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WATER CONSERVATION AND USE PATTERNS IN THE TRADITIONAL CROPPING SYSTEM OF EASTERN BOTSWANA

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Sorghum, Sorghum bicolor L., grain yield and return per mm rainfall were assessed as functions of plowing and planting dates, traditional tillage systems, rainfall and land type in farmer implemented trials over a five season period of drought. Land type categories were based on characteristics of soil profile and topography. Tillage systems included single and double plowing with broadcast seeding. Early plowing was more important than planting date or plowing system in determining grain yield and return to rainfall. High potential sites combining high water holding capacity, natural water run-on potential with surface and internal drainage produced highest yields and yield returns. Upland deep coarse loamy sands also give good yield response under drought in spite of low water holding capacity. Restricting ferric and calcic sub-soil strata limit yield responses to rainfall and to double plowing tillage system. Early plowing benefits yield responses for all land types. Regression models with significant variables were constructed for double and single plowing systems. Approximately 60 percent of yield variation can be explained through dates of plowing, season rainfall and land type. Implications for the traditional farming system are discussed.

A system of broadcasting seed on untilled land followed by one plowing (moldboard or disc) is practiced on more than 95 percent of the area cultivated in the Mahalapye area of eastern Botswana (MOA, 1985a). Sorghum, Sorghum bicolor (L.) Moench, the dominant crop both in mixed and sole plantings, has produced an average of 161 kg/ha in monitored plots over five seasons under this system, with a coefficient of variation of more than 12 percent.

Variable and often low annual rainfall (60 year average of 465mm for Mahalapye) with erratic intra-seasonal distribution is a major hazard for rainfed production. The yield response to rainfall on a District average basis, was calculated by Vossen (1987). Average farm sorghum grain yields were closely related to total season variation but with a heavy weighting for January-February rainfall. These calculations indicate that traditional yield averages only reach 250 kg/ha with an above average 500mm (P<0 35 at Mahalapye). During drought, area yield averages fail to reach 10 kg/ha (MOA: 1985a).

DLFRS (1985) showed a good linear relationship between sorghum research plot yields and seasonal rainfall with an incremental increase of 3.49 kg/ha/mm above a minimum rainfall threshold at 60,000 plants per ha. This corresponds to an average return of 2.9 kg/ha/mm at 300mm rainfall for a season. This is approximately five times the average return measured on-farm. Gaining a better understanding of the discrepancy between station and farm results as well as of differences occurring between farms is a major challenge for the research program of Botswana.

Soils, weather and management interact to affect soil moisture and cropping potential. Except following tillage, surface bulk densities tend to be high, those of certain Luvisols reaching more than 1.8 (Soil Conservation Service - USDA, 1987). Plowing will temporarily increase infiltration of several soil types, as measured by wetting depth in the soil, by more than 35% early in the season (ATIP, 1986). The effect of landscape on soil moisture retention and availability in eastern Botswana is

not well documented.

This purpose of this paper is to evaluate practices occurring in the traditional farming system that relate to water conservation and improved rainfall use efficiency, particularly during drought. Included are early plowing, double plowing and land selection. The effects of these management and landscape/soil factors are compared with several rainfall variables to determine their relationship to grain yield and to rainfall use efficiency.

MATERIALS AND METHODS

Data for this study were obtained from eighty farmer implemented trials conducted over a five season period in three village areas. A comparison of plowing systems was super-imposed onto the farmer's normal practice. Non treatment variables were set at a typical level or left to the discretion of the farmer.

Tillage comparisons were between large adjacent strips with implementations across farms constituting replications in the analysis. Harvest outcomes were assessed on a standard sample of 96 m@|2|@/plot using a quadrat sampling procedure (Siebert, 1985).

Sole sorghum was used at all sites with all but three v.Segaolane. Plots were broadcast planted at a uniform seeding rate of 6kg/ha. Thinning or gap-filling was not done on measured areas as plant establishment was considered to be part of the response to treatments.

Two basic tillage systems were included. These were a broadcast followed with a single plowing (single plow-planting) and an early sole plowing with a broadcast and second plowing following some accumulation of moisture in the soil profile (double plowing). In addition to the double versus single comparison, there were 38 pairs of early and late implementation of single plow-planting corresponding to the two days of operations with double plowing. Early plow-planting outcomes provide a measure of the opportunity cost of sole plowing.

Soil, landscape and weather were evaluated by research staff. Soil texture, soil pH, restricting sub-soil strata and slope were measured at all sites. Surface drainage ratings were made in consultation with host farmers. Double ring infiltration rates were measured on a sub-sample of sites. Locations in the landscape were determined from aerial photographs. Seven land type categories were tentatively identified.

Five rainfall parameters were calculated for each planting. RF.arable season gives rainfall from September 1 to harvest, RF.preplw gives rainfall prior to first plowing, RF.crop growth from planting to harvest, RF.plowed soil from first plowing to harvest and RF.plw-plt for the period of water conservation between early plowing and plow-planting when double plowing.

RESULTS AND DISCUSSION

Early plow-planting and early plowing have been consistently linked with good single plow-plant and double plowing yield outcomes (Table 1). This relationship is important for area farming. Monitoring of farm activities has shown that even though field work can begin in October or early November, more than 50% of the cultivated area is single plow-planted after December 15. On average, following this date, more than 50% of total season rainfall has fallen before plowing. Pre-plowing weed growth after

this date averages 59% cover of land area resulting in additional water losses and poor broadcast single-plow seedbeds. Farmers who are dependent on hired traction are most affected by delayed operations (ATIP, 1986).

During this study, total season rainfall averaged just above 300mm ($P<0.24$). Individual field amounts ranged from 200 to 450mm. This was not a sufficient range to permit the establishment of a yield response for a full range of seasons. Partitioning of season rainfall (RF.season) into pre-plowing and crop growth components gives interesting indications of how two tillage systems utilize rainfall (Table 1). Single plow-planting yields are only related to rainfall during crop growth. In double plowing, early sole plowing contributes a moisture conservation phase that along with rainfall during crop growth translates into the level of grain yield. These results show that early plowing (plow-planting or sole plowing) and not early planting, per se, result in higher yields during drought.

The plowing treatment in these comparisons should not be considered independently of the date of first plowing. Double plowing has consistently given higher grain yields than single plow-planting planted on the same day, though this comparison does not consider that first plowing occurs earlier in double plowing. Earlier single plow-planting could provide nearly the same benefit and be less costly to farmers. When the plowing treatment effect is adjusted for first plowing date, double plowing provides no statistically significant benefit. In an ANOVA with the residuals of grain yield regressed on plowing date as a response to plowing treatment, the probability for significance of the benefit of double plowing is 0.179.

Results given in Table 2 show that land type categories, relating to soil texture and depth along with topography, are a major determinant of grain yield and of how well rainfall is utilized. Highest kg/ha returns per mm of season rainfall in Table 2 compare reasonably well with expected returns in research station work where levels of management and input are much higher.

Negative effects on rainfall utilization are due to alluvial and to restricted upland Luvisol land types. Drainage problems at many alluvial sites (less than 0.5% slope with sandy clay to sandy clay loam surfaces) persist even in drought. The potential for major water run-on is underscored by the frequency of intense showers even during drought. Twenty-four hour event showers of 65mm or more are expected at least once in 75% of all seasons (ATIP 1986). Area farmers generally lack the resources to provide drainage on these soils. Nevertheless, management of these soils deserves attention because of the relatively high fertility status they possess.

Luvisols with restricting sub-soil strata are common in the Mahalapye area. Ferric (within 50-75cm of surface) and (petro-) calcic (within 60-90cm of surface) layers cause problems because because they limit water storage capability and restrict rooting. This explains the failure of these soils to respond to additional moisture from double plowing. Plinthic concretions in the case of ferric Luvisols do not impede water movement as much as limit root exploration.

The situations of lower (0.5 to 1.5% slope) to middle (1 to 2% slope) slopes on well defined pediplains and upland deep coarse loamy sands both provide for relatively successful utilization of rainfall though the method of utilization differs considerably. Grain yield levels on these sites are higher and more consistent during drought than on other types.

Coarse deep loamy sands profiles have low (5% volumetric) water holding capacities but with a total water storage spread over more than 3m. Wetting to depth is more rapid in these soils than in heavier textured sandy loams. Rooting is also assumed to be easier. The poor land capability rating of such soils in Botswana should be reconsidered. A positive response to double plowing indicates the importance of tillage for water infiltration on these soils in spite of their coarse texture. Under high rainfall, the limited storage capacity of these soils may reduce the benefit derived from early plowing.

Lower slopes and to a lesser extent middle slopes possess soil profiles with sufficient clay content to store water at medium depths but with adequate surface and internal drainage to provide a satisfactory air regime for sorghum. Water run-on from watershed areas on the same field or above the field contribute to the water status in these soils. The combination of drainage, water storage and water run-on characteristics of these sites would indicate a high potential for production in a range of rainfall circumstances. Farmers would do well to focus investments of other inputs such as fertilizers into these land types with less limiting soil water status.

Upland sandy loams are highly variable as are yield outcomes on this land type. Sub-soil textures vary from sandy loam to sandy clay loam with considerable variation in water holding capacity. Water movement at the surface is more determined by micro-relief factors than by macro-topography.

In Table 3, the relative importance of management factors, rainfall and land type are evaluated for single plow-planting, double plowing and combined grain yields. R2 for the regression models are good given that distribution of rainfall during the cropping cycle is not considered. Early operations are important as is season rainfall in determining grain yield. These results also show that land type categories given in this paper are useful determinants of grain yield under drought.

According to these findings, several statements can be made for resource poor farmers in the Mahalapye area. Farmers should increase the area plowed early in the season. To achieve this, plowing and planting operations can be separated. Sole plowing for later double plowing is a good option for days in the early season when soil moisture isn't adequate for plow-planting. As row planting resources become available, early plowing followed by row planting should be encouraged. Double plowing should not be focused on certain upland soils with restricted water storage capacity. Greater research attention should be given to targeting for specific land type situations.

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Table 1. Correlation coefficients for the relationships between grain yields and dates of plowing, dates of planting and rainfall parameters.

Management and rainfall factors	Grain yield		
	Single plow-planting	Double plowing	Overall
Date of planting	-0.48***	-0.41***	-0.41***
Date of plowing		-0.44***	
RF.arable season	0.14	0.17	-0.17
RF.crop growth	0.44***	0.30**	0.18
RF.plowed soil		0.37***	
RF.plw-plt		0.24*	

*P<0.05, **P<0.01, ***P<0.001.

Table 2. Effects of land type and plowing treatment on sorghum grain yield and returns to mm. total season rainfall.

Land type	Single plow-planting			Double plowing		
	kg/ha	C.V.%	kg/ha/mm	kg/ha	C.V.%	kg/ha/mm
Alluvial flat	33	181	0.11	82	120	0.27
Lower slope	551	56	1.75	627	49	2.08
Middle slope	232	67	0.91	302	94	1.09
Upland sandy loam	112	104	0.33	179	80	0.53
Upland deep coarse loamy sand	309	36	1.08	512	34	1.58
Upland ferric Luvisol	232	81	0.65	129	80	0.38
Upland calcic Luvisol	44	223	0.13	45	245	0.14
Mean	181	112	0.60	224	108	0.73
L.S.D. (0.05)	45		0.13	57		0.18

Table 3. Multiple linear regression models for on-farm grain yields overall, under traditional plow-planting and under double plowing.

Independent variables	b(i)	s(b)	t-value	b(0)	Model R2
	Overall model				
Planting date (julian)	-2.57	0.38	-6.7***		
RF.arable season (mm)	0.69	0.19	3.7***		
Calcic Luvisol dummy	-80.67	29.57	-2.7***		
Upland deep loamy sand dummy	244.49	33.81	7.2***		
Middle slope dummy	113.44	25.87	4.4***		
Lower slope dummy	377.76	36.50	10.3***		
Plowing treatment dummy	112.00	20.32	5.5***		
				159.0	0.572***
	Single plow-planting model				
Planting date (julian)	-2.71	0.42	-6.1***		
RF.arable season (mm)	0.64	0.23	2.8***		
Upland calcic Luvisol dummy	-62.85	34.37	-1.8*		
Upland ferric Luvisol dummy	98.16	50.95	1.9*		
Upland deep loamy sand dummy	225.00	38.57	5.8***		
Middle slope dummy	123.30	31.79	3.9***		
Lower slope dummy	397.06	43.25	9.2***		
				199.4	0.640***
	Double plowing model				
Plowing date (julian)	-1.33	0.56	-2.4***		
RF.arable season (mm)	0.99	0.34	2.9***		
Upland deep loamy sand dummy	409.20	85.10	4.8***		
Upland sandy loam dummy	85.97	43.49	2.0*		
Middle slope dummy	245.21	53.56	4.6***		
Lower slope dummy	491.14	69.49	7.1***		
				-100.6	0.603***

*P<0.05, **P<0.01, ***P<0.001.