species (donkeys, camels, oxen, horses, etc.) and tend to ignore the high variability that exists within species. In order to insure effective use of draft animals, a thorough understanding of the animal's power, speed, and endurance is needed throughout various seasonal and working conditions. As not all draft animals have the same capacity to work, these measures warrant intense documentation.

The training of six animal traction operators for the Soil-Water Management Program has been carried out on a continuing basis. In addition, several pairs of oxen and donkeys have been trained for work in the experimental areas with traditional and drawbar equipment. The equipment for earth moving projects has been designed, manufactured and, in some instances, purchased for constructing roads, terraces, field plot levelling, and contoured ridges (open and tied). The animal traction personnel are being trained to design and implement field trials at the experiment station and on farmers fields for the most efficient use of

Soil-Water Management techniques.

Water Harvesting Program

A team of technicians has been trained to survey and layout rainfall-runoff plots to measure the effect of soil surface treatment on slope, evapotranspiration, chemical losses, seepage losses and erosion losses. An interactive computer program has been completed which will be used for simulating the hydrologic characteristics of watersheds will be calibrated and verified using the data from the 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 will be used in the design and layout of hydrologic agricultural management systems and water harvesting projects at the village level.

SUMMARY AND RECOMMENDATIONS

An evaluation of the SAFGRAD Phase I project of the Soil-Water Management Program in Upper Volta was carried out in the Fall of 1980. The results of this evaluation were extremely positive as to ICRISAT's progress in the research program of Soil-Water Management. In general, all tasks of the phase I program have been investigated, implemented, and, where possible, analysis has been completed and reports are being written for eventual publication. Examples of the performance of the soil-water research program are given as follows:

The soil surface management studies were designed to investigate the relative size of the catchment area using tied-ridges and the effectiveness of different quantities of crop residues for mulching on several varieties of both sorghum and millet. The 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., etc., were measured and analyzed to aid in data interpretation.

During rainfall, it was observed that mulch improved infiltration by two distinct methods: one, by reducing raindrop impact; and the other, by increasing termite and biological activity. The straw absorbs the impact of the raindrops and no puddling or muddy water was observed in the catchment area. A typical rainfall in Upper Volta may have an instantaneous intensity of about 1000 mm per hour where the raindrops fall at a velocity of about 60 cm/sec. Without a mulch, the energy of the water falling at this velocity is absorbed by the bare soil surface and, as expected, these falling raindrops break down and disperse soil aggregates. When the bare soil surface is covered by a thin film of

water, the force of the raindrops striking the surface causes the water film to become puddled or muddy. As surface water infiltrates into the soil, the puddled soil particles are filtered out in the surface layer. This process rapidly impedes water flow into and through the soil pores. This thin dense layer has a much lower infiltration rate (estimated to be more than 2000 times lower) than the soil had before the rainfall started. When this process is permitted to continue it causes surface sealing and compaction which reduces infiltration and may increase surface runoff. However, tied-ridges or microcatchment basins store water and if puddling and surface sealing is severe, then this stored water is essentially lost through evaporation.

The mulch encouraged termite activity and biological activity at the soil surface. The termite activity started to consume the plant material immediately after it was placed on the catchment area. Thus, surface water collected from the rainfall entered the soil through micro-holes or pores made by the termites. The termites consume the mulch material at a rather slow rate and by the end of August only a small amount of the debris remains. Rainfall was never observed to accumulate and runoff from the tied-ridges which were protected by the mulch. Also, the termites consumed only the rice, sorghum and millet dry mulch material and did not attack the growing plants. During the termite activity, large amounts of clay materials were transported from the deeper horizons to the surface which should, in time, benefit the upper layers of these sandy surfaced alfisols.

Biological decomposition also started immediately after the first rainfall. As these materials are decomposed and digested by soil organisms, their by-products become a part of the underlying soil horizons by infiltration. The biological activity increases the micro-pores in the soil profile, thus providing another pathway for the entry of water into the root zone.

During heavy rainfall, water puddled on all the plots without mulch. Standing water remained in the tied-ridge plots without mulch for up to 3 days after rainfall ceased and algae formed in the bottom of the tied ridges. No standing water was observed to remain shortly after rainfall in the tied-ridge plots with straw mulch. Nearly all of the straw mulch was decomposed by harvest time and it did not interfere with post harvest operations.

By using a mulch, yields will be significantly increased over traditional flat plantings in spite of the method chosen for water catchment: flat, ridged or with tied-ridges. The best treatment was the use of tied-ridges with mulch; however, tied-ridges provided the most satisfactory yields when mulch was not used. During the mid-season droughts on all treatments using mulch, the plants showed less stress, as observed by color and curling of leaves, than those in the other treatments. When no plowing was done, E 35-1 was affected severely by loss of seedlings which resulted in significant yield reductions;

nevertheless, a great deal of this seedling loss was circumvented when mulch was applied.

The traditional method of planting on flat bare surfaces restricts yield and 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%. Although the yield of Ex-bornu was depressed by pollen wash, the other growth characteristics were greatly improved by using mulch.

Local varieties are well adapted to environmental conditions and the low level of management usually found in most parts of Upper Volta on alfisols. The exotic varieties will provide a much greater yield response in relation to an increase in work effort; whereas, more work does not necessarily mean a greater yield response for the local varieties.

The use of tied-ridges on alfisols reduces the amount of weeding necessary. During rainfall, water may pond in the tied-ridge plots for 2 to 3 days after a rainfall making the environment extremely poor for seedling growth and development and, thus, easier to control weeds. When mulch is used, then the work of weeding is further reduced without the resultant ponding and puddling that is associated with tied-ridges without mulch. Mulching shades the soil surface of the catchment area which, in turn, creates a poor environment for weed development.

The recommendations based on the analyses of these studies can be summarized as follows:

1. Mulching with crop residues has been shown to be extremely effective, especially under no-till conditions.
2. The use of tied-ridges reduces water lost by surface runoff and subsequently increases yield.
3. More yield results from better surface water management, better varieties, more fertilizer, and, unfortunately, more actual hours of labor.
4. The use of Animal Traction as a source of draft power can be used to construct terraces, contour ridges, drainage ditches, and many other water conveyance and storage projects.

FUTURE RESEARCH PLANS

Short Range Plans

To continue to develop and improve techniques of water use efficiency, controlled field plot studies will be implemented employing water harvesting technology and soil conservation practices for rainfed agriculture. The following areas of concern will be studied:

1. The design and construction of terraces will be used for a demonstration project. The use of terraces is the ultimate method for the control of erosion and the management of water.
2. Tied-ridges and water conveyance systems will be implemented in small projects at the farmers' level. These designs are based upon the controlled research results obtained at the Kamboinse Agricultural Experimental Station.
3. Controlled studies will be used to evaluate the tied-ridge techniques for evaluating the effects of anti-transpirants, mulches, and crop varieties on drought. In Upper-Volta, the effect of drought can occur any time during the rainy season and if it extends for more than 10 days, it is considered severe.
4. The animal traction program at Kamboinse will continue to assist in the establishment of soil-water management and conservation programs. Because most of the energy for agriculture is produced by human labor, very few conservation programs have been initiated. 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 will be to coordinate an integrated program of soil-water management with the national scientists taking an increased role in it's implementation and development. The research trials will be based on findings from the Phase I studies and these findings will be translated into a technology at the

farmer's level which can be readily adopted by the farmers. The water harvesting farm layout design will incorporate all of the necessary soil-water-engineering information available to develop a comprehensive system to insure a complete evaluation of the techniques of soil and water conservation. Reports will be written concerning each element of the hydrologic farming system, delineating specific items which are supportive of technological transfer. Information from these studies will also serve to increase the baseline data source for the Sahel. The adoption of these findings at the farmers' level may require extension activities that are not within reach of the planned project staff; nevertheless, such activities will be monitored to promote feedback for evaluation of problem areas.

Animal Traction Program:

Animal traction is playing an increasingly important role in the agriculture of the Sahel; in fact, the sale of the animal draft equipment is increasing at an exponential rate. During Phase I, it has been demonstrated at the Kamboinse Experimental Station that there are improved animal traction equipment and management techniques available which can reduce the operation time and human power requirements for growing crops.

The effectiveness of the animal traction studies of the Soil-Water Management Program in Upper Volta could be greatly improved with the addition of an Agricultural Engineer (national scientist). A Ph.D. (or an M.S. with experience) in agricultural engineering should have a specialty in animal traction and/or power and machinery. This national staff member should be well versed in animal traction research and development to maintain on-going cooperative research, develop and implement new research efforts, assist with on-the-job training programs, and direct the work loads of supervisory staff and field managers.

Tied Ridge Studies:

Basic research studies will continue to be conducted at the Kamboinse Experimental Station where variables can be controlled and techniques using microcatchment of water can be evaluated. These studies would emphasize the use of terraces, tied ridges, contour ridges, and the utilization of crop residues for mulching under no-till and tillage operations. In Phase II, greater emphasis will be placed on the drought tolerance of various crops as to 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, micro-wells for supplemental irrigation and many others will be examined and evaluated as to effectiveness in increasing crop production and decreasing risk of crop failure. In many cases these studies will 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 utilization studies.

Rainfall-Runoff and Water Harvesting Techniques:

Water is the single most important resource limiting crop production in the Sahel. Its conservation and efficient utilization 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 inducement and collection of runoff (water harvesting), but also upon efficient utilization of the water by agricultural crops. The uncertainties of rainfall-runoff events are difficult to reconcile with crop requirements; thus, it is crucial to choose the kind of crop and the management system that can make the best use of long term water storage in the soil. Optimal water storage in a soil requires that an adequate amount of rainfall should infiltrate into the soil to the root depth with the remainder of the water stored in a catchment area for later distribution and use.

Water harvesting techniques will 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 for isolated areas will be developed in conjunction with the animal traction program. Demonstration projects will be implemented at the village level in areas representative of rainfall patterns within the Sahel Ecological Region.

Training of Scientists and Technicians:

The program for Phase II needs to provide University training for the Undergraduate as well as University training of selected students at the graduate level to the Ph.D. or Masters degree in the area of Soil-Water Management. In addition, 5th year thesis students should be actively recruited to prepare dissertation problems in Soil-Water Management research areas. The ICRISAT Center in Hyderabad, India, can provide additional technical training in agricultural research to those staff members who have completed their secondary education. An effort should be made to assist and provide opportunities for staff personnel to complete their primary and secondary schooling certification. Short courses on specific topics in the area of Soil-Water Management should be made available for qualified staff members. On-the-job training programs should be a continuing and on-going effort throughout the Phase II program.

PUBLICATIONS AND REPORTS:

A monitoring procedure throughout Phase II will evaluate the associated progress and development of the implemented research studies. Reports will be written concerning 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, and the use of mulch and anti-transpirants, and water harvesting and supplemental irrigation systems. The research results will be prepared for publication in professional journals. In addition, instructional manuals and brochures will be written supportive of technological transfer. Detailed graphic designs and displays of the on-going and completed project activities will be prepared for use as visual aids and instructional packages.

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THE SOIL-WATER MANAGEMENT PROGRAM OF UPPER VOLTA

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