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Stand establishment of both pearl millet and sorghum is a problem in most areas where these crops are grown. Seed characteristics, particularly size and density, are important in stand establishment and, in some cases, yield. This study evaluated the effects of seed characteristics on stand establishment and yield in farmers' fields in Botswana in conjunction with two ongoing farming systems programs, Agricultural Technology Improvement Project (ATIP) and Agricultural Development Ngamiland Project (ADNP). In the Etsha villages near Gumare, bold (large and dense) millet seed was compared with control seed using both conventional hill and rotary jab planting methods. In the Francistown and Mahalaype areas, millet (bold and control) and sorghum (dense and control) seed characteristics were compared under conventional broadcast planting. Bold millet or dense sorghum seed did not improve establishment. Median values for the stands showed that bold millet seed produced a higher establishment percentage and a slightly higher population than control seed, at least for short durations following planting.

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EFFECT OF PEARL MILLET AND SORGHUM SEED QUALITY ON STAND ESTABLISHMENT IN BOTSWANA

I. Farmer field experiments: Stand establishment and yield, 1986/87

M.Y. Mortlock and R.L. Vanderlip

Agronomy Department

Kansas State University

Fighting Hunger with Research ... a team effort

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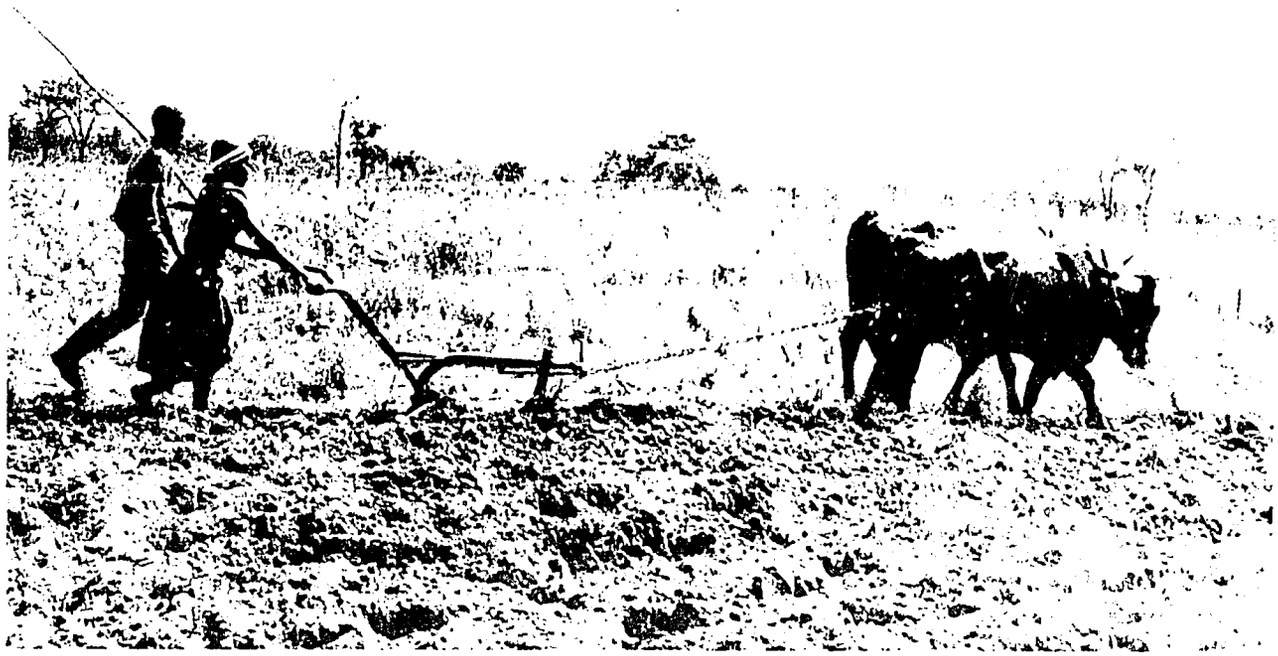

Executive Summary

Stand establishment of both pearl millet and sorghum is a problem in most areas where these crops are grown. Seed characteristics, particularly size and density, are important in stand establishment and, in some cases, yield. This study evaluated the effects of seed characteristics on stand establishment and yield in farmers' fields in Botswana in conjunction with two ongoing farming systems programs, Agricultural Technology Improvement Project (ATIP) and Agricultural Development Ngamiland Project (ADNP). In the Etsha villages near Gumare, bold (large and dense) millet seed was compared with control seed using both conventional hill and rotary jab planting methods. In the Francistown and Mahalaype areas, millet (bold and control) and sorghum (dense and control) seed characteristics were compared under conventional broadcast planting. Bold millet or dense sorghum seed did not improve establishment. Median values for the stands showed that bold millet seed produced a higher establishment percentage and a slightly higher population than control seed, at least for short durations following planting. There were no consistent trends in the sorghum data. It was a very dry season and establishment and yields were extremely variable. At least under these severe conditions, it does not appear that seed quality effects are great enough to be of value as a factor for improving traditional stand establishment.

Farmer Field Experiments

Stand Establishment
1986/87 Season

I. Farmer Field Experiments: Establishment and Yield, 1986/7.

CONTENTS

Page

1. Introduction. 4
2. Literature Review 4
3. Materials and Methods 10
   3.1. Seed Production. 10
   3.2 Agronomic Trials 10
      3.2.1. Design and Sampling in Etsha. 13
      3.2.2. Design and Sampling in Francistown and Mahalapye. . . . 14
      3.2.3. Analysis. 16
4. Results 17
   4.1. Establishment. 17
      4.1.1 Results on Establishment in Etsha 17
      4.1.2. Results on Establishment from Francistown 22
      and Mahalapye.
   4.2. Yield. 24
      4.2.1. Yield results from Etsha. 24
      4.2.2. Yield results from Francistown and Mahalapye. 25

Acknowledgments. 27

References 28

Appendix: Summary of Daily Rainfall by Site 30

List of Tables

Table 1. Emergence of Senegal Bulk millet separated by size and density in Kansas (Gardner, 1980).

Table 2. Improvement of millet seed physical characteristics as observed in trials in Kansas.

Table 3. Thousand seed weights and germination percentages for the seed used in on-farm trials in Botswana.

Table 4. Location, crop, and planting method of on-farm sites.

Table 5. Summary of plot size and layout for the on-farm trials.

Table 6. Planting dates of the on-farm trials.

Table 7. Amount of millet seed planted in Gumare field trials.

Table 8. Amount of seed planted in Francistown and Mahalapye trials.

Table 9. Soil moisture (5-15 cm) at planting for Francistown and Mahalapye locations.

Table 10. Percentage of plots with no emergence at 4 and 6 days after planting.

Table 11. Summary of Wilcoxon signed rank test for Gumare.

Table 12. Median hill number established at the Etsha villages by planting method and seed quality.

Table 13. Median plant plant number established at the Etsha villages by planting method and seed quality.

Table 14. Median number of plants/hill established at the Etsha villages by planting method and seed quality.

Table 15. Establishment as a percentage of that at 8 days after planting.

Table 16. Percent emergence of viable seed planted (median value from 12 plots).

Table 17. Summary of the Wilcoxon signed ranks test for Francistown and Mahalapye sites at 5, 8, and 12 days after planting.

Table 18. Median plant populations established for the Francistown and Mahalapye sites.

Table 19. Percentage emergence based on number of viable seed planted (n=9).

Table 20. Effect of seed quality on yield, seed weight, and population ratio on millet and sorghum.

Table 21. Effect of seed quality on yield, seed weight, and population ratio of millet and sorghum.

1. Introduction

Low seed vigor and poor stand establishment of pearl millet [*Pennisetum americanum* (L.) Leeke] and sorghum [*Sorghum bicolor* (L.) Moench] have been identified as production constraints in many semi-arid areas (Peacock, 1982). Millet seed is small relative to most cereals and is variable in size and density. Seedlings of both millet and sorghum are subjected to high soil temperature, low soil moisture, soil crusts, and a fast-drying, aerial environment in many areas where they are grown. These conditions result in low populations or crop failures. Research in the 1986/87 cropping season examined the role of seed quality within a genotype on establishment and yield of millet and sorghum. This was part of the INTSORMIL (International Sorghum and Millets Project) cooperation with the Department of Agricultural Research at Sebele and the farming systems programs of the Agricultural Technology Improvement Project (ATIP) and the Agricultural Development Ngamiland Project (ADNP).

2. Literature Review

SEED VIGOR

Seed vigor often is overlooked as a factor contributing to successful crop production. Vigorous seed is able to germinate faster and establish a good stand more rapidly than poor quality seed. Vigor includes a genetic (among variety) and an environmental component (Grabe, 1973). Environmental factors are imposed on the genetic potential of a seed of a particular variety. Just as the environment can affect performance through adverse soil moisture, temperature, or soil physical properties, a variety may not perform well if the seed is of low vigor. Seed size, maturity, chemical composition, and deterioration (bad storage, aging, mechanical damage) are contributors to the environmental component of seed vigor. Seed deterioration in storage is affected by temperature and moisture and is predictable for a species (Roberts, 1960).

TESTS FOR VIGOR

Woodstock (1973) reviewed tests for vigor and concluded that correlations of these tests with field establishment are unlikely to be consistent because of the unreproducibility of conditions in the field from day to day or among locations. Matthews (1981) remarked that vigor is a relative term, and a seedlot in isolation can have no absolute level of vigor. Several vigor tests have been developed, such as the cold test, exhaustion (dark) test, electrical conductivity, tetrazolium, ammonium chloride, or accelerated aging (Heydecker, 1972).

Artificial aging, soil cold test, and soaking in ammmonium-chloride vigor tests correlated with field emergence of sorghum (Abdullahi and Vanderlip, 1972). A standard germination test (AOSA, 1970) for sorghum was poor in discerning the physiological condition of a seed lot. Low vigor seeds produced shorter seedlings, fewer tillers, and a lower grain yield (Carmargo and Vaughan, 1973).

DIFFERENCES AMONG GENOTYPES

Seed characteristics vary among genotypes. In wheat (Triticum aestivum, L.), semi-dwarf genotypes have short coleoptiles, which have trouble breaking the surface from deep plantings. Krishnasamy (1986) found that initial germination of sorghum was positively correlated with rate of germination which varied greatly among genotypes.

In evaluating correlations between seed and seedling characteristics for millet genotypes, seed size was found to have a significant positive correlation with seedling vigor, ear length, yield, and size of seed produced (Chhina and Phul, 1982). Seedling vigor also was postively correlated with plant height, tiller number, ear length, and grain yield. Thus, yield could be improved by selecting for large seed, because the results were consistent under stress and non-stressed moisture conditions. Under moisture stress conditions, seed size was postively correlated with days to maturity. Seed size was negatively correlated with the initiation and termination of tillering.

SEED SIZE AND COMPOSITION

Seeds may be separated by weight, diameter, or density (apparent specific gravity). Heydecker (1972), reviewed seed size for several species and larger seeds often produced larger seeds. Seed treatments for improved field performance include selection-grading, hygiene, dormancy breaking, germination advancing, conditioning by application of chemicals, and mechanical pelleting (Heydecker and Coolbear 1977). In soils deficient in nutrients, there may be an advantage in a seed having high levels of minerals. Seed size varies as a result of plant to plant variability, interplant competition for water and nutrients, and locational differences on the infloresence because of temporal or nutritional conditions. Barley (Hordeum vulgare L.) showed variation of 35, 73, and 52 % in seed size because of among-plant, among-ear and among-ear position, respectively (Wood et al, 1977). Large wheat seeds germinated faster and produced seedlings with higher dry weights than smaller seed. Wheat seed weight correlated significantly with plant weight (Kittock and Law, 1968). Austin and Longden (1967) found that larger-seeded carrots (Daucus carota L.) had a higher percent emergence and produced larger seedlings for 15 to 18 weeks of growth than those from smaller seed. Yield differences did not occur. Wood et al., (1977) suggested that for a short season crop, where economic yield is grain, the advantage of large seed often persists through to yield.

Seed size effects of sorghum were not consistent on resulting seedling characteristics among seedlots (Abdullahi and Vanderlip, 1972). Seed size in twin-seeded (smaller) compared to single-seeded sorghum had little effect on seedling characteristics or emergence (Suh et al., 1974). Gardner (1980) working in Kansas, found that relatively dense seed or seed that was relatively large gave improved percentage emergence and grain yield (Table 1).

In some studies, small seeds are better; small wheat seeds germinated faster (Lafond and Baker, 1986), and smaller corn seeds hydrated faster (van de Venter, 1987). Rate of water uptake has been correlated to sorghum seed

size (Maiti et al., 1985). It may be that large seed shows an advantage over smaller seed under equal stand densities and in spaced plantings, but not if planted at an equal weight or volume (Grabe, 1973).

Table 1. Emergence and yield of Senegal Bulk millet separated by size and density in Kansas (Gardner, 1980).

Density (g/cm_3)	Emergence	Grain Yield
	%	kg/ha
<1.241	42	1,190
1.241	50	1,600
>1.275	60	1,940
Original Seed	46	1,650

Diameter (mm)	Grain Yield
	kg/ha
<2.0	1,600
2.4	3,100
>2.8	2,900
Original Seed	1,800

Seedling emergence was increased 22% with large, dense millet seed compared to small, light seed. The interactions of size and density suggested that seed weight was the important determinant in improving seedling vigor (Lawan et al., 1985). Rate of emergence [Maguire's index, (Maguire, 1962)] was higher for larger or denser seed. Density was associated with a high fraction of vitreous starch in the endosperm. Singh and Makne (1985) found correlations between millet seed weight and seedling fresh weight and shoot and root length.

The interaction of size and temperature was significant in an experiment with three seed sizes of five pearl millet varieties (Misra et al., 1966). Germination of small seeds was reduced more at 40 C than that of medium or large seed. The optimum temperature for germination was 30-35 C.

MANIPULATION OF SEED SIZE

By changing the supply of assimilates, grain size can be manipulated. Grain size in wheat was increased by thinning before anthesis and decreased by shading after anthesis (Martinez-Carrasco and Thorne, 1979). Halving the ear also increased grain size. Under poorer growing conditions, a larger effect was found with the halved-ear treatment; the rate of grain fill in halved ears was increased throughout the period under poorer growing conditions but only during early grain growth under better growing conditions (see also Okonkwo and Vanderlip, 1985).

Kansas State University (KSU) is one of six US institutions cooperating in the International Sorghum and Millets Project (INTSORMIL). KSU-6 is the INTSORMIL Project concerned with the study of seedling vigor and stand establishment of pearl millet. Work has centered around the improvement of seed quality by manipulating the millet head or applying treatments to increase grain size and density. The most promising methods for improving seed size and density were head selection (HS) and spikelet removal (SR) (Okonkwo and Vanderlip 1985). These methods involved removal of one-third of the spikelets by removing either the top of the head or a longitudinal strip of spikelets. Seed physical characteristics were affected as shown in Table 2.

Table 2. Improvement of millet seed physical characteristics as observed in trials in Kansas.

Year	Management practice	Seed size	Seed density	Seed protein	Improved establishment (out of 3 experiments)
1980	SR	*	*	*	1
1981	SR	*	*	*	3
"	HS	*	*	*	3
1982	SR	*	*	.	2
"	HS	*	*	.	2

* Denotes significantly improved compared to the control (5%).

Seed quality effects on emergence were less evident under good growing conditions (Gardner, 1980). Various cultural treatments manipulating the assimilate supply to the grain were tested on pearl millet. A longitudinal removal of one-third of the spikelets and selection of heads improved field emergence and yield (Table 2). In good growing conditions, there were fewer differences among seed produced from these treatments (Okonkwo and Vanderlip, 1985).

Freyenberger (1986) examined physical separations of the seed produced from spikelet removal and head cutting treatments. Large and bold (both large and dense) separation classes improved establishment at Manhattan, KS and dense seed improved establishment at St. John, KS. Neither treatment improved seedling emergence.

A series of field trials conducted in Kansas examined seedling establishment under high soil temperatures by using a plastic mulch to raise soil temperature (Modiakgotla, 1985). Growth chamber, greenhouse, and incubator experiments were conducted on millet germination and establishment. Results from the field showed no interaction of seed quality response with temperature and, thus, improved establishment arising from better seed quality was expected to be found in areas with high soil temperatures (Vanderlip 1986).

In summary, the advantage of good seed vigor is likely to be greater with a crop planted to stand or under spaced plantings and with an annual crop rather than a perennial. Seed vigor is defined by Grabe (1973) as 'the actual performance potential of a seed in relation to its genetic potential'. Seed vigor may show its effect in speed of establishment, density of stand, rate of seedling and plant growth, the time and uniformity of flowering and maturity, yield, and storability. Therefore, a season's testing was planned in Botswana to determine whether improved establishment and yields could be obtained from planting large and/or high density seed. Effects of seed quality on stand establishment and yield of Serere 6A millet and Segaolane sorghum under Botswana farmer field conditions are reported here.

3. Materials and Methods

3.1. SEED PRODUCTION

Trials in Botswana were to be done using seed that had been produced in Kansas. This was hampered by the very wet conditions at planting and the occurrence of gray head molds on the grain. Thus Serere 6A millet and Segaolane sorghum seed obtained from the Seed Multiplication Unit, Agricultural Research Station, Sebele was physically separated and used for the trials. Size and density separations were obtained by sieving and flotation in sucrose solution. 'Bold' millet seed (larger than 2.58 mm diameter and greater than 1.26 g/cc density) was compared to 'control' (original, unseparated) seed. For the sorghum variety Segaolane there was little difference in seed size. Therefore, dense seed (greater than 1.29 g/cc) was compared to control seed. Density separation with sucrose solution requires that the seed be washed after separation, which may remove the Captan and Malathion[1], so the control seed was also rinsed and dried. Standard germi-nation was determined by the seed testing laboratory at Sebele (Table 3).

Table 3. Thousand seed weights and germination percentages for the seed used in on-farm trials in Botswana.

Seed	Germination	Thousand Seed Weight		(±SE)
	%	g		
Millet Control	93	12.15	±	.08
Millet Bold	99	14.93	±	.17
Sorghum Control	91	21.30	±	.15
Sorghum Dense	98	19.89	±	.31

3.2. AGRONOMIC TRIALS

Eleven farmers were identified to test establishment of control and bold or dense seed for millet and sorghum, respectively. The farming systems team in Gumare from the Agricultural Development Ngamiland Project (ADNP) identified five farmers in the Etsha villages. The Agricultural Technology

[1] Captan and 5% malathion seed dressing at 180g/100kg seed

Improvement Project (ATIP) in Central Districts at Francistown and Mahalapye identified three farmers in each area in their project villages (Table 4).

Table 4. Location, crop, and planting method of on-farm sites.

Village	Farmer's name	Planting method	Crop
Ngamiland (ADNP project offices in Gumare)			
ETSHA 9	SEKGOMA	Hill (Hoe and Jab)	Millet
ETSHA 1	MEIEME	Hill (Hoe and Jab)	Millet
ETSHA 7	KADTHIMO	Hill (Hoe and Jab)	Millet
ETSHA 8	MOSENYEGI	Hill (Hoe and Jab)	Millet
ETSHA 6	SAODIMO	Hill (Hoe and Jab)	Millet
Francistown (ATIP)			
MATHANGWANE	MS MATHANGWANE	Broadcast	Millet,Sorghum
MARAPONG	BAYA	Broadcast	Millet,Sorghum
MATOBO	GECHE	Broadcast	Millet,Sorghum
Mahalapye (ATIP)			
MAKORO	SETSHWAELO	Broadcast	Millet,Sorghum
MAKORO	MS RABABEDI	Broadcast	Millet,Sorghum
MAHALAPYE	KHUMELO	Broadcast	Millet,Sorghum

Objectives of the testing were to examine crop establishment in many environments (site by date combinations). The 11 farmers were to plant on three dates giving 33 different environments. A simple design of four plots (replicated across farms) was used. Plot size and sampling methods are given in Table 5. Planting dates in chronological order for the three regions are given in Table 6. Rainfall data are in Appendix Tables 1 through 7. In Francistown, the plots were broadcast-planted on land that had been ploughed following an earlier rain. At the second planting, two replicates were planted since it was too late to expect to get a third date as planned. In Mahalapye, the plots on the first planting were not pre-ploughed. On the second date, the land had been ploughed following a previous rain.

Table 5. Summary of plot size and layout for the on-farm trials.

Region	Plot size m	Quadrats[1] per plot	Quadrat layout	Sampling % of plot
GUMARE	10 X 10	5	RANDOM	20
FRANCISTOWN	20 X 10	10	SYSTEMATIC	20
MAHALPYE	20 X 10	10	SYSTEMATIC	20

[1] Quadrat size 2 X 2 m

Table 6. Planting dates of the on-farm trials.

Code	Location	Village	Planting date	Day of the year
A	GUMARE	ETSHA 9	28 NOV	332
M	GUMARE	ETSHA 6	3 DEC	337
G	GUMARE	ETSHA 7	4 DEC	338
D	GUMARE	ETSHA 1	7 DEC	341
H	GUMARE	ETSHA 7	10 DEC	344
E	GUMARE	ETSHA 1	27 JAN	27
B	GUMARE	ETSHA 9	30 JAN	30
N	GUMARE	ETSHA 6	3 FEB	34
J	GUMARE	ETSHA 8	5 FEB	36
K	GUMARE	ETSHA 8	13 FEB	44
O	GUMARE	ETSHA 6	16 FEB	47
I	GUMARE	ETSHA 7	19 FEB	50
L	GUMARE	ETSHA 8	19 FEB	50
F	GUMARE	ETSHA 1	20 FEB	51
C	GUMARE	ETSHA 9	27 FEB	58
R	FRANCISTOWN	MATHANGWANE	not planted	
S	FRANCISTOWN	MARAPONG	4 DEC	338
V	FRANCISTOWN	MATOBO	10 DEC	344
P	FRANCISTOWN	MATHANGWANE	16 DEC	350 1*
Q	FRANCISTOWN	MATHANGWANE	16 DEC	350 2*
W	FRANCISTOWN	MATOBO	21 JAN	21 1*
X	FRANCISTOWN	MATOBO	21 JAN	21 2*
T	FRANCISTOWN	MARAPONG	23 JAN	23 1*
U	FRANCISTOWN	MARAPONG	23 JAN	23 2*
AE	MAHALAPYE	MAKORO	not planted	
AF	MAHALAPYE	MAKORO	not planted	
AH	MAHALAPYE	MAHALAPYE	not planted	
AI	MAHALAPYE	MAHALAPYE	not planted	
AG	MAHALAPYE	MAHALAPYE	5 DEC	339
AA	MAHALAPYE	MAKORO	6 DEC	340
AD	MAHALAPYE	MAKORO	8 DEC	342
AB	MAHALAPYE	MAKORO	4 FEB	35
AC	MAHALAPYE	MAKORO	4 FEB	35

1* and 2* = Rep 1 and 2 at these sites, since these were planted on the same date.

3.2.1. Design and Sampling in Etsha.

The Gumare research team (which works with farmers in the Etsha vilages) was interested in comparing hand-planting and jab-planting, therefore, this was incorporated in the design for the Etsha villages. (The jab planter was originally invented by G.Banbury and called the 'Banbury Dibber Seeder'. Then it was developed into the 'MASDAR Rotary Injection Planter' distributed by Hayters Ltd.,Bishops Stortford,U.K. It currently is made by L.P.Engineering Co, of Bishops Stortford, U.K. Also, ATIP has recently contracted with a local manufacturer to assemble 50 units).

In the Etsha villages, two planting methods were used with control and bold millet seed (Table 4). The millet was planted by the field assistants. They were given four color-coded packets of seed per trial with each color representing a plot to be planted. The packets were pre-weighed to contain 30g and 265g for the hand- and jab-planted plots, respectively, because the jab planter was known to need more seed. After planting, any seed remaining was reweighed to give the seed weight planted. Seeding rate planted ranged from 0.7 to 2.06 kg/ha for hand planting and 5.64 to 24.8 kg/ha for the jab planter. Mean values are shown in Table 7.

Table 7. The amount of millet seed planted in Gumare field trials.

Method	Seed	Mean Wt planted	1000 seed wt.	Seed No. per quadrat	Germi-nation	Viable seed per quadrat
		kg/ha	g		%	
Hand	Control	1.2	12.15	159	93	148
Jab	Control	14.9	12.15	1965	93	1828
Hand	Bold	1.3	14.93	140	99	139
Jab	Bold	12.8	14.93	1374	99	1359

The sampling method was 5 randomly placed quadrats that sampled 20% of the plot area (Table 5). The number of hills and plants emerging in each

quadrat 4, 6, and 8 days after planting were recorded by the field assistants. Total hill number and total plant number for the five quadrats were used in the statistical analysis. Trials that produced yield were harvested by plot (100 m sq^2).

3.2.2. Design and Sampling at Francistown and Mahalapye.

In Francistown and Mahalapye, 'control' and 'bold' millet seed and 'control' and 'dense' sorghum seed were tested (Table 4). Twenty percent of the plot area was sampled by quadrats (Table 5).

In conjunction with the field staff, a suitable planting day was arranged with the farm family so that the principal scientist could be present at all plantings. A Cyclone Seeder (Model X4A. Allegheny International Hardware Group, Shiremanstown, Pennsylvania) was used to broadcast the seed. Seed weights and number planted are described in Table 8. All seed was distributed within the plot.

Table 8. The amount of seed planted in Francistown and Mahalapye trials.

Crop	Seed	Wt planted	1000 Seed weight	Seed No. per quadrat	Germi-nation	Viable seed/ quadrat
		kg/ha	g		%	
Millet	Control	3.5	12.15	115	93	107
Millet	Bold	3.5	14.93	94	99	93
Sorghum	Control	4.0	19.88	81	91	74
Sorghum	Bold	4.0	21.30	75	98	74

The mean number of viable seeds planted per 2 m sq quadrat was 100 for millet and 74 for sorghum. This represents a planted population of 250,000 and 183,750 seeds per hectare, respectively.

Quadrats (2 x 2 m) were permanently marked on the day of planting at two corners. The markers (drink cans painted red and yellow) were positioned with

a metal peg and labeled with an indelible marker. These permanent positions allowed for recounting at the same position over the season. Soil moistures at planting are shown in Table 9. Total number of plants/quadrat was counted on 5, 8, and 12 days after planting.

Table 9. Soil moisture (5-15 cm) at or shortly after planting for Francistown and Mahalapye locations.[1]

LOCATION Farmer, Village	Date of sampling	Gravimetric soil moisture	Days after planting
		%	
FRANCISTOWN			
Baya, Marapong			
1st Date	17 Dec	5.58	13
2nd Date (rep 1)	23 Jan	7.83	0
2nd Date (rep 2)	23 Jan	5.75	0
Geche, Matobo[2]			
1st Date (Plot 1 & 2)	10 Dec	9.23	0
1st Date (Plot 3 & 4)	10 Dec	14.30	0
1st Date (Plot 1 & 2)	15 Dec	6.44	5
1st Date (Plot 3 & 4)	15 Dec	9.68	5
2nd Date (rep 1)	21 Jan	10.50	0
2nd Date (rep 2	21 Jan	11.30	0
Ms. Mathangwane, Mathangwane			
1st Date	16 Dec	7.12	0
1st Date	24 Dec	5.99	8
MAHALAPYE			
Setshwenlo, Makoro			
1st Date	6 Dec	6.44[3]	0
2nd Date (rep 1)	4 Feb	5.76	0
2nd Date (rep 2)	4 Feb	4.38	0

[1]Sampling was at one position per plot, and the mean for 4 plots is given (except 6 Dec at Makoro with 3 plots).

[2]There was a difference at Matobo (1 st Date) between plots 1 and 2 and the other two plots due to a difference in timing of the double ploughing.

[3]Field capacity determined at 0-10cm as 7.9% from report by SMSS (1987).

Trials that produced yield in the broadcast plots were harvested by quadrat (10 /plot). Weights of grain from each of the 10 quadrats per plot were recorded, and after the seed was bulked, three replicates of hundred seed weights per plot were made. Moisture percentage was determined by a

moisture meter (Steinlite Electronic Moisture Tester, Fred Stein Laboratories Inc, Atchison, Kansas), using 100 g and 150 g of millet and sorghum, respectively. If there was not enough seed, the seed from the two plots of that crop was bulked.

Yield and hundred seed weights were adjusted to 12.5 % moisture for both crops, before statistical analysis. A ratio of the population at harvest to that at 12 days after planting was also calculated from the summed values for the 10 quadrats.

3.2.3. Analysis

Inspection of the data showed that they were not normally distributed. This meant that nonparametric tests were applicable. A Wilcoxon matched-pairs, signed-rank test (Steel and Torrie 1976) was used to compare the bold and control seed within the millet and sorghum. The two seed types were considered to be a pair for each environment. The planting methods at Etsha were compared in the same way by combining data for both seed types, rather than performing tests within seed type. The test allocates the signed differences between (X1,Y1) up to (Xn,Yn), and then ranks them. No difference situations are ignored and n is reduced accordingly. The sums of the positive ranks S+ and the negative ranks S- are then calculated. The smaller one is checked with a set of tables (Steel and Torrie 1976) to show the level of significance. For example the smaller rank needs to be less than 3.7 when n = 8 to be significant (P=.05).

These tests were carried out using the DAISY statistical package (written by K.C.Killion in 1983, Rainbow Computing Inc., Version 2.3). The analysis for Francistown and Mahalpye was done by crop in SPSS/PC+ with the code (date by location) as one factor and 9 levels and seed quality (control and bold or dense) as the second.

4. Results

4.1. ESTABLISHMENT

4.1.1. Results for Establishment in Etsha.

Exact percentage of hills that emerged was not known, since the number of hills planted was not recorded. At Etsha 1 only two location-date combinations have been included for the hill numbers, because the data were incorrectly taken on the first date. By 8 days after planting, all plots had plants emerged, and in three of the sites, all plants had emerged by 6 days after planting.

Failures to emerge early were examined by treatment (Table 10). There were more failures in the hand-planted plots, but eventually all plots did have some plants emerged.

Table 10. Percentage of plots with no emergence at 4 and 6 days after planting.

Method	Millet seed	Number of plots	Days after planting 4	6
			%	
Hand-planted	Control	14	36	14
	Bold	14	36	14
Jab-planted	Control	14	29	7
	Bold	14	29	7

Results of Wilcoxon Signed Rank tests showed no significant difference in hill or plant number or plants/hill because of seed quality when tested within the planting method (Table 11). In every case, however, the comparison between the two planting methods gave highly significant differences. The differences were evident on 4, 6, and 8 days after planting. There were more hills, more plants, and more plants per hill in the jab-planted crop. This was expected, since approximately 10 times more seed was planted (Table 7).

Since the data were not normally distributed, median values rather than means are presented in the following tables. The final established hill population was 13,500 hills ha^{-1} for hand-planted and 44,000 for the jab-planted

(Table 12). At 4 days after planting, the median hill population was 4 or 5 times greater for jab planting than for hand planting; this ratio had reduced to 3 times by day 8. There was a tendency for hill number to be greater from bold seed in both planting methods on all three days when counts were made.

Table 11. Summary of Wilcoxon Signed Rank Test for millet planted at Gumare.

Comparison	DAP	Number of plots	Number with a difference (n for test)	Lowest S value	Significance level
Total hill numbers					
Seed within hand-planted	4	14	8	16	NS
Seed within jab-planted	4	14	10	20.5	NS
Between methods	4	28	20	1	***
Seed within hand-planted	6	14	10	23.5	NS
Seed within jab-planted	6	14	13	36.5	NS
Between methods	6	28	26	1	***
Seed within hand-planted	8	14	14	37.5	NS
Seed within jab-planted	8	14	14	26	NS
Between methods	8	28	27	0	***
Total Plant Number					
Seed within hand-planted	4	13	8	16	NS
Seed within jab-planted	4	13	9	14.5	NS
Between methods	4	26	18	0	***
Seed within hand-planted	6	13	11	28	NS
Seed within jab-planted	6	13	12	29	NS
Between methods	6	26	24	0	***
Seed within hand-planted	8	13	13	36.5	NS
Seed within jab-planted	8	13	12	38.5	NS
Between methods	8	26	26	0	***
Plant Number per Hill					
Seed within hand-planted	4	13	8	18	NS
Seed within jab-planted	4	13	9	21	NS
Between methods	4	26	18	0	***
Seed within hand planted	6	13	11	26	NS
Seed within jab-planted	6	13	12	28	NS
Between methods	6	26	24	0	***
Seed within hand-planted	8	13	13	37	NS
Seed within jab-planted	8	13	13	32	NS
Between methods	8	26	26	0	***

NS = not significantly different at the 5% level.
*** = significantly different at the .01% level.

Table 12. Median hill number established at the Etsha villages by planting method and seed quality.

Method	Millet seed	Days after planting 4	6	8
		---------hills/ha---------		
Hand-planted	Control	6,500	9,750	13,750
	Bold	7,250	12,750	13,250
Jab-planted	Control	29,000	33,250	43,500
	Bold	33,500	34,500	45,750

The median values for the total plant number established for jab-planted as a ratio of hand-planted are 7:1, 5:1 and 4:1 at 4, 6 and 8 days after planting respectively (Table 13). The jab method planted approximately 10 times more seed and, thus, produced a much higher plant population per hectare. The plant number tended to be greater from bold seed for hand planting but not jab planting.

Table 13. Median plant number established at the Etsha villages by planting method and seed quality.

Method	Millet seed	Days after planting 4	6	8
		-------- plants/ha--------		
Hand-planted	Control	13,000	28,500	40,500
	Bold	16,500	30,500	39,500
Jab-planted	Control	121,500	147,000	152,500
	Bold	95,500	139,000	172,500

The median plant number/hill (Table 14) was significantly larger in the jab-planted plots. There was no consistent difference between control and bold seed.

Table 14. Median number of plants/hill established at the Etsha villages by planting method and seed quality.

Method	Millet seed	Days after planting		
		4	6	8
		------plants/hill------		
Hand-planted	Control	1.7	2.7	2.3
	Bold	2.1	2.3	2.4
Jab-planted	Control	3.6	3.8	3.7
	Bold	3.2	4.3	4.2

In order to compare the proportion of the final establishment reached 4 and 6 days after planting, median values are presented as a percentage of those 8 days after planting. Table 15 shows that at 4 days after planting and for both seed types, a higher percentage of the total hills was established for jab- than for hand-planting. By day 6, however, there was little difference between the two methods, except that a high percentage (96%) had been established for hand planting of the bold seed. Similarly, the greater proportion of total plants established tended to occur earlier in the jab-planted plots (Table 15).

Median plants/hill showed that by 4 days after planting, hills had reached 80% of their final number; however, there was evidence of early plant mortality because number of plants/hill at 6 days was larger than that at 8 days.

Table 15. Establishment as a percentage of that at 8 days after planting.

Method	Millet seed	Days after Planting	
		4	6
		- - - - - %	- - - - -
Hill Population Established			
Hand-planted	Control	47	71
Hand-planted	Bold	55	96
Jab-planted	Control	67	76
Jab-planted	Bold	73	75
Plant Population Established			
Hand-planted	Control	32	70
Hand-planted	Bold	42	77
Jab-planted	Control	80	96
Jab-planted	Bold	55	80
Plant/Hill Established			
Hand-planted	Control	72	114
Hand-planted	Bold	87	94
Jab-planted	Control	95	100
Jab-planted	Bold	76	102

Using the number of viable seed planted (Table 7) and the number of emerged plants, it was possible to estimate establishment percentage (Table 16). There was an overall establishment of 37% with hand planting and 16% with jab planting at 8 days after planting. There was a consistently higher percentage of viable seed established from bold seed, with 23%, 28%, and 31% compared to 17%, 19%, and 22% established with control seed at 4, 6, and 8 days after planting, respectively.

Table 16. Percent emergence of viable seed planted (median value from 12 plots).

Method	Millet seed	Days after planting 4	6	8
		%		
Hand-planted	Control	23	26	30
	Bold	30	39	44
Jab-planted	Control	11	11	14
	Bold	15	17	18

In summary, the quality of the seed was not a significant factor in these trials. There was a trend for the median population of hills and the establishment percentages to be larger for bold seed. Despite more hills planted and an increase in plant number and plants per hill, the jab planter was less efficient because a smaller percentage of viable seed was established. Also, the number of hills and the high population per hill might necessitate thinning. However, there appeared to be a trend towards faster establishment with the jab planter, which may be an advantage under rapid soil drying.

4.1.2. Establishment results from Francistown and Mahalapye.

In Francistown and Mahalapye, the trials compared control and improved seed of Serere 6A millet and Segaolane sorghum. Separate Wilcoxon tests were done within the two crops (Table 17). No differences were found between the stands established from the control and bold seed of millet or from the dense and control seed of sorghum for any of the counts (5, 8, and 12 days after planting).

Table 17. Summary of the Wilcoxon Signed Ranks Test for Francistown and Mahalapye sites at 5, 8, and 12 days after planting.

Comparison	Days after planting	Number of plots	Number with a difference (n for test)	Lowest S value	Significance level
Established Population					
Seed within millet	5	9	9	22(16)[1]	NS
Seed within sorghum	5	9	9	21	NS
Seed within millet	8	9	9	20(9)[1]	NS
Seed within sorghum	8	9	9	22	NS
Seed within millet	12	9	9	22(16)[1]	NS
Seed within sorghum	12	9	9	22	NS
Establishment Percentage					
Seed within millet	5	9	9	16	NS
Seed within sorghum	5	9	9	21	NS
Seed within millet	8	9	8	9	NS
Seed within sorghum	8	9	9	22	NS
Seed within millet	12	9	9	16	NS
Seed within sorghum	12	9	9	22	NS

[1] Adjusted for number of seed planted.

NS = not significantly different at the 5% level.

Since slightly fewer 'bold' seeds were planted (see Table 7), an adjustment was made (multiplying by 107/93) to compare seeds on an equal basis; this made no difference to the results.

Median plant populations are given in Table 18. The range was from 0 to 75,000 plants/ha. Bold millet seed produced a higher median population 5 and 8 days after planting than control seed. There was little difference in median values for sorghum.

Table 18. Median plant populations established for the Francistown and Mahalapye sites.

Crop	Seed	Days after planting 5	8	12
		-------plants/ha--------		
Millet	Control	1,500	13,500	29,750
	Bold	22,250	27,750	23,250
Sorghum	Control	12,000	27,750	33,000
	Dense	11,000	25,250	35,000

Table 20 shows that percentage emergence (for germination percentages and seed planted per plot; see Table 7) was lower for millet than for sorghum. Seed density appeared to have no effect on sorghum emergence. Emergence 5 days after planting was nearly 10% for bold millet seed compared to only 4% for the control. This suggests a faster rate of emergence for bold seed. However, this effect was lost by 12 days after planting.

Table 19. Percentage emergence based on number of viable seed planted (n=9).

Crop	Seed	Days after planting 5	8	12
		----------%----------		
Millet	Control	4.3	5.0	11.1
	Bold	9.6	11.9	10.0
Sorghum	Control	6.5	15.0	17.8
	Dense	5.9	14.2	18.9

4.2 YIELD

4.2.1. Results for Etsha.

Etsha plot yields were not analyzed statistically because of large errors involved from loss of yield to cattle, birds, rats, and drought. The range was from 0 to 490 kg/ha, with a mean for 40 plots (four villages) of 84 kg/ha. Head number per plot ranged from 0 to 64,700, with a mean of 18,500 heads/ha.

4.2.2. Results for Francistown and Mahalapye.

Yields were realized from nine sites, three from Mahalapye and six from Francistown. Seed quality did not significantly affect yield, seed weight, or harvest:emergence ratio for either crop (Table 20). Mean results for these three variables are given in Table 21.

Table 20. Effect of seed quality on yield, seed weight, and population ratio of millet and sorghum.

Crop	Seed Quality	Yield	Seed weight	Harvest:emergence population ratio
		kg/ha	g/1000	
Millet	Control	140	8.76	.94
Millet	Bold	136	9.08	1.21
Sorghum	Control	210	10.95	.95
Sorghum	Dense	198	10.87	.82

Table 21. Yield, seed weight, and population ratio of millet and sorghum for the nine environments (location by dates).

Region Environment	Code[1]	Seed weight		Yield		Harvest:emergence population ratio	
		Millet	Sorghum	Millet	Sorghum	Millet	Sorghum
		----g/1000-----		-----kg/ha-----			
FRANCISTOWN	S	9.99	1.83	278	208	.28	.50
FRANCISTOWN	T	8.68	1.65	57	27	1.22	.96
FRANCISTOWN	U	8.57	1.73	30	25	.78	.84
FRANCISTOWN	V	9.80	1.70	118	444	1.98	1.13
FRANCISTOWN	W	8.18	2.08	136	230	.65	.89
FRANCISTOWN	X	9.71	2.08	208	397	.60	.82
MAHALAPYE	AA	8.37	2.34	162	292	.78	.70
MAHALAPYE	AD	10.06	1.97	194	148	2.44	2.21
MAHALAPYE	AG	6.96	1.87	62	43	.93	.58
Significance of environment		*	*	*	+	**	***

*, **, significant at .10, .05, .01, and .001, respectively.

[1]See Table 6 for location-date codes.

Environment significantly affected millet yield (P=.05), seed weight (P=.05), and harvest:emergence stand ratio (P=.01) (Table 21). Yields ranged from 30 to 278 kg/ha, with seed weights from 7.0 to 10.1 g/1000 seeds. Sorghum yields ranged between 25 and 397 kg/ha, with significant differences among environments (P=.10). Seed weights ranged between 16.5 and 23.4 g/1000 seed and varied with environment (P=.10). (Table 21).

Insummary, the establishment from bold millet or dense sorghum seed was not statistically better than that from control seed. Median values of the stands showed that bold millet seed tended to produce a higher establishment percentage and a higher population, at least for 5 and 8 days following planting. There were no such trends in the sorghum data.

It was a very dry season and the yields were very variable and significantly affected by the environment.

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Appendix Table 1. Daily rainfall (mm) for Etsha 1986/87.

	Month							
Date	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1								
2							12.5	
3		.5		7				
4			2.5	5.3				
5			1			6.3		
6				8.9		8.1		
7			10.8			1.9	5.3	
8								
9					1.6	5.2		
10		3.7						
11								
12								
13						3.8		
14								
15		4				.5		
16		17.8				8.7	2	
17		3.4		.6				
18								
19		1.9					4.8	
20			.5					
21					2.5			
22						3		
23						3.5	16.3	
24								
25			2.1					
26		3.7	3.5			1.2		
27	44.1	7.2	22.8					
28		.5						
29								
30		1.3	12.1					
31								
Total	44.1	44	55.3	21.8	4.1	42.2	40.9	0

Appendix Table 2. Daily rainfall (mm) for Matobo 1986/87, (Av 5 sites).

Date	Month					
	Oct	Nov	Dec	Jan	Feb	Mar
1						
2				6.2		
3			12.8		8.6	
4						
5					4.8	
6		2.6	8.6			
7						
8		2.2				
9	4.8		.8			
10						
11						
12						
13						
14				6		
15				7.6		
16	21.4			45.6		
17						
18		3.6		19.6		
19				5.2		
20		4.8				1.4
21						
22						
23				4.8		
24		2.6	13.4			
25			3.8			8.4
26					3.8	
27		21.6			.8	
28		18.8	11.4			
29						
30		6.4				
31	14.6					
Total	0 40.8	62.6	50.8	95	18	9.8

Appendix Table 3. Daily rainfall (mm) for Mathangwane 1986/87, (Av 6 sites).

Date	Month					
	Oct	Nov	Dec	Jan	Feb	Mar
1			19.6			
2			14.9			
3			31.1		9.7	
4						
5						
6		.7	16.3			
7					16.9	
8		6.3				
9						
10	3.3					
11						
12						
13				5.7		
14						
15				6.6		
16	1.4			15		
17	19.9					
18				4.3		
19				9.1		
20		4.6				
21						3.4
22						
23						1.7
24						
25						
26						
27						
28		4.7				
29		24.7	1.6			
30		52.7				
31	41.9					
Total	0 66.5	93.7	83.4	40.7	26.6	5.1

Appendix Table 4. Daily rainfall (mm) for Marapong 1986/87, (av. 3 sites).

Date	Month					
	Oct	Nov	Dec	Jan	Feb	Mar
1						
2						
3			8.3		16.3	
4						
5					18.7	
6		3.7	8.3			
7			1.0			
8		2.7				
9	23.3					
10						
11				7.3		
12						
13				3.7		
14						
15	.7			10		
16	14		5.3			
17			8.7			
18				2.3		
19		2.7		29		
20		5.7		3.3		3.3
21						
22				10		
23				3		
24			1.0			
25						
26					12.3	
27		6.7				
28		13.7	.3			
29	3.3	13.7				
30		8.7	1.0			
31	49.3					
Total	0 90.6	57.6	50.0	68.6	47.3	3.3

Appendix Table 5. Daily rainfall (mm) for Mahalapye 1986/87.

Date	Month							
	Oct	Nov	Dec	Jan	Feb	Mar		
1				22				
2								
3								
4								
5								
6								
7								
8					2			
9				4				
10								
11					6			
12								
13								
14								
15								
16					8			
17								
18								
19								
20		30						
21								
22					6			
23					10			
24				7				
25								
26					12			
27				4				
28		4						
29		11			29			
30		20		30				
31								
Total	0	0	65	67	73	0	0	0

Appendix Table 6. Daily rainfall (mm) for Makora 1986/87, (Setswaelo).

Date	Month							
	Oct	Nov	Dec	Jan	Feb			
1			8					
2								
3								
4						5		
5								
6								
7				5				
8								
9			8	1.3				
10								
11								
12								
13								
14								
15								
16		16			2.5			
17		5		1				
18								
19								
20								
21								
22								
23								
24				2	42			
25		1						
26			26					
27				5				
28			2					
29		4	36					
30			15	8				
31		5			12			
Total	0	31	95	22.3	56.5	5	0	0

Appendix Table 7. Daily rainfall (mm) for Makora 1986/87, (Rababedi).

Date	Month							
	Oct	Nov	Dec	Jan	Feb			
1			1.5					
2								
3								
4						9		
5								
6								
7			20					
8								
9								
10								
11								
12								
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Total	0	0	61	42.5	50	9	0	0