SIMULATING THE EFFECTS OF DOUBLE PLOWING AND DATE OF PLANTING ON SORGHUM YIELDS IN BOTSWANA

by

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This is dedicated to Christopher Julian Davis whose loyalty, friendship, and love are an inspiration. He has been with me every step in this process, listening, advising, commiserating, and rejoicing, and for that I will always be grateful.

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LITERATURE REVIEW

Agriculture is important for economic growth in many developing countries; as agriculture grows and becomes more productive, the other economic sectors grow as well. Unfortunately, agriculture in Botswana is weak and unstable; Botswana must import most of its food (Riches). Eighty percent of Batswana are subsistence farmers; they grow corn, millet, beans, and other crops, but sorghum [Sorghum bicolor (L.) Moench] is the primary crop. Over half the 200,000 hectares planted each year from 1979 to 1985 were planted to sorghum. The average total sorghum production in this time span was 13,000 metric tons or about 160 kg/ha harvested (Anon., 1985b). About 30% of traditional (non-commercial) planted hectares failed (Riches). These sorghum yields are quite low compared to similar regions in Australia which yield 500 to 4000 kg/ha (Clewett, 1985). Over 1200 kg cereal grain and 130 kg legume grain per year are consumed by a family living at the subsistnece level (Riches). Rainfall in eastern Botswana would allow for yields over 2000 kg/ha in most years (Lightfoot, 1979);

research shows that sorghum yields can exceed 4000 kg/ha (DLFRS, 1978).

Climatic conditions play an important role in areas where water demand by crops exceeds precipitation, Worman et al.(1988), and this is especially true in Botswana. In most regions, yield from a particular field can be estimated if the fertility, and date and rate of planting are known. In Botswana, however, "the chance effects of the weather tend to be predominant over those of soil and technology, and the potential of a site at planting may, quite literally, be anything between zero and 2 t/ha or more depending on subsequent weather" (DLFRS, 1978).

While precipitation may be adequate for crops, little moisture is available due to high evaporation and high runoff. The rainy season coincides with the growing season, lasting from October to May. Yearly rainfall averages about 250 mm in the southwest, less than 400 mm in the central part, and 400 - 600 mm in the northern part, with greater than 650 mm in the northwest. Potential evapotranspiration is high--1500 to 2000 mm compared to an average of 500 mm precipitation. Rains are intense and of short duration, so much of the moisture--estimates can run as high as 70%--runs off. Soils are prone to crusting and have low infiltration rates as well, increasing the amount of runoff, so soil moisture is a limiting factor in crop growth, Virmani and

Kanemasu (1988).

To cope with these stringent conditions, farmers have adapted by planting after each planting rain--a rain greater than 10 mm. This ensures adequate soil moisture for germination and establishment, reduces risk by spreading out the planting dates, and takes advantage of different climatic conditions.

Eighty-five percent of the farmers in Botswana use traditional planting methods: They broadcast seed across the soil surface, often using a mixture of crops. Seventy-five percent of all sorghum is grown in mixed crop stands, usually with legumes. Seeds are then incorporated using a single furrow, animal powered, moldboard plow. Each family plants about 3.7 hectares, with a plowing time of about 15 hours per hectare (Riches).

Soils in Botswana are usually very sandy with low water holding capacity and about 1% organic matter in the surface layer. Clays are usually kaolinitic or illitic. The soils also have poor structure, poor fertility, and low infiltration rates; they compact easily and form crusts, Virmani and Kanemasu (1988). In the eastern part of Botswana, the primary crop area, three soil types are identified by traditional cultivators: Seloko, a heavy soil formed by deposition, Mokate, a medium-textured soil, and Mothlaba, a wind-blown sand (Persaud).

Soil factors seem to have played a large role in a sorghum row-spacing/population trial in Botswana. High population plots on a sandy loam showed severe drought stress and resulting yield loss. Yields peaked at populations of 63,000 plants/ha. On a loamy sand, however, high populations had higher water use than low populations, and yields peaked at populations of 140,000 plants/ha. From these results it was hypothesized that soil buffers a crop from drought, due to soil depth, water holding capacity, and rainfall infiltration (Jones et al., 1981). Another spacing study, however, concluded that it is not clay or water holding capacity that makes a difference in yields, but perhaps the infiltration rate, penetrability, or a combination of factors (DLFRS, 1985).

At the Sebele Research Station in 1983-1984, it was noted that sandy loams had poor emergence and establishment, while loamy sands successfully established crops. Loamy sands, having lower volumetric water contents than sandy loams, do not require as much moisture to wet to the rooting zone; a light rain would wet deeper in a loamy sand, resulting in greater water storage, more even distribution of moisture in the profile, and movement of water from even light rains to depths suitable for planting. In sandy loams, a light rain would barely wet the top layer. Sandy loams are preferred in Botswana due to their higher water holding capacities, but loamy sands may be better for more stable yields. Farmers do, however, choose a range of soil types to reduce risk (Anon., 1985a).

Compaction is another problem; the soils of Botswana are unstable and heavy rains quickly destroy existing structure. Because compaction is related to the particle distribution within a soil, the sandy soils are less likely to compact. Although these soils have relatively low water holding capacities, they at least allow for normal initial root growth. Often roots are restricted to the plowing depth due to high soil bulk densities (Anon., 1984).

Runoff also is closely related to the soil texture or condition. A 112 mm rain caused little or no runoff on a plowed loamy sand, but caused over 50% runoff in smoothed seedbeds and an unplowed sandy loam; 10 mm rains can cause runoff on unplowed plots. The threshhold intensity for runoff is 20mm/hr for a minimum of 15 minutes (Anon., 1984). After a 31 mm rain, plowed plots on a sandy loam had a wetting depth of 35 cm, while the unplowed plots had a wetting depth of 10 cm (Anon., 1985a).

Tied ridges, furrows blocked at intervals along the row to keep rain where it falls, is one method under testing for storing water in the soil. Tied ridges controlled runoff from a 70 mm storm on a 12% slope while the neighboring flat-tilled fields had about 40% runoff (Njihia, 1979). Tied ridges, rough plowed tilling, and other small scale conservation measures are very limited in water retention in heavy storms, however (Anon.,1984).

Farming systems teams are working with farmers in Botswana to find more productive agricultural methods. Because rainfall seems to be sufficient for crops, methods to retain precipitation--water harvesting--are sought. Double plowing, which consists of an extra preplant tillage operation in the fall or early spring, seems promising, and is the basis for many experiments. The reported effects of double plowing are improved soil moisture content, reduced stubble, fewer weeds, reduced compaction, decreased crusting, lowered runoff, increased infiltration and storing of pre-plant rains, easier planting conditions, and higher yields (Anon. 1983, 1984, 1985a; ATIP 1985, 1986).

Double plowing stored more water than other water harvesting methods such as tied ridges. After a 20.5 mm rain in mid-November, the double plowed plots had a deeper wetting depth than the single plowed or tied ridge plots. In addition tied ridges averaged soil temperatures 5 C higher than flat-tilled, and had greater evaporation due to greater surface area (Anon., 1985a).

Double plowing lessens the effect of crusting, a common problem in these poorly structured soils, which inhibits crop emergence, truncates seedlings, and prevents established plants' adventitious roots from entering the soil (Anon., 1984). Crusts on disked fields in Israel were also found to be twice as resistant to penetration as crusts on plowed fields, Hadas and Stibbe (1977).

The eighties have been a drought period in Botswana; experimental results from these years are good indicators of appropriate methods for dry conditions. In one study, sorghum yields in double plowed plots were significantly higher than yields in single plowed plots (Table 1). It was concluded that double plowing is beneficial regardless of water storage (ATIP, 1985).

Table 1. Effects of double plowing on sorghum grain yields 1983-1984.

Treatment	Yield	
	Trial A	Trial B
	(kg/ha)	
Double plowed	643	491
Single plowed	493	391
level of significance	5%	10%

Double plowing experiments at Francistown in 1984-85 resulted in a 262 kg/ha increase in grain yield over single plowing (traditional method); average plant populations were 17,761 plants/ha on double plowed plots, and 10,509 plants/ha for single plowed plots (ATIP 1985). These experiments repeated the following year showed double plowing improved grain yields 109% over single plowing. In on-farm trials for sorghum, millet, and cowpeas, double plowing improved yields 84% or 234 kg/ha (averaged across all crops) over single plowed plots (Heinrich, 1988). At Mahalapye, double plowing produced about 300 kg/ha more than single plowing. Double plowing was more successful when planting was followed by a dry period, when fields had not been regularly cultivated for several years, or when perennial weeds such as Elephantorrhiza spp. (mositsane) or Sida spp. (Moshrashagana) were a problem (ATIP, 1986).

The Francistown double plowing experiment also showed that the same amount of time was required to plow one hectare twice, as to plow two hectares once, and since the yield was roughly doubled,the ratio of yield to plowing time was the same for single and double plowing. The total labor, however, was 25% less, perhaps due to less time spent weeding and bird scaring(ATIP 1985,1986). Increased total production should come when total plowing time can be increased, perhaps through plowing first in drier soils, or using a double furrow plow (ATIP, 1986).

In the on-farm, double plowing study, farmers report that the second plowing took 25% less time than the initial plowing, and that double plowed plots seemed to have more moisture, greater seedling vigor, and fewer weeds than single plowed plots. Seventy-five percent of these double plowed plots had good planting conditions, while 67% of the traditional plots were too dry for planting (ATIP, 1986).

Another double plowing experiment was conducted at Sebele to determine the optimum time period between initial plowing and planting. Double plowing was, again, superior to single plowing, but the results indicated that it is more effective on sandy loams than loamy sands, Carter et al. (1985).

Farmers in the Francistown double plowing study planted three to five hectares each year. Average yields from four double plowed hectares met the grain requirements of an average seven person family; average yields from five hectares traditionally planted did not meet those requirements (Heinrich, 1988).

Many farmers in the experiment said they would try double plowing again, and several non-participating farmers were trying it; apparently it is successful enough to engender interest--an important part of effective farming systems research (ATIP, 1986).

One of the greatest obstacles to accepting double plowing is the condition of cattle at the end of the dry season. The cattle are weak due to lack of forage, and can also be wild (ATIP, 1985). In addition, 30% of the farmers have no draft power of their own and must hire or trade for tractors or animals (Garforth, 1979); they cannot schedule their operations for optimum conditions (Heinrich, 1988; Anon, 1983). Many farmers know about improved farming methods, but still choose to use traditional methods, perhaps to reduce risk.

Early planting is another practice receiving much attention recently. Early (November) planting may increase yields by as much as 68% over late (late December) planting (Livingstone, 1979).

Early planting may not be accepted by farmers because in the early part of the growing season, the cattle are very weak; owners like to wait for several rains to begin planting so grass and water are readily available (Heinrich, 1988). Other farmers fear damage to the young crop by cattle (Garforth, 1979) because there are few fences.

Recommendations, then, call for plowing immediately after harvest or soon after the first rains, and planting sorghum in November or early December; October plantings are risky, and planting after December exposes plants to low night temperatures and sorghum midge *Contarina sorghicola* (DLFRS, 1978).

Early planting alone is not the key; it is important to begin planting early and keep planting throughout the growing season. Late planting is discouraged because plants do not reach physiological maturity; short season varieties are unavailable, but would ameliorate this problem (Anon., 1984). Another study reached similar conclusions: "there can be no such thing as a correct or recommended time for planting sorghum in Botswana. One plants when one can and, according to the nature of the season, different advantages or disadvantages attach to early or late planting; and the safest strategy is one which spreads planting over a range of dates." (DLFRS, 1985).

One method to assist extension or farming systems teams is computer modelling. Computer models or physiological crop-response models consist of equations describing physiological processes in crop growth. They attempt to simulate or mimic the growth and development of a crop. The output predicts the yield acheived under the given conditions. Models have been used for north-west Queensland, Australia to determine the effectiveness of water harvesting strategies on sorghum yields (Clewett, 1985). Because average yields are often misleading, a distribution of yields with the distribution of weather can be helpful. Worman, et al. (1988) used physiological crop response models to study management strategies for three crops--corn, sorghum, and wheat, in western Kansas. From the models the most efficient or profitable strategies can be chosen by determining for each practice the "distribution of yields and returns associated with the climatic conditions at the location", Worman et al. (1988).

SORKAM, Rosenthal et al. (1988), is a physiological crop response model for sorghum. It simulates the daily growth and development of a sorghum plant, computing light interception, soil water, leaf area, and dry matter accumulation and partitioning (Worman et al., 1988; Hammer, 1987). Daily climatic data, soil data, sowing data, and plant data are required to run the model.

With the detailed climatic data required for many crop models, WGEN, a weather generator model (Richardson and Wright, 1984), can be useful in crop modelling. Using several years of actual climatic data, WGEN generates daily values for maximum and minimum temperatures, precipitation, and solar radiation for any number of years. These generated data have "the same statistical characteristics as the actual weather at the location" (Richardson and Wright, 1984).

These two models, SORKAM and WGEN, were used to simulate double plowing and date of planting experiments in Botswana. Forty years of weather data for several locations across Botswana were generated using WGEN. The climatic data were subsequently used to run SORKAM simulations for these locations. These simulations, like the field experiments, were run to determine the effects of double plowing and date of planting on sorghum yields. The computer simulations, however, were run for more locations and soil types than the field trials, and due to the number of years of weather data used, covered wet as well as dry cycles. A detailed account of these simulations is given in the following section.

MATERIALS AND METHODS

Recent field experiments in Botswana compared single and double plowing, as well as several planting dates to determine their effects on sorghum yields. SORKAM, a crop growth model for sorghum, was used to simulate the effects of different planting dates and tillage operations with the hope that SORKAM could become a tool for evaluating new farming methods.

For simplicity, two planting times, early and late, were used for each year of simulation. In fact, with the criterion used, only one crop could be planted in some years, much less than the five or six planted in the double plowing/date of planting experiment (Carter et al. 1985). For the early planting, the sowing date for each year was the day after the first planting rain (rainfall > 10 mm) of the growing season. Sowing date for the late planting was the day after the second planting rain of the season. The second planting rain was defined as the next rain greater than 10 mm falling more than three days after the first planting rain, but before January 1. Three days' separation was chosen to ensure that two separate rains were used and not the beginning and end of one rainfall; one rainy period seemed to last up to three days. In addition, in this time span enough moisture might still be retained in the soil to allow the farmer to continue planting. If the rainfall was late or less than 10 mm, the planting date was set at March 1 so the crop would not reach physiological maturity in the simulation.

Double plowing seems to reduce runoff, improve soil structure, and allow greater infiltration of rainfall. To simulate the differences between single and double plowing, two runoff values were used. Hydrologic curve numbers from the Soil Conservation Service are used in SORKAM, Rosenthal et al., (1988), to govern runoff. These numbers only represent runoff calculations--they are not percentages. To represent single plowing, the highest curve number, 91, was used; soils in Botswana have extremely high runoff (Virmani and Kanemasu, 1988; Anon., 1984). A low curve number, 72, was used for the double plowing simulations to represent the improved soil conditions.

For each location and year, four SORKAM runs were made:

High runoff (SP) - early planting
High runoff (SP) - late planting
Low runoff (DP) - early planting
Low runoff (DP) - late planting

All inputs except date of planting and runoff curve numbers were held constant for all runs at a location. To expand on the field experiments in Botswana, a forty year simulation for each of the four combinations per location was run. Four locations--Gaborone, Mahalapye, Francistown, and Maun--representing several soil types throughout the country were used, making this experiment relevant for a larger region (Fig. 1).

SORKAM uses two input files--one for climatic data and one for other inputs. For the climate input file, SORKAM requires daily precipitation, maximum (tmax) and minimum (tmin) temperatures, and solar radiation. Complete weather records, especially for long periods, are hard to find for Botswana. Some daily rainfall information, as well as monthly temperature and radiation averages from stations in Botswana were available.

WGEN, a weather generating program (Richardson and Wright, 1984), was used to generate forty years of climatic data, having the same statistical characteristics as the actual weather, for each of the four locations. Table 2 lists the first inputs needed to run WGEN. A sample input file and description of inputs for WGEN are provided in the Appendix. Forty years of maximum and minimum temperatures, rainfall, and solar radiation were generated, and generated temperatures and rainfall were corrected to match actual monthly averages.

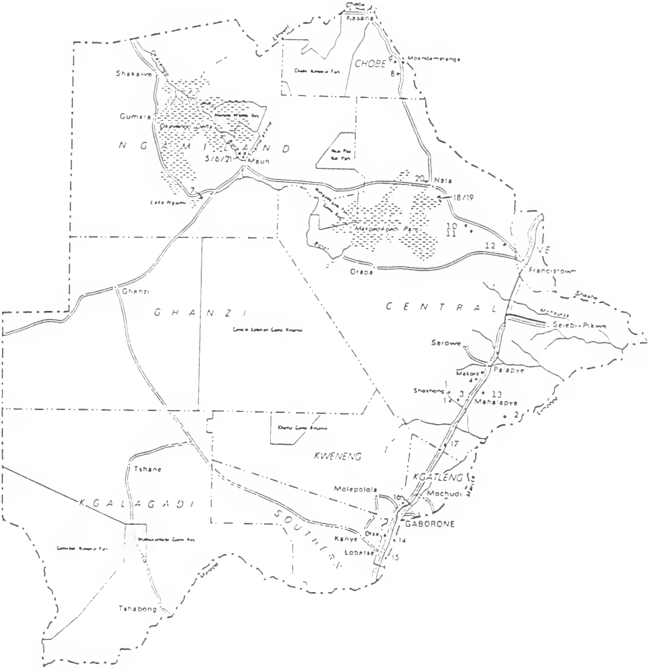

Fig. 1. Location of climatic data and soil report sites.

Table 2. Control parameters for WGEN.

Number of years of data to be generated
Generation option code-generates tmax, tmin,rain, and rad
Latitude
Temperature correction factor code
Precipitation correction factor code

WGEN documentation gives maps with typical input values for different regions of North America. Values for Yuma, Arizona, with a climate similar to Botswana, were used for the variables not available (Table 3).

Table 3. Generation parameters given for Yuma, AZ.

Mean of coefficient of variation of tmax (wet or dry)
Amplitude of coefficient of variance of tmax (wet or dry)
Mean of coefficient of variance of tmin (wet or dry)
Amplitude of coefficient of variance of tmin (wet or dry)
Amplitude of radiation (wet or dry)

The next group of parameters (Table 4) were from the actual Botswana data. Average monthly maximum and minimum temperatures and monthly standard deviations were available. Monthly maximum temperatures were averaged and five degrees added for mean maximum temperatures for dry days, and five degrees subtracted for wet days. Maps in Richardson and Wright (1984) show a difference of about 10 degrees between maximum temperatures for wet and dry days. Monthly minimum temperatures were also averaged; no differentiation between wet and dry days was required. To obtain a value for the amplitudes of the maximum and the minimum temperatures, the standard deviations given for these monthly values were averaged. Monthly radiation values were averaged for the dry day mean; 150 was subtracted from this value for the wet day mean--about the difference shown on the map for this variable (Richardson and Wright, 1984).

Table 4. Generation parameters from Botswana data.

Mean of tmax (dry)
Amplitude of tmax (wet or dry)
Mean of tmax (wet)
Mean of tmin (wet or dry)
Amplitude of tmin (wet or dry)
Mean of radiation (dry)
Mean of radiation (wet)

WGEN requires rainfall probability and distribution parameters (Table 5); a companion program, WGENPAR, was used to generate these parameters. WGENPAR requires twenty years of actual rainfall data to calculate accurate parameters. The rainfall data available were used; Maun and Mahalapye data were not available, so locations nearby, Gweta and Debete, respectively, were substituted.

Table 5. Rainfall generation parameters for WGEN.

Monthly probability of wet day given wet previous day
Monthly probability of wet day given dry previous day
Monthly values of gamma distribution shape parameter
Monthly values of gamma distribution scale parameter

The WGEN programs will only accept English units and positive latitudes. Both WGENPAR and WGEN, therefore, were run with positive latitudes. All results have been corrected, coinciding with the actual growing season in Botswana.

Monthly values for average maximum and minimum temperatures and rainfall (Table 6) were from weather stations in Botswana.

Table 6. Monthly data required for WGEN.

Monthly values of mean maximum temperatures
Monthly values of mean minimum temperatures
Monthly values of mean precipitation

When all the inputs are entered, WGEN creates the climate file required for SORKAM--forty years of data with daily observations for rainfall, maximum and minimum temperatures, and radiation. A Fortran program was used to divide the file into 40 files and truncate them to the length of the growing season; the climate files began with 1 November and were 220 days long.

SORKAM requires another input file, with three categories: sowing, plant, and soil inputs. These can also be changed from the SORKAM program, but due to the size of the runs, this was done through the input file (Table 7). These inputs, with the exception of date of planting and runoff curve numbers, were held constant for all runs at a location. A summary of the inputs is given in the Appendix.

Table 7. Sample input file for SORKAM.

```
PTTL    FRANCISTOWN MATHANGWANE DATA - LOW RUNOFF
PCLM         11
PMFL      FTON  .MET
PSOW   6   1      5.0    76.2     25000.
PVAR   1  0   150. 15 -.910  .087 .00083
PSOI     .70      .21      .15     1.13  1  5
PLYR    18.0      .00      .12     1.50     18.1
PLYR     5.0      .00      .10     1.45     27.5
PLYR    20.0      .00      .08     1.53     28.9
PLYR    13.0      .00      .05     1.57     38.0
PLYR    25.0      .00      .08     1.59     48.4
PLYR    29.0      .00      .08     1.61     41.9
PLYR    40.0      .00      .09     1.29     43.5
PMET   5   1 220     220.     495.     345.
PROF   72.0     1.0     21.0    0     1.00
POUT   4   2
```

Sowing: To simulate farming systems experiments on date of planting and double plowing, sowing information (Table 8) from the field experiments was used. A sowing depth of 5.0 cm was used, although depth is variable due to the farmers' planting method. Row spacing was 76.2 cm and plant density was 25,000 plants/ha (ATIP, 1986).

Table 8. SORKAM inputs: sowing

Date of planting
Sowing depth
Row spacing
Plant density

Plant Inputs: (Table 9) Since values were available, the growth of RS610 was simulated instead of the native Segaolane sorghum; RS610 is an early, photoperiod insensitive hybrid with fifteen leaves. Tillering slope used was -0.910g/tiller/day/C, tillering intercept was

0.087g/tiller/day, and seed number slope was 0.00083 g/seed.

Table 9. SORKAM inputs: plant

Maturity class
Photoperiod
Maximum rooting depth
Leaf number
Tillering slope and intercept
Seed number

Soil Inputs: Soils information (Table 10) came from the SCS report on Botswana soils (SCS, 1987). Data from the soil located at Sebele were used for the Gaborone runs. Three soils near Maun had been sampled. One was a wetland; the other two were quite similar, so the deeper one was used. At Francistown, one soil at Mathangwane was used, and for comparison, of the two soils at Marapong, the one most different from the Mathangwane soil was chosen. These soils were run individually but used the same climatic data. For Mahalapye, the soils at Shoshong and Makwate were chosen for their dissimilarities.Sand, silt, and clay contents found in the soil report were used to calculate stage 1 and 2 soil evaporation coefficients by the method given in Jafaar et al.(1978). These values were not close to coefficients given for similar Kansas soils. The texture of the Gaborone soil was between Carwile sand and Manter fine sandy loam, so the coefficients for these two soils were averaged to give the coefficients for the Gaborone soil (Table 11). Manter fine sandy loam and Muir silty clay loam values were averaged for the soil at Shoshong, and for Makwate the values for Carwile sand were used. For the soil at Marapong values for Carwile sand were used; for Mathangwane, the values for Carwile sand and Manter fine sandy loam were averaged. Coefficients for Manter fine sandy loam were used for the soil at Maun. Maximum rooting depths used were the bottom of the last layer in which roots were noted in the soil report. Maximum rooting depths for the soils chosen were: Gaborone 180 cm, Shoshong 200 cm, Makwate 86 cm, Marapong 100 cm, Mathangwane 150 cm, and Maun 200 cm. Dry soil albedo was set at .15 and air-soil temperature at 1.13 for all soils used. The Priestly-Taylor method was used to calculate potential evapotranspiration. Soil layer information--depth of layer, bulk density, and percent clay content--came from the soil report. Initial available soil water was set to zero for all layers because no rain falls from May until planting--the profile would be dry and would fill after a rainfall. Maximum available water data came from the soil report.

Table 11. Summary of soil data from the 1987 SCS report for Botswana.

Location	Soil no.	Sand (%)	Clay (%)	H20 (cm)	Lyr (cm)	Stg 1	Stg 2	Classification (FAO)
Gaborone	16	74	19	10.5	180	.7	.21	Chromic Luvisol
Mahalapye: Shoshong	1	30	54	28.9	200	.96	.28	Haplic Vertisol
Makwate	2	74	15	6.6	86	.5	.16	Calcic Luvisol
Francistown: Marapong	11	92	6	3.1	100	.5	.17	Eutric Cambisol
Mathangwane	12	56	40	13.8	150	.7	.21	Haplic Luvisol
Maun	6	68	24	33.6	200	.9	.24	Gleyic Phaeozem

Table 10. SORKAM inputs: soil

Soil evaporation coefficients--Stage 1 and 2
Dry soil albedo
Air-soil temperature ratio
PET method
Soil layer thickness
Initial available soil water
Maximum available soil water
Bulk density
Percent clay

In the input file, SORKAM requests additional climatic information (Table 12) to calculate evaporation and runoff. Insolation amplitude and annual average insolation for wet and dry days were those used in WGEN. Runoff curves were 72 and 91, representing double and single plowing. Field slope percent came from the SCS report.

Table 12. SORKAM inputs: climate

Amplitude of insolation
Average insolation for wet and dry days
Runoff curve
Field slope

Two input files were created for each location, one with high runoff and one with low; all other inputs were constant. Two batch files were created for each location, one with early planting dates and one with late;the batch files controlled all forty years of a simulation, automatically changing the year (climate file name) and date of planting.

Output data was converted; means; standard deviations; maximum and minimum values; coefficients of variation; and measurements of skewness and kurtosis of yield, sowing date, and growing season rainfall were calculated. No economic analysis was conducted. Cumulative frequency of yield, yield versus rainfall, and yield versus sowing date were plotted for each location. Years not planted were given zero yield except in the graphs of yield versus rainfall where these yields were considered missing data. March sowing dates for years not planted were left as day 428.

RESULTS

The SORKAM model was run using 40 years of climatic data and six soils from Botswana to determine the effects of double plowing and date of planting on sorghum yield. Four treatments used were:

High Runoff (SP) - Early Planting

High Runoff (SP) - Late Planting

Low Runoff (DP) - Early Planting

Low Runoff (DP) - Late Planting

Three of the 40 years simulated had no late plantings because the second planting rain did not occur before 1 January. In addition, Maun had one year with no early planting, and a total of six years with no late planting.

Average simulated yields show that double plowing (reduced runoff) always produced higher sorghum yields than traditional methods, regardless of planting time (Tables 13-18). Average yields were about 2000 to 3000 kg/ha--the level many feel Botswana is capable of obtaining (Lightfoot, 1979; DLFRS, 1978). These are much higher than average yields currently produced, but SORKAM assumes no problems with soil fertility, diseases, pests,

Table 13. GABORONE: Statistics by treatment for yield, date of planting, and rainfall.

	Traditional		Double Plowed	
	Early Planting	Late Planting	Early Planting	Late Planting
Yield				
Mean	2283	2288	2550	2539
Std.Dev.	1252	1326	1436	1459
Range	493-5154	0-5047	493-5672	0-5486
CV	54.8	58.0	56.3	57.5
Skewness	.72	.27	.51	.08
Kurtosis	-.14	-.43	-.66	-.73
Date of Planting$				
Mean	321	342		
Std.Dev.	14	28		
Range	306-358	312-428		
CV	4.2	8.2		
Skewness	.95*	2.19*		
Kurtosis	.20	5.01*		
Rain				
Mean	305	333	295	318
Std.Dev.	68	73	76	78
Range	167-455	179-489	146-455	179-489
CV	22.3	21.9	25.9	24.4
Skewness	.40	.24	.25	.42
Kurtosis	-.01	-.50	-.50	-.55

$ no difference in date of planting between traditional and double plowing.
* significant at the p = .05 level.

Table 14. SHOSHONG: Statistics by treatment for yield, date of planting, and rainfall.

	Traditional		Double Plowed	
	Early Planting	Late Planting	Early Planting	Late Planting
Yield				
Mean	2297	2174	2975	2875
Std.Dev.	1410	1449	1464	1659
Range	362-5143	0-4942	421-5596	0-5710
CV	61.4	66.7	49.2	57.7
Skewness	.60	.48	.13	-.08
Kurtosis	-.91	-.81	-.98	-.96
Date of Planting$				
Mean	320	338		
Std.Dev.	15	29		
Range	306-357	311-428		
CV	4.6	8.7		
Skewness	1.24*	2.17*		
Kurtosis	.55	4.73*		
Rain				
Mean	336	346	331	342
Std.Dev.	110	117	113	121
Range	145-615	145-665	133-615	133-665
CV	32.7	33.9	34.2	35.4
Skewness	.84*	.88*	.70	.75*
Kurtosis	.33	.59	.21	.45

$ no difference in date of planting between traditional and double plowing.
* significant at the p = .05 level.

Table 15. MAKWATE: Statistics by treatment for yield, date of planting, and rainfall.

	Traditional		Double Plowed	
	Early Planting	Late Planting	Early Planting	Late Planting
Yield				
Mean	2738	2523	2920	2732
Std.Dev.	1346	1415	1362	1495
Range	430-5395	0-5446	644-5428	0-5578
CV	49.2	56.1	46.6	54.7
Skewness	.32	.10	.15	-.06
Kurtosis	-.83	-.45	-1.07	-.71
Date of Planting$				
Mean	320	338		
Std.Dev.	15	29		
Range	306-357	311-428		
CV	4.6	8.7		
Skewness	1.24*	2.17*		
Kurtosis	.55	4.73*		
Rain				
Mean	318	330	317	329
Std.Dev.	117	125	118	126
Range	133-615	133-645	133-615	133-645
CV	36.9	37.9	37.3	38.3
Skewness	.83*	.78*	.82*	.78*
Kurtosis	.25	.19	.22	.16

$ no difference in date of planting between traditional and double plowing.

* significant at the p = .05 level.

Table 16. MARAPONG: Statistics by treatment for yield, date of planting, and rainfall.

	Traditional		Double Plowed	
	Early Planting	Late Planting	Early Planting	Late Planting
Yield				
Mean	2343	2160	2359	2171
Std.Dev.	1115	1265	1118	1269
Range	577-5464	0-5344	600-5465	0-5344
CV	47.6	58.6	47.4	58.4
Skewness	.89*	.18	.88*	.17
Kurtosis	.57	-.15	.49	-.18
Date of Planting$				
Mean	320	338		
Std.Dev.	15	29.4		
Range	306-357	311-428		
CV	4.6	8.7		
Skewness	1.24*	2.17*		
Kurtosis	.55	4.73*		
Rain				
Mean	319	355	318	355
Std.Dev.	76	96	75	96
Range	147-503	211-603	147-503	211-603
CV	23.7	27.1	23.7	27.1
Skewness	.17	.57	.21	.57
Kurtosis	-.07	-.24	-.04	-.24

$ no difference in date of planting between traditional and double plowing.
* significant at the p = .05 level.

Table 17. MATHANGWANE: Statistics by treatment for yield, date of planting, and rainfall.

	Traditional		Double Plowed	
	Early Planting	Late Planting	Early Planting	Late Planting
Yield				
Mean	2890	2744	3178	3024
Std.Dev.	1471	1666	1564	1755
Range	351-7039	0-7124	381-7041	0-7127
CV	50.9	60.7	49.2	58.0
Skewness	.51	.38	.26	.09
Kurtosis	.12	-.19	-.52	-.60
Date of Planting$				
Mean	320	338		
Std.Dev.	15	29		
Range	306-357	311-428		
CV	4.6	8.7		
Skewness	1.24*	2.17*		
Kurtosis	.55	4.73*		
Rain				
Mean	324	347	321	343
Std.Dev.	78	90	78	91
Range	147-497	211-603	147-497	211-603
CV	24.1	26.0	24.4	26.5
Skewness	.33	.56	.39	.61
Kurtosis	.11	.20	.08	.18

$ no difference in date of planting between traditional and double plowing.
* significant at the p = .05 level.

Table 18. MAUN: Statistics by treatment for yield, date of planting, and rainfall.

	Traditional		Double Plowed	
	Early Planting	Late Planting	Early Planting	Late Planting
Yield				
Mean	2190	2059	2551	2351
Std.Dev.	1217	1415	1289	1531
Range	0-5396	0-5313	0-5396	0-5313
CV	55.6	68.7	50.5	65.1
Skewness	.24	.18	-.09	-.09
Kurtosis	-.06	-.62	-.37	-.90
Date of Planting$				
Mean	327	350		
Std.Dev.	21	36		
Range	308-428	314-428		
CV	6.5	10.3		
Skewness	3.01*	1.47*		
Kurtosis	13.19*	.99		
Rain				
Mean	343	363	339	360
Std.Dev.	89	94	91	97
Range	175-517	175-592	175-517	175-584
CV	26	26	27	27
Skewness	.19	.36	.16	.29
Kurtosis	-.59	-.06	-.06	-.27

$ no difference in date of planting between traditional and double plowing.
* significant at the p = .05 level.

weeds, or uneven stands--all of which limit production in Botswana. A hybrid was used instead of the native variety; this may in part account for higher yields. In addition, average actual yields were from a drought period in Botswana. Predicted yields from dry years were under 1000 kg/ha and are, perhaps, not unrealistic.

Low runoff, simulating double plowing, produced the greatest increase in mean yields(32%) over single plowing at Shoshong--the soil with the highest clay content of the six used (Table 11). Double plowing had the smallest gain (1%) at Marapong--the soil with the highest sand content.

Significance tests for skewness and kurtosis (Snedecor, 1956) of yields, determined that at all locations except Marapong yields were normally distributed (Tables 13-18). Marapong had a peaked (leptokurtic) distribution of yields in both (traditional and double plowing) early planting runs; at Mathangwane, the other location using Francistown climatic data, yields were normally distributed. Double plowing increased the variability as measured by the standard deviation over that of single plowing, but decreased the relative variability as measured by the coefficient of variation for all locations but Gaborone.

Early planting increased average yields up to nine percent over late planting for all sites except Gaborone, where there was no difference. No date of planting, however, was optimum (Fig. 2); planting after each planting rain, then, seems to be the best practice.

Late planting always had higher variability in sowing date than early planting. Sowing dates were positively skewed for both planting times at all locations. This is to be expected due to the limitations set on planting date. All locations but Maun had peaked distributions for late planting; Maun had a peaked distribution for early planting. (Since sowing dates for a given year are based on rainfall, single and double plowing have the same sowing date and need not be considered separately).

Average dates of early sowing were the same (November 16) at the Mahalapye and Francistown locations, one day later at Gaborone, and one week later at Maun. The ranges of sowing dates also were similar. For early planting, Maun's earliest planting date was November 4; all other locations' earliest planting date was November 2. The latest sowing date was December 23 for the Mahalapye and Francistown sites; Gaborone was one day later. Maun had one year with no early planting, so its latest date for early planting was set in March(day 428). The Mahalapye and Francistown locations had the same average date for late planting, but Gaborone and Maun were four and twelve days later, respectively. The

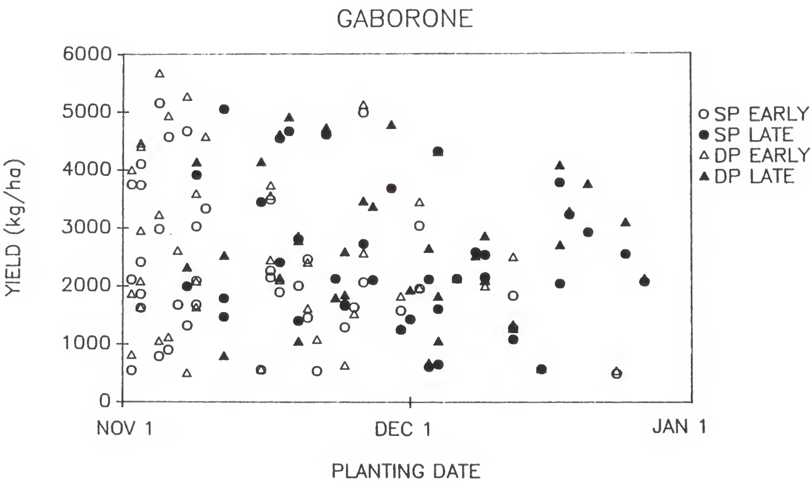

Fig 2. Effects of planting date and plowing scheme on sorghum yield at Gaborone.

earliest date was November 7 for Mahalapye and Francistown (an average of five days later than early planting, given a three day minimum restriction), November 8 for Gaborone, and November 10 for Maun.

Rainfall amounts used for statistical analysis were those given in the SORKAM output; they are total rainfall from the first date of climatic data (November 1) through physiological maturity. It is, therefore, not surprising that late planting received greater average rainfall (up to nine percent) than early planting, although their growing season was usually shorter. In spite of having the same date of sowing and emergence, single plowing runs took longer than double plowing to reach physiological maturity; single plowing runs received greater average rainfall (up to five percent). It seems, then, that by using double plowing to reduce runoff, farmers could produce higher yields with less rainfall.

In general, yield increased with rainfall at all locations. Ranges of yields increased with rainfall, as well. Significance tests for kurtosis showed little evidence of departure from normality. Only Shoshong and Makwate had skewed (positive) distributions for rainfall. Rainfall for double plowing-early planting at Shoshong was, however, normally distributed.

GABORONE: Gaborone received the lowest average rainfall of all the locations, and produced some of the lower average yields (Table 13). Cumulative frequency of yield (Fig. 3) shows, as do mean yields, that double plowing has a greater effect on yields than date of planting. Below 1500 kg/ha all the combinations are about equal.

Yield does decrease slightly with later planting dates (Fig. 2). Double plowing produced greater yields than single plowing. From the regression equations (Table 19), it is clear that every day planting is delayed, up to 30 kg/ha are lost; yields from double plowing (with the greatest negative slope) are affected the most by delay. The equations account for very little of the variability. Late planting, due to limited season length, and increased rainfall, accounts for more of the variability than early planting. No planting time is optimum. Planting after each rain not only allows farmers to adapt to soils that crust and harden quickly after a rain, but also makes sense in terms of yield.

For a given rainfall, double plowing produces higher yields than single plowing, and early planting produces higher yields than late planting (Fig. 4). Double plowing-early planting is the most productive combination for this location. Of the four treatments, the double plowing-early planting regression line has the greatest slope, that is, for every additional millimeter

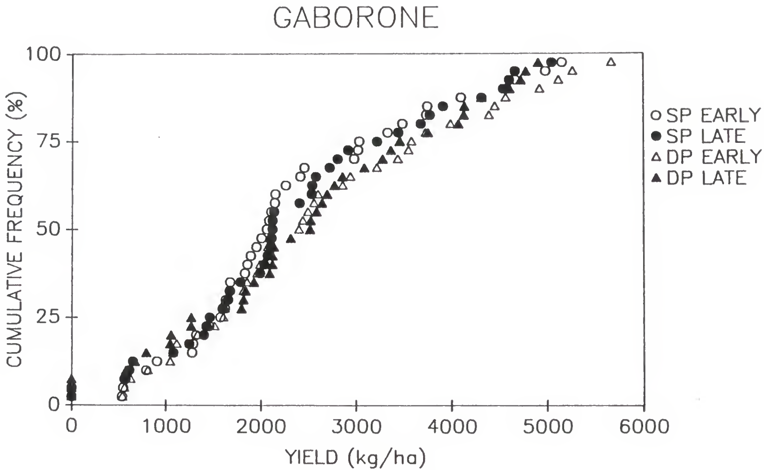

Fig. 3. Cumulative frequency of yield as affected by planting date and plowing at Gaborone.

Table 19. Regression equations for GABORONE

	Equation	R2
DOP/YLD		
SP Early	Y = 10490.0 - 25.6 kg/ha/day	.08
SP Late	Y = 10914.0 - 25.3 kg/ha/day	.29
DP Early	Y = 12027.0 - 29.6 kg/ha/day	.08
DP Late	Y = 10955.0 - 24.9 kg/ha/day	.25
RAIN/YLD		
SP Early	Y = -2667.7 + 16.2 kg/ha/mm	.78
SP Late	Y = -2149.0 + 13.9 kg/ha/mm	.65
DP Early	Y = -2369.7 + 17.1 kg/ha/mm	.77
DP Late	Y = -2074.2 + 15.2 kg/ha/mm	.76

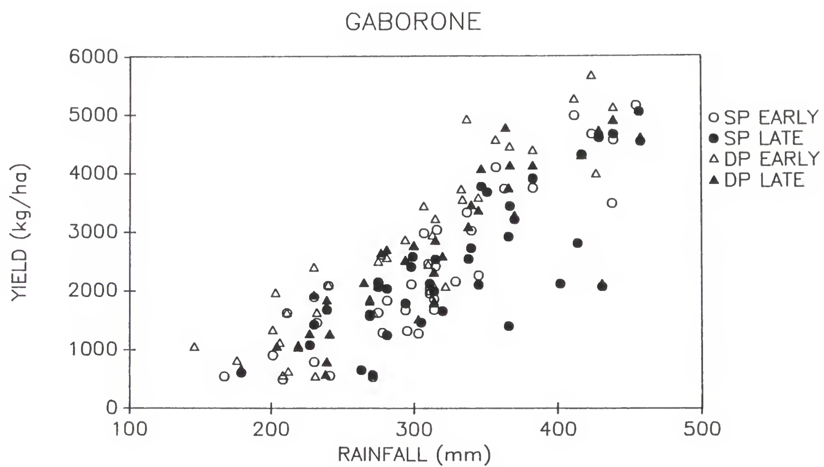

Fig 4. Effects of rainfall, plowing scheme, and planting date on sorghum yield.

of rain, this treatment produces more grain than the others (Table 19). Up to 70% of the variability is explained by these equations. Setting Y equal to zero for these equations and solving for X gives the minimum rain needed for each treatment to obtain some yield:

SP Early	164.3 mm
SP Late	154.1 mm
DP Early	138.7 mm
DP Late	136.5 mm

Gaborone requires more rain than most of the locations to produce any yield; this may be due to a combination of deep soil and high clay content. Single plowing-early planting needs the most rain (164 mm) to produce a yield. Early planting probably needs more than late because of the longer growing season; high runoff may be the cause for the single plowing's higher rainfall requirement. At Gaborone, the average difference in runoff between high and low runoff schemes was 19 mm for early planting, and 21 mm for late--nearly the difference in the minimum rainfall required to produce a yield.

MAHALAPYE:SHOSHONG and MAKWATE. These had the same climatic data, yet produced quite different yields. The soil at Shoshong, with about 50% clay, produced almost 20% less sorghum using traditional methods than the soil at Makwate, with roughly 76% sand (Tables 14 and 15). Shoshong had yields up to 5% higher than Makwate, using double plowing. Double plowing caused the greatest yield increases--up to 32%--at Shoshong.

Cumulative frequency of yield shows that at Shoshong double plowing is more likely to produce a given yield than single plowing (Fig. 5). Early planting will nearly always produce some yield; at low yields, timing of planting has a greater effect on yield than runoff control. Under conditions producing higher yields, planting time makes little difference, especially compared to effects of double plowing; for this location, one's plowing scheme is more important than timing of planting.

For Shoshong it is difficult to determine which planting date/runoff combination is the most productive (Fig. 6). From the regression equations (Table 20), double plowing-late planting seems the best. Late plantings have the steepest (negative) slopes, or in other words, for each day planting is delayed, 15 and 22 kg/ha are lost, compared to 0 and 3 kg/ha for corresponding early planting. The difference between single plowing-early planting and double plowing-late planting supports the double plowing hypothesis--yield gains greatly outweigh losses due to late planting. Less than 15% of the variability is explained by these equations, much less than at the other locations.

The graph of yield versus rainfall shows higher

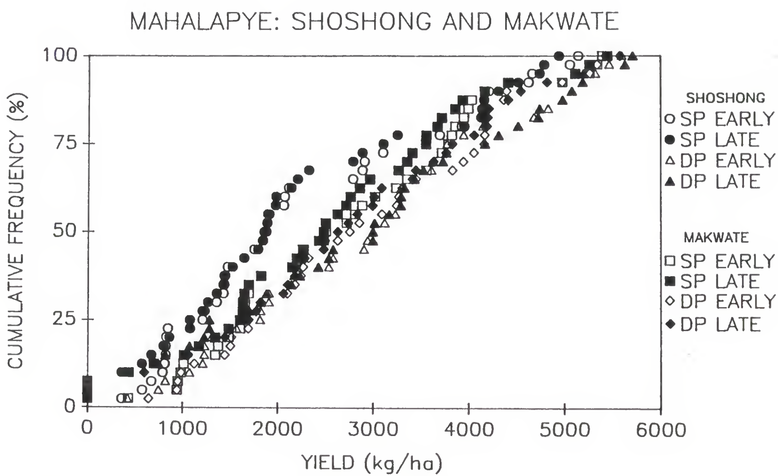

Fig 5. Cumulative frequency of yield as affected by planting date and plowing at Shoshong and Makwate.

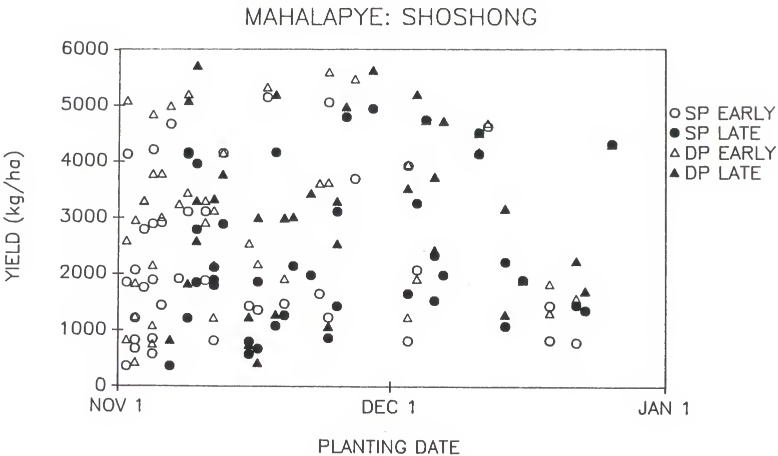

Fig 6. Effects of planting date and plowing scheme on sorghum yield at Shoshong.

Table 20. Regression equations for SHOSHONG

	Equation	R2
DOP/YLD		
SP Early	Y = 2401.4 - 0.3kg/ha/day	.00
SP Late	Y = 7223.5 - 14.9kg/ha/day	.09
DP Early	Y = 3811.7 - 2.6kg/ha/day	.00
DP Late	Y = 10377.0 - 22.2kg/ha/day	.16
RAIN/YLD		
SP Early	Y = -1590.8 + 11.6kg/ha/mm	.81
SP Late	Y = -1290.5 + 10.6kg/ha/mm	.80
DP Early	Y = -676.0 + 11.0kg/ha/mm	.73
DP Late	Y = -395.2 + 10.3kg/ha/mm	.68

yields resulting from low runoff; date of planting does not seem to make much difference (Fig. 7). The regression equations show that the slopes of the four combinations are about the same, but from the intercepts, one sees that for a given amount of rainfall double plowing-late planting is the most productive (Table 20). Single plowing-late planting uses rainfall more efficiently than the other combinations, producing 12 kg/ha for each additional millimeter of rain. Solving these equations for Y equal to zero gives the minimum rain needed to obtain a yield:

SP Early	137.6	mm
SP Late	121.6	mm
DP Early	61.3	mm
DP Late	38.4	mm

With single plowing over twice the rain is needed to grow at least some sorghum. Early planting runs also require more rainfall than late planting to produce. The average difference in runoff between the two plowing schemes is 43mm for early planting, and 44mm for late. This is much less than the difference in minimum rainfall required.

Cumulative frequency of yields shows that at lower yield levels, early planting is more likely to produce a given yield than late planting at Makwate (Fig. 5). At higher yield levels, double plowing (early as well as late) is better than single plowing (early and late).

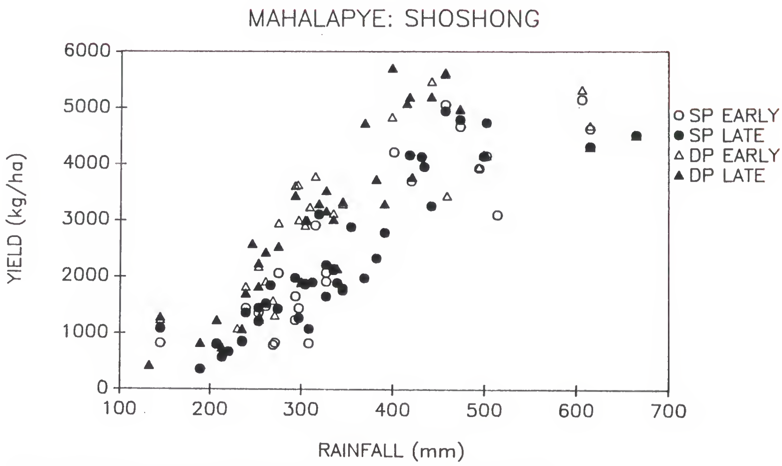

Fig 7. Effects of planting date and plowing, and rainfall on sorghum yield at Shoshong.

With conditions producing over 4000 kg/ha, it does not matter which plow/plant combination is used--they are about the same. All the Makwate treatments fall between the single and double plowing treatments for Shoshong, but at lower production levels Makwate is more likely to produce a given yield.

It is difficult to determine which planting date/ plowing combination is the best at Makwate (Fig. 8). The regression equations for date of planting are similar and very little variability is explained with these equations--less than 25%, perhaps due to timing variations in rainfall (Table 21).

For a given rainfall, double plowing-early planting produces higher yields than the other treatments(Fig. 9). Calculating the minimum rain needed to produce some yield gives negative values. Negative values are unreasonable for producing a yield. From the graph (Fig. 9), it appears that a quadratic equation might solve this problem. In addition, the amount of variability explained is the lowest of all the locations (Table 21).

FRANCISTOWN: MARAPONG and MATHANGWANE. These locations used the same climatic data. Marapong had the lowest average yields of all locations for double plowing, and moderate to low yields for traditional methods. Mathangwane produced average yields 23-39% greater than those produced at Marapong (Tables 16 and

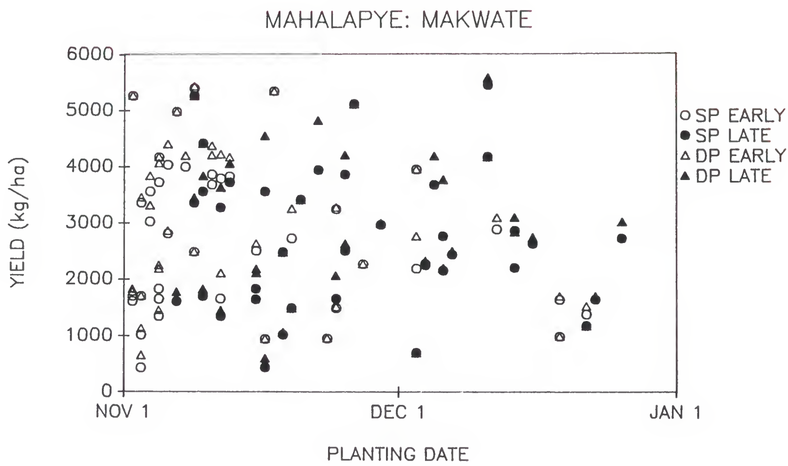

Fig 8. Effect of planting date and plowing on sorghum yield at Makwate.

Table 21. Regression equations for MAKWATE

	Equation	R2
DOP/YLD		
SP Early	Y = 9806.7 - 22.1kg/ha/day	.06
SP Late	Y = 10314.0 - 23.0kg/ha/day	.23
DP Early	Y = 10660.0 - 24.2kg/ha/day	.07
DP Late	Y = 11158.0 - 24.9kg/ha/day	.24
RAIN/YLD		
SP Early	Y = 271.8 + 7.8kg/ha/mm	.46
SP Late	Y = 478.8 + 6.9kg/ha/mm	.45
DP Early	Y = 629.9 + 7.2kg/ha/mm	.39
DP Late	Y = 848.6 + 6.5kg/ha/mm	.37

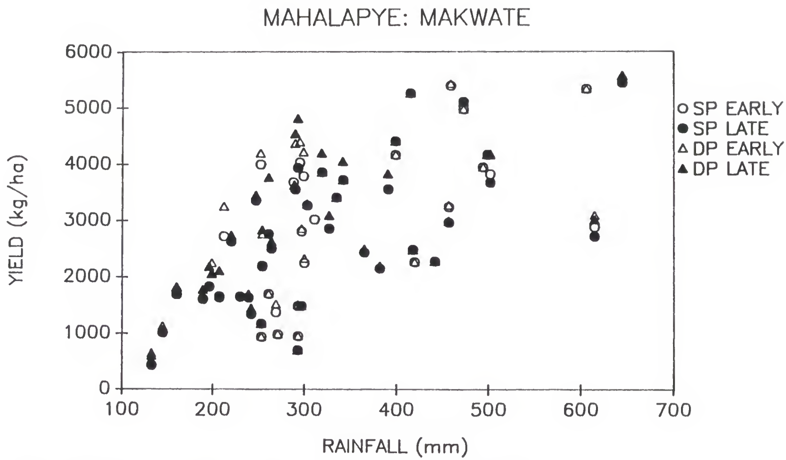

Fig 9. Effect of planting date and plowing, and rainfall on sorghum yield at Makwate.

17). In addition, of all the locations, Mathangwane had the highest average yields for all plowing and planting combinations.

Marapong had almost no yield difference between plowing schemes--only between planting times; Mathangwane displayed the greatest yield difference between plowing methods, and little difference between planting times.

Cumulative frequency of yield shows that for yields less than 2000 kg/ha early planting is more likely to produce a given yield at Marapong, but above this point early and late planting dates produce similar yields (Fig. 10). Little difference, about one percent, occurs between the plowing schemes throughout the range of yields. At Marapong double plowing produced the smallest gain over single plowing of all the locations. Marapong had the highest sand content and lowest water holding capacity of all the soils, so reducing runoff does little good if the soil cannot retain the moisture.

From the graph of planting date versus yield (Marapong)it is evident that a delay of six weeks can cut yield in half (Fig. 11). Late planting produces slightly higher average yields than early and the regression lines have steeper slopes (Table 22). For each day planting is delayed, up to 24 kg/ha are lost. Little yield variability is explained with these equations; higher order equations were slightly better.

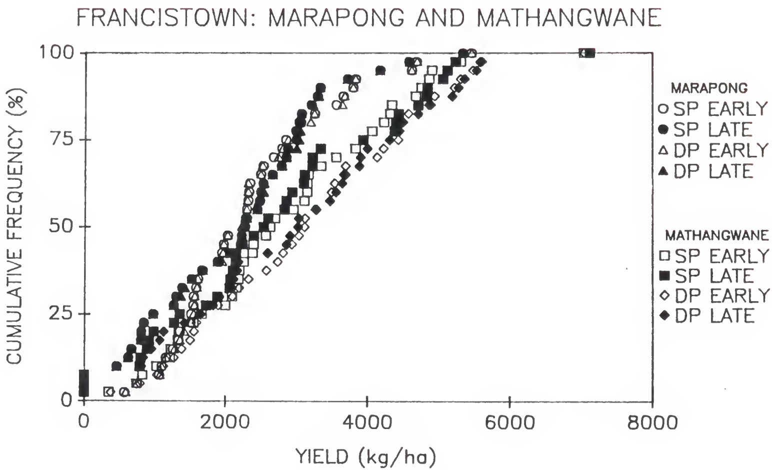

Fig 10. Cumulative frequency of yield as affected by planting date and plowing at Marapong and Mathangwane.

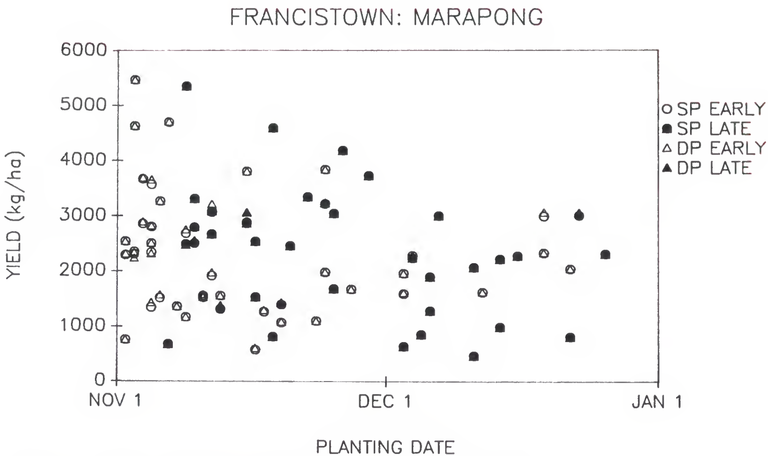

Fig 11. Effect of planting date and plowing scheme on sorghum yield at Marapong.

Table 22. Regression equations for MARAPONG

	Equation	R^2
DOP/YLD		
SP Early	Y = 7147.1 - 15.0kg/ha/day	.04
SP Late	Y = 10231.0 - 23.9kg/ha/day	.31
DP Early	Y = 7165.8 - 15.0kg/ha/day	.04
DP Late	Y = 10304.0 - 24.1kg/ha/day	.31
RAIN/YLD		
SP Early	Y = -1019.9 + 10.6kg/ha/mm	.51
SP Late	Y = -526.8 + 8.1kg/ha/mm	.49
DP Early	Y = -987.8 + 10.5kg/ha/mm	.51
DP Late	Y = -503.7 + 8.1kg/ha/mm	.49

For a given rainfall, plowing scheme has less effect on yield than planting time (Fig. 12). Double plowing-late planting produced the highest yields at this location. Single plowing-early planting used rain most efficiently, producing 11 kg/ha for each additional millimeter of rain (Table 22). The minimum amount of rain necessary to obtain some yield was:

SP Early	96.7 mm
SP Late	65.0 mm
DP Early	93.8 mm
DP Late	62.4 mm

These amounts are lower than for other locations; perhaps because of the high sand content, on a given rain, water reaches greater depths than in a soil with more clay (Anon., 1985a). Double plowing requires less rain to produce a yield due to reduced runoff. Early planting requires over 30 mm more rain than late planting to produce a yield; early plantings had longer growing seasons than late, increasing the water requirements. The difference in runoff between the two plowing schemes is 21mm for early planting, and 24mm for late planting--fairly close to the difference in the minimum rainfall required. About 50% of the variability is explained by these equations, much less than for other locations.

Cumulative frequency of yield shows that Marapong has almost no differences among treatments and that a

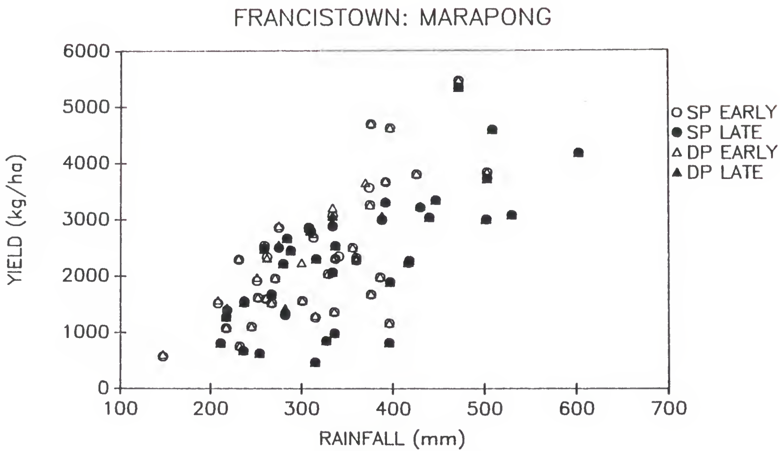

Fig 12. Effects of rainfall, planting date and plowing scheme on sorghum yield at Marapong.

given yield is less likely to be produced than at Mathangwane (Fig. 10). Yields at Mathangwane show greater effects from plowing schemes than planting dates. At yields less than 2000 kg/ha the early plantings for both locations are much better than late plantings. Double plowing-early planting is the best practice for the whole range of yields at Mathangwane. The high yields (over 7000 kg/ha) correspond to the year with the highest rain (497 mm).

Little difference between treatments is evident on the planting date versus yield graph for Mathangwane (Fig. 13). From the regression equations, late plantings have much greater slopes; for each day planting is delayed, up to 31 kg/ha is lost, while for early planting the loss is no more than 10 kg/ha (Table 23). Delaying planting to double plow is, however, profitable. Little yield variability is explained by these equations.

Double plowing produces higher yields than single plowing for a given rainfall (Fig. 14). The regression equations show that double plowing-early planting is the most responsive to rainfall--one millimeter adds 17 kg/ha (Table 23). Early planting may be more responsive because less soil water is available at planting than for late planting; up to 71% of the yield variability is explained. Calculating the amount of rain needed to produce some yield gives:

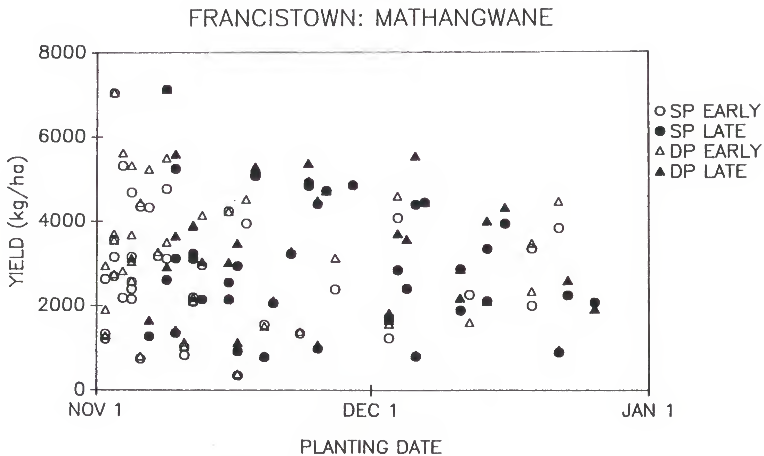

Fig 13. Effects of planting date and plowing on sorghum yield at Mathangwane.

Table 23. Regression equations for MATHANGWANE

	Equation	R2
DOP/YLD		
SP Early	Y = 4890.6 - 6.3kg/ha/day	.00
SP Late	Y = 12102.0 - 27.7kg/ha/day	.24
DP Early	Y = 6487.1 - 10.4kg/ha/day	.00
DP Late	Y = 13398.0 - 30.7kg/ha/day	.29
RAIN/YLD		
SP Early	Y = -2192.2 + 15.7kg/ha/mm	.69
SP Late	Y = -1587.8 + 13.2kg/ha/mm	.65
DP Early	Y = -2203.7 + 16.8kg/ha/mm	.71
DP Late	Y = -1387.5 + 13.7kg/ha/mm	.66

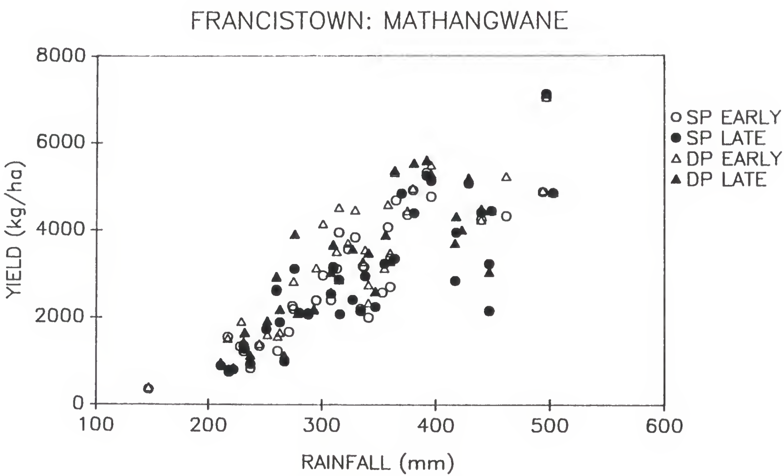

Fig 14. Effects of rainfall, planting date and plowing scheme on sorghum yield at Mathangwane.

SP Early	139.6 mm
SP Late	120.1 mm
DP Early	131.6 mm
DP Late	101.5 mm

The mimimum rain required is higher for early planting than for late, and slightly higher for single plowing than double. The difference in runoff between high and low treatments is 20 mm for early planting and 22 mm for late planting--accounting for the difference in minimum rainfall required.

MAUN: Maun received the highest average rainfall yet had the lowest yields for traditional plowing and moderately low for double plowing relative to the other locations (Table 18). The lower yields may be due to later planting dates or higher average temperatures. Fifteen percent of the time, late planting would not be possible and three percent of the time early planting would be impossible.

Cumulative frequency of yield shows that double plowing is more likely to produce a given yield than single plowing (Fig. 15). Early planting for both plowing schemes is better than late planting at lower yield levels. Above 1500 kg/ha timing has little effect on yields, while double plowing has a greater effect on yields than single plowing.

The graph of planting date versus yield gives little

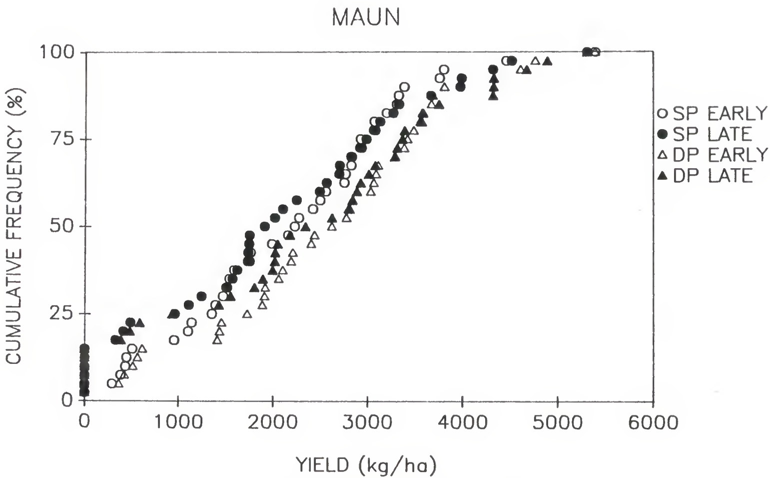

Fig 15. Cumulative frequency of yield as affected by planting date and plowing at Maun.

specific information (Fig. 16). From the regression equations it is evident that double plowing-late planting produces the highest yields, and is also most affected by delay in planting (Table 24). Little yield variability is explained.

The graph of rainfall versus yield shows little difference among treatments (Fig. 17). From the regression equations it appears that the four treatments are quite similar (Table 24). Up to 73% of the variability is accounted for. Solving these equations to determine the minimum rain needed to produce some yield gives:

SP Early	132.6 mm
SP Late	132.5 mm
DP Early	91.7 mm
DP Late	85.6 mm

Double plowing-late planting requires less water due to improved infiltration and a short growing season. The single plowing treatments require 40 mm more rain since runoff is not controlled; the difference in runoff between the two plowing schemes is, however, 21 mm for early planting, and 24 mm for late planting.

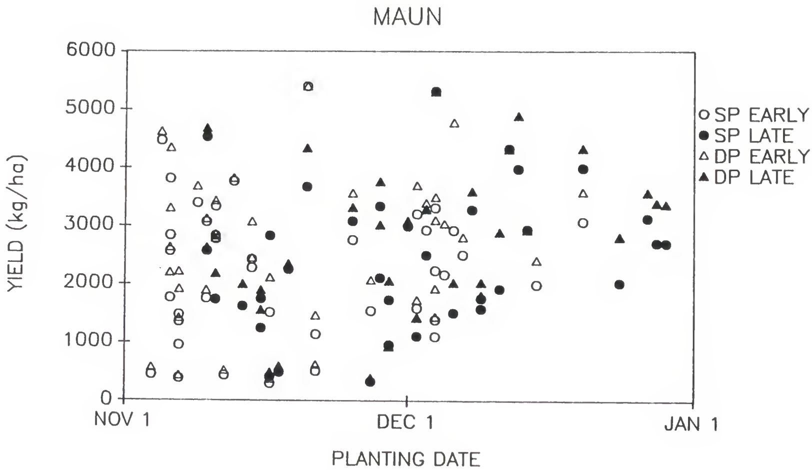

Fig 16. Effects of planting date and plowing scheme on sorghum yield at Maun.

Table 24. Regression equations for MAUN

	Equation	R2
DOP/YLD		
SP Early	Y = 5868.6 - 11.3kg/ha/day	.04
SP Late	Y = 8942.2 - 19.7kg/ha/day	.25
DP Early	Y = 5625.5 - 9.4kg/ha/day	.02
DP Late	Y = 9944.0 - 21.7kg/ha/day	.26
RAIN/YLD		
SP Early	Y = -1432.2 + 10.8kg/ha/mm	.66
SP Late	Y = -1384.8 + 10.5kg/ha/mm	.73
DP Early	Y = -982.3 + 10.7kg/ha/mm	.62
DP Late	Y = -859.5 + 10.0kg/ha/mm	.66

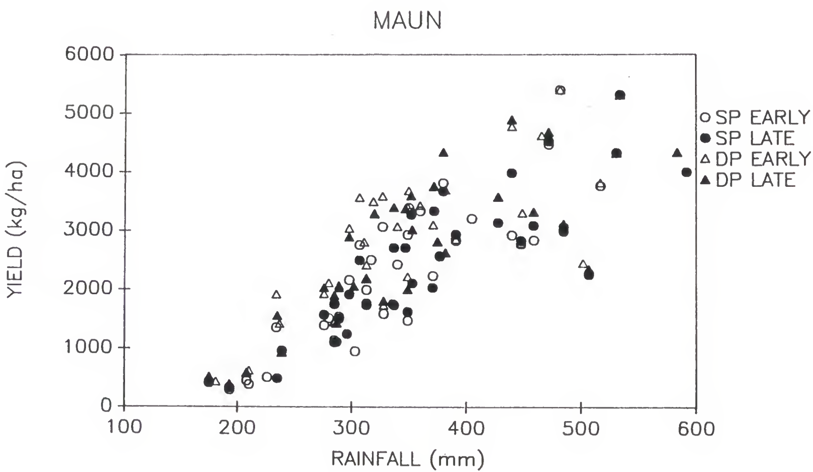

Fig 17. Effects of rainfall, planting time and plowing scheme on sorghum yield at Maun.

CONCLUSIONS

Using SORKAM with Botswana data produced results in agreement with previous studies, but also went beyond the scope of the field trials, giving information on sorghum yields under different soil, water, and climatic conditions.

From this project it was determined that double plowing (reduced runoff) increased sorghum yields up to 32% over single plowing. The lowest increase was at Marapong, a soil with over 90% sand. The greatest increase was at Shoshong, a soil with about 50% clay. Double plowing seems to be most effective on soils with higher water holding capacities, which can store the greater amounts of water intercepted. Using a wide range of soils is still recommended; double plowing may not be as effective on sandy soils, but as discussed earlier, sandier soils may allow even light rains to penetrate to the root zone (Anon., 1985a).

Except for Gaborone, double plowing increased the variability as measured by the standard deviation over that of single plowing, but decreased the relative variability as measured by the coefficient of variation. Although double plowing may have a greater range of yields, average yields are higher than for single plowing. In other words, double plowing may be a practical method even for risk-averse farmers.

Early planting increased average yields over late planting except at Gaborone where there was no difference, and had lower variability than late planting.

For both double plowing and date of planting, it might be useful to compare individual years during wet and dry cycles to determine the effects of these treatments under specific conditions.

No date of planting was optimum, so the practice of planting after each rain is sound. Plowing anytime after harvest when moisture is available and again when planting in the spring would be the most practical solution, given the weakened condition of cattle at the beginning of the growing season. This would give the advantage of double plowing without planting much later in the season.

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Appendix Table 1. Sample input file for WGEN.

```
GENERATED TMAX, TMIN, RAIN, AND RADIATION  - FRANCISTOWN
    40    1 21.2    2    1
.001 .250 .333 .338 .439 .483 .581 .543 .500 .468 .250 .417
.006 .005 .028 .089 .181 .207 .196 .177 .114 .080 .029 .012
.998 .771 .634 .686 .789 .746 .677 .648 .671 .687 .716 .494
.038 .195 .458 .297 .384 .492 .597 .743 .387 .416 .452 .433
   88.19   38.95     .08     -.04
   78.19
   56.35   38.61     .10     -.05
  495.00  220.00
  345.00
   73. 80. 85. 87. 88. 88. 88. 88. 86. 83. 79. 73.
   40. 47. 55. 63. 65. 66. 67. 67. 62. 57. 48. 41.
    .0  .0  .1 0.9 2.2 3.6 4.0 3.2 2.7 0.7  .2  .1
```

Appendix Table 2. Summary of inputs for WGEN.

Line no.	Variable	Description
1	Heading	
2	Number of years of data to be generated	
	Generation option code	Chose to generate p, tmax, tmin, and r
	Latitude, deg	
	Temperature correction factor code	Chose correction factors for max and min temps
	Precipitation correction factor code	Chose to correct precipitation
3	Monthly probability of wet day given wet previous day	WGENPAR
4	Monthly probability of wet day given dry previous day	WGENPAR
5	Monthly values of gamma distribution shape parameter	WGENPAR
6	Monthly values of gamma distribution scale parameter	WGENPAR
7	Mean of tmax (dry)	Avg of max temps + 5 deg
	Amplitude of tmax (wet or dry)	Avg of std. dev. of max monthly temps
	Mean of coef of var of tmax (wet or dry)	Used value given for Yuma
	Amplitude of coef of var of tmax (wet or dry)	Used value given for Yuma
8	Mean of tmax (wet)	Avg of max temps - 5 deg
9	Means of tmin (wet or dry)	Avg of min temps

	Amplitude of tmin (wet or dry)	Avg of sd of min temps
	Mean of coef of var of tmin (wet or dry)	Used value given for Yuma
	Amplitude of coef of var of tmin (wet or dry)	Used value given for Yuma
10	Mean of r (dry)	Avg radiation
	Amplitude of r (wet or dry)	Used value given for Yuma
11	Mean of r (wet)	Avg rad -150
12	Monthly values of actual mean max temp (F)	Botswana - beginning with July
13	Monthly values of actual mean min temp (F)	Botswana - beginning with July
14	Monthly values of actual mean precip amount (in)	Botswana - beginning with July

Appendix Table 3. Summary of inputs for SORKAM.

Date of planting:	For early planting this is the day after the first rain >10mm (.39 in). For late planting this is the day after the second rain (>3 days after the first rain, and > 10mm).
Sowing depth:	5.0 cm.
Row spacing:	76.2 cm.
Plant density:	25,000 plants/ha.
Maturity class:	Early. RS610.
Photoperiod:	Not sensitive. RS610.
Maximum rooting depth:	From SCS soil report.
Leaf number:	15 RS610.
Tillering slope and intercept:	0.087 -.910 RS610.
Seed number:	0.00083 RS610.
Soil evap coefs Stage 1: Stage 2:	Calculated from coefficients given in Jafaar et al. (1978) for Kansas soils.
Dry soil albedo:	.15
Air-soil temp ratio:	1.13
PET method:	Priestly-Taylor.
Soil layer thickness:	From soil report.
Initial avail soil water:	0.0
Max avail soil water:	From soil report.
Bulk density:	From soil report.
Percent clay:	From soil report.

Starting date of climate data:	November 1.
Length of simulation:	220 days.
Amplitude of insolation:	Same as for WGEN.
Avg insolation for wet and dry days:	Same as for WGEN.
Runoff curve:	From SORKAM documentation. 91 used to represent single plowing, 72 used to represent double plowing.
Field slope:	From soil report.

SIMULATING THE EFFECTS OF DOUBLE PLOWING AND DATE OF PLANTING ON SORGHUM YIELDS IN BOTSWANA

by

COLLIN KAY THOMPSON

B.A., University of Kansas, 1986

AN ABSTRACT OF A THESIS

Submitted in partial fulfillment of the

requirements for the degree

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Kansas State University
Manhattan, Kansas

1988

ABSTRACT

Traditional farming methods in the tropics usually yield 500-1000 kg/ha of sorghum; in Botswana, however, sorghum yields are 150-300 kg/ha. In the eastern part of Botswana, traditional planting involves broadcasting the seed, and then plowing it in. No rain falls from May to October; the soils become very hard so the farmers must wait for the first planting rain (a rainfall >10mm) before they can begin planting in November. Because the soils dry quickly, only part of a field can be planted after a rain. The farmers wait for the next rain before they continue planting. In this way, planting occurs throughout the growing season, thereby spreading risk. Average yearly rainfall here is about 460mm, but much of the rain is unavailable to crops due to crusted soils and rapid runoff.

Farming systems teams in Botswana are working with farmers to find more productive farming methods. Currently they have field studies on double plowing (an extra preplant tillage operation in late fall or early spring) and date of planting.

SORKAM, a computer growth model for sorghum, was used to simulate these field experiments to determine the effects of double plowing and date of planting on sorghum

yields in Botswana.

WGEN, a weather generator program, was used to generate forty years of climatic data to run SORKAM simulations. Climatic data from four areas, data from six soils in these areas, and planting data from the farming systems field experiments were inputs for SORKAM.

High and low runoff values were used to represent the two plowing schemes--traditional, or single plowing, and double plowing, respectively. Two planting times were used for each year of the simulation; early planting was the day after the first planting rain of the season, and late planting was the day after the next planting rain occurring more than three days after the first planting rain. Four combinations were run for each of the forty years at a location: single plowing-early planting, single plowing-late planting, double plowing-early planting, double plowing-late planting.

Double plowing always increased yields over traditional plowing,and early planting always increased yields over late planting. Early planting decreased variability, but double plowing tended to increase variability; yields were always higher with double plowing, so this should not dissuade risk-averse farmers. No planting date was optimum, so the current practice of planting after each rain is supported.