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The Green Revolution in Zimbabwe

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Abstract

This paper presents a historical overview of plant breeding research, variety release and seed supply of staple food grains in Zimbabwe, and assesses the impacts of the new varieties on yields using national aggregate yield data. The paper also analyses farm-level factors determining farmers' adoption decisions in the semi-arid areas, where the mini-green revolution lagged behind more favorable areas. The results indicate that the adoption of improved crop varieties will not lead to substantial yield gains unless improved soil management methods, such as application of manure and fertilizer, are also adopted..

Keywords: *Green Revolution, maize, semi-arid areas, soil fertility management, drought, Zimbabwe*

1. Introduction

In southern Africa, unlike in Asia, the Green Revolution was maize-based. It was built on the technological foundations established in the 1900s by early explorers who introduced maize into African farming systems, where it has remained a main food crop to this day. White settlers started commercial maize production in response to the increasing demand for the grain as food for African mine laborers, maize became widely accepted because maize was easier to process than the traditional staples of sorghum and millet. Maize continues to be the main staple food grains in Zimbabwe, and most of it is produced in the more favorable agro-ecological areas with higher rainfall and better soils. Sorghum and pearl millet production is concentrated in the drier regions because they are more tolerant towards drought. Over the past 50 years, public and private sector investments in maize, sorghum and pearl millet research, seed systems, and extension have resulted in the development, release and adoption of several high-yielding open-pollinated varieties and hybrids. Adoption rates, especially for maize, are very high. Farm surveys indicate that as much as 90 percent of the country's maize area is sown with hybrids. About 25 percent of sorghum and 30 percent of pearl millet area is planted with improved varieties.

The switchover from traditional to improved open-pollinated varieties and hybrid maize was initially accompanied by increases in average smallholder yields in the 1980s. This led to early optimism that the Green Revolution was unfolding in Zimbabwe's smallholder sector. This success has been attributed to a favorable mix of policies, institutions and political support including the development and availability of high performance technologies, human capital development, and physical infrastructure such as roads, telecommunications, markets, small dams and irrigation facilities. Farmer support institutions were also put in place, facilitating access to credit, input and product markets (Eicher, 1995; Rukuni, 1999). Nonetheless, the success of the Green Revolution was highly polarised, firstly towards the large-scale commercial farming community and secondly towards a minority of smallholder farmers, who were mostly in the favored areas. In the 1990s, the national average maize yield stagnated due to a combination of constraints with information, market, institutions and policies (Rukuni and Eicher, forthcoming). The objective of this paper is to examine why the Green Revolution in maize production in Zimbabwe only concentrated in large-scale commercial farming and in smallholder farming in the farmed areas.

The structure of this paper is as follows. An overview of crop improvement research and technological change in Zimbabwe is presented in the next section. The impact of technological changes on maize fields are examines in the following section. Fourth section identifies the factors influencing farmers' adoption of improved varieties of maize and crop management practices in semi-arid areas. A final section begins at the overall conclusions of this paper.

2. Overview of crop improvement research and technological change in Zimbabwe

Historically, maize, sorghum and pearl millet improvement research and extension in Zimbabwe has been dominated by the public sector (Weinmann, 1972 and 1975; Rukuni and Eicher, 1994). Scientific maize breeding started in Zimbabwe by the Department of Agriculture at the Harare Research Experiment Station in 1904, following demands by European farmers to organize agriculture along scientific lines (Smith, 1979). In 1932 the government initiated a maize hybrid-breeding program. In 1945 researchers released several top crosses, which they began bulking and distributing to commercial farmers. In 1949 Zimbabwe became the second country in the world after the United States to produce double hybrid seeds from locally developed inbred lines. The Seed Maize Association produced and marketed this double hybrid, SR1, through the Farmers Co-operative Society[1], and this marked the beginning of the seed industry. The Seed Maize Association developed into the Seed Cooperative Company that evolved into Seed Co., which today is one of the leading companies in Africa. Beginning in 1952, the Department of Native Agriculture purchased hybrid maize seeds from the Seed Maize Association for distribution to smallholders in five-kilogram packs, thereby laying the institutional foundations for hybrid seed systems for smallholders.

The rapid development of the hybrid maize seed industry led the government to expand investments in research stations and experimental farms in the main maize growing areas, and carry out advanced breeding trials. The establishment of the Federation of Rhodesia and Nyasaland in 1954 greatly increased the demand for hybrid maize seeds in the region. During the Federal era from 1953 to 1963, the Seed Maize Association expanded hybrid maize seed exports to Malawi, Zaire, and Mozambique. Seed exports were greatly facilitated when Zimbabwe joined the International Seed Testing Association (ISTA) in 1956 and adopted ISTA's seed quality standards. In the same year, government researchers began a maize breeding program at the Matopos Research Station for the lower and less reliable rainfall areas of the country where, at that time, more than 60 percent of the area used for commercial crops was planted with maize (Rusike and

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[1] SR1 stands for Southern Rhodesia hybrid one.

Donovan, 1995). Throughout the 1950s the hybrid maize program made significant advances, which resulted in the release of 12 hybrids with better yield, grain quality, and agronomic characteristics.

A milestone was achieved in 1960 when government researchers released SR52, which was the world's first single hybrid for commercial cultivation. Although SR52 was initially intended for areas in Zimbabwe with higher and more reliable rainfall and better soil, it was widely adapted to various conditions throughout Eastern and Southern Africa, particularly in the Natal region in South Africa. The success of SR52 in international markets made Zimbabwe one of the leaders of maize seed production in Africa. Following the release of SR52, government researchers turned their attention to crossing local inbred seeds with inbred seeds from South Africa, Mexico and Colombia, which led to the development of double cross hybrids SR13 in 1964 and SR14 in 1966. The Matopos maize breeding program produced four synthetic varieties and a top-cross (American White Flint x K64R) known as Matopos Topcross in 1964, which became the first maize-cultivator bred specifically for the country's lower rainfall areas. It was the forerunner of robust three-way hybrids in the R200 series that replaced it in the 1970s. In the late 1960s, maize breeding at the Harare Research Station was consolidated for greater effectiveness, and three-way hybrids that were well-adapted to lower rainfall areas due to their superior silk-to-pollen synchronization and early maturity, were released. The first three-way hybrid was R200, which was released in 1970, followed by R201 in 1975 and R215 in 1976. The R200 series was widely adopted by smallholders throughout Eastern and Southern Africa, and this enabled Zimbabwe to become the leading exporter of hybrid maize seeds in Africa.

In 1970, the Seed Maize Association, the Commercial Farmers' Union, and the government established a Tripartite Agreement, under which the Seed Maize Association agreed to produce a sufficient amount of maize seed for normal domestic use in addition to maintaining a strategic reserve of 20 percent of Zimbabwe's annual maize seed requirements (Tattersfield and Havazvidi, 1993). In exchange, the government agreed to give the Association exclusive marketing rights to the parent lines developed by its breeders. The agreement also included annual review of maize prices for the domestic market and government control over maize seed exports. The Tripartite Agreement served as a barrier to private competition because it denied access of private companies to government germplasm. The government also devolved responsibility for seed certification to the Seed Maize Association (Hanssen, 1978). The Tripartite Agreement conferred property rights to the Seed Association, which reduced uncertainty and stimulated a small number of commercial seed farmers to produce seeds and reap economies of scale at relatively low profit margins. In exchange, the government was assured a countrywide availability of hybrid maize seeds and a seed reserve that could be used by farmers to replant in case of drought.

The development and introduction of hybrid maize has been described as the greatest single contribution of government research to Zimbabwe’s agricultural industry (Weinmann, 1975). The government breeding program released 30 hybrids between 1950 and 1980 that fuelled the country's first Green Revolution by commercial farmers (Eicher, 1995). Comparisons of improved maize varieties in Zimbabwe relative to the rest of the southern Africa region, and in specific to South Africa, are shown in Table 1.

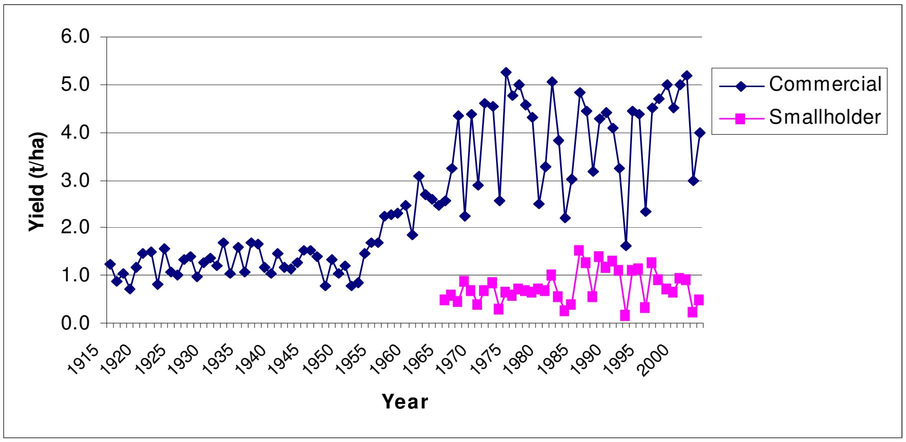
Table 1. Availability Of Improved Maize Varieties in Zimbabwe

	Open-Pollinated Varieties	Hybrids
Number released by public sector breeding (1966-98)		
Zimbabwe	0	12
Southern Africa	43	55
Southern Africa, excluding South Africa	43	55
Number released by private seed Companies and available in 1998		
Zimbabwe	3	30
Southern Africa	6	125
Southern Africa, excluding South Africa	6	57

Source: Hassan, Mekuria and Mwangi (2001).

Considering that seed prices were controlled under the Tripartite Agreement, the seed-to-grain price ratio of single cross hybrids was reduced from 10 to 8 and similarly the price ratio of three-way hybrids was also reduced from 8 to 4 between 1966 and 1981. Without doubt, Zimbabwe's low prices of hybrid maize seeds were a major cause of its rapid expansion in sales, which grew from 10,000 tons in 1980 to 30,000 tons by 1990. Commercial farmers adopted hybrids at a rate faster than in the United States, and it took only 17 years for farmers to switch from local varieties to 100 percent certified hybrid seeds. Commercial maize yield and production began to rise in the 1950s when large-scale farmers started to adopt hybrids, and continued to rise until the late 1980s (Figure 1). Although mechanization, fertilization and improved agronomic practices contributed to improving the maize yield between 1950 and 1980, more than 45 percent of the yield increase is directly attributable to superior-performing hybrids (Tattersfield, 1982).

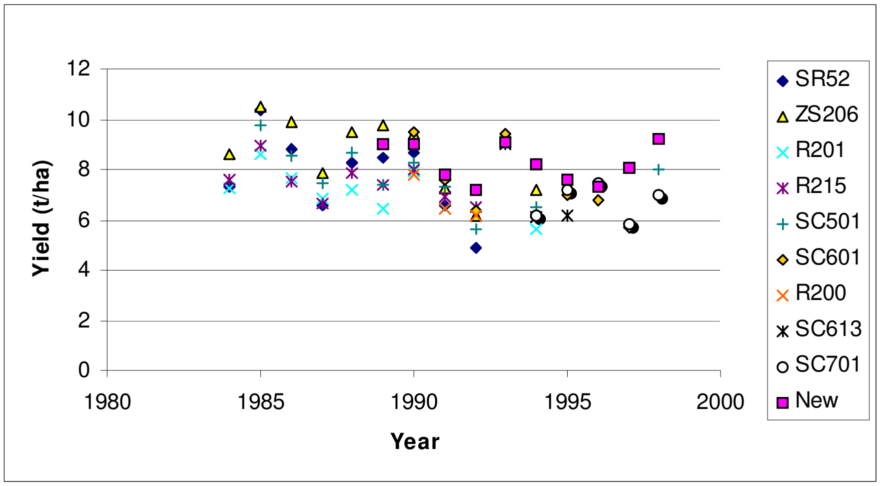
Figure 1. Yield trends of maize for commercial and smallholder farmers, 1915-2003



The rapid adoption of hybrids by smallholders was stimulated by the agricultural extension service during the 1970s with demonstration plots, field days, and other dissemination methods that convinced smallholders of the benefits of planting hybrids (De Woronin, 1993). Since the government committed resources to infrastructure development in smallholder areas after the break-up of the Federation in 1964, small-scale farmers were able to tap the backlog of three-way hybrids at independence in 1980 and spearhead the second Green Revolution in the early 1980s (Eicher, 1985). Hybrid adoption by smallholders rose to about 50 percent by 1975 and 90 percent by 1985 (Rohrbach, 1988; Mashingaidze, 1994). However, the collapse of the public credit system, the escalating prices of hybrid maize seeds, and liquidity constraints in the recent few years have led to the recycling of hybrids by farmers.

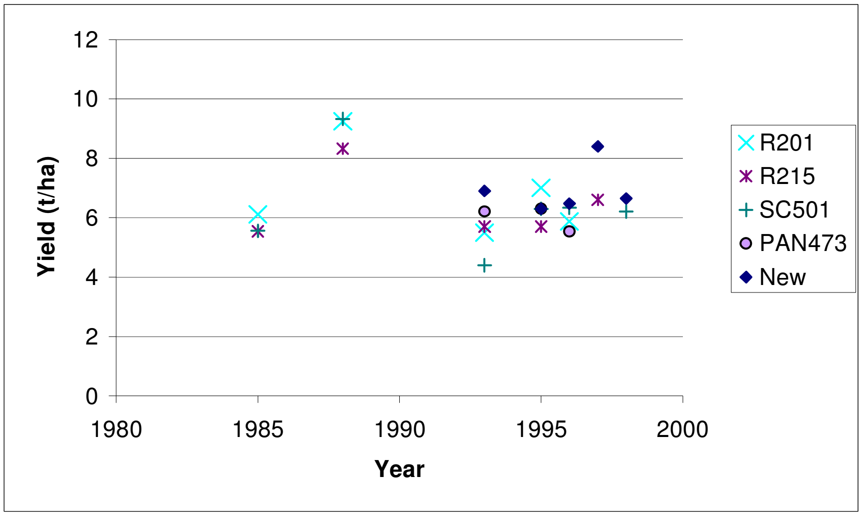
Starting in the mid-1980s several commercial seed companies entered maize breeding and seed marketing in Zimbabwe, thereby increasing competition. There was intense competition to service the smallholder market in particular, because small-scale purchases constituted more than 80 percent of hybrid seed sales in the early 1990s. Seed companies focused on breeding high-yielding hybrids for the favored areas and early-maturing, drought-tolerant hybrids for the less-favored areas. In the high potential areas there was a general decline in the yield potential of old varieties from 1984 to 1996, especially for varieties such as SR52, ZS206, R201 and R215 (Figure 2). This was because the varieties succumbed to grey leaf spot (GLS). The new hybrids released by seed companies from 1988 to 1996 (including PNR609, PAN695, PHB3412, PHB 3043 and SC601) also succumbed to GLS.

Figure 2. Maize variety performance in on-station and on-farm trials, high potential environments, 1983-1998



Starting in about 1997 new GLS-tolerant hybrids were released (e.g. SC709, PAN6243, SC625), and these improved yield potentials to the 10 ton per hectare levels that were achieved in the early 1980s. National and private breeding programs benefited from the infusion of elite germplasm by the International Maize and Wheat Improvement Centre (CIMMYT). For low potential areas, it has been difficult for seed companies to develop new genetics with a yield potential significantly better than R201 and R215 which were both released in the mid-1970s. As recent as 1995, more than 20 years after its release, R201 was still the best variety in low potential environments. However, starting in 1997, new varieties with the potential to raise yields have been released (Figure 3), but despite their release the varieties have not yet been widely multiplied and distributed to farmers.

Figure 3. Maize variety performance in on-station and on-farm trials, low potential environments, 1983-1998



Sorghum improvement started as early as 1940 at the Matopos Research Station (Mushonga and Rao, 1986), where breeders introduced and tested materials from the US, South America and East Africa. There were three phases in the program. In the first phase from 1940 to 1960, the program identified nine fodder and 20 grain sorghum types suited to the country. During the second phase from 1968 to 1979, emphasis was placed on red-grained hybrids. During the third phase starting from 1979, emphasis shifted to developing white-grained varieties preferred for local consumption, high yielding red-grained hybrids for beer brewing, and short-statured, high yielding white and red-grained hybrids for commercial production. The target of the program for the breeders was to have yield stability for food security, early maturity for tolerance to drought, and resistance to insects and diseases. The program benefited from elite germplasm from the International Crops Research Institute for the Semi-rid tropics (ICRISAT). From ICRISAT materials, researchers developed early-maturing, short-statured, bold-seeded open-pollinated varieties, such as SV1 which was released in 1985 and SV2 released in 1987. A white sorghum hybrid ZWSH1 was released in 1992, but was not multiplied and distributed because of low seed yields. In 1998 two further open-pollinated varieties, SV3 and SV4, were released.

Adoption of improved varieties has been slow because of constraints with seed production and distribution. Seed Company concentrated on hybrid maize seeds, which offers higher margins than sorghum seeds. Yet under the Bipartite Agreement before the seed industry was liberalized in the 1990s, sorghum varieties released by the national programs could only be passed to Seed Company for multiplication and distribution. Most rural traders prefer to stock seeds with a ready market (often maize seeds) that they are familiar with. The bulk of the varieties was distributed through government and NGO drought relief schemes. Consequently, improved varieties are concentrated in specific areas where ICRISAT conducted on-farm trials and where farmers received drought relief seeds.

Pearl millet research started in 1978 (Muza *et al.*, 1986). The program focused on developing open-pollinated varieties for smallholders that are high yielding, drought tolerant, early maturing, and resistant to diseases. In 1987 the national program released the first improved variety, PMV1. Four years later in 1991, breeders released PMV2, developed using elite germplasm from ICRISAT (Monyo *et al.*, 1996), and this was followed by the release of PMV3 in 1998, again derived from ICRISAT germplasm. As with sorghum, the diffusion of improved varieties was initially slow due to seed multiplication and distribution constraints, but adoption increased dramatically in the 1990s because of government and NGO seed relief programs.

3. Impact of technological change on yields

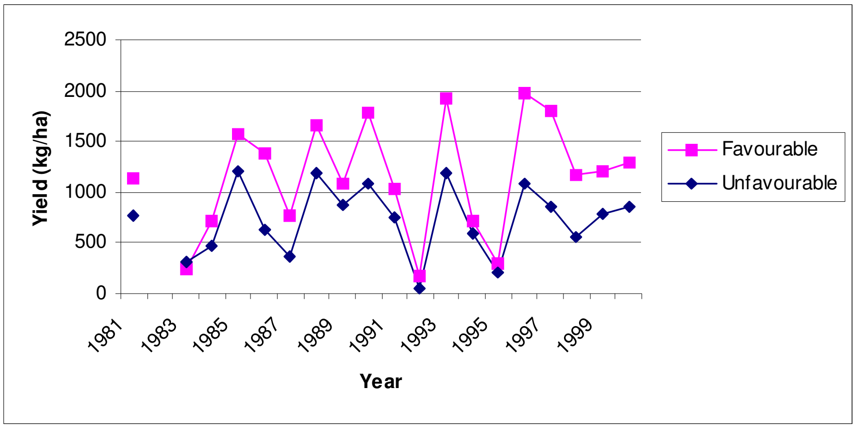
Smallholder maize yields began to rise in the early 1980s with the increased use of hybrid seed and inorganic fertilizers (see Figure 1). However, this momentum fell in the late 1980s because of declining soil fertility caused by inadequate nutrient replenishment and poor crop management, including monocropping without rotations, and poor mixing of crops in intercropping systems. Smallholder farmers failed to adopt complementary crop management technologies to improve land preparation, planting time and method, soil and water conservation, and weed and pest control. Adoption rates for soil fertility enhancement technologies remain low to this day, especially in the semi-arid parts of the country. Table 2 shows the extent of application of manure and fertiliser to specific cereal crops in the drier parts of the country.

Table 2. Adoption of Fertiliser and Manure in Tsholotsho and Kezi in Southern Zimbabwe (%)

	Tsholotsho (N=81)		Kezi (N=101)	
	Fertiliser	Manure	Fertiliser	Manure
Maize	21	44.4	22.8	62.4
Sorghum	7.4	16	4	22.8
Millet	8.6	14.8	2	26.7

Disaggregating yield by district shows that although the national average maize yield was erratic, it increased in the favorable areas and declined in the unfavorable areas (Figure 4). Yet, due to genetic breakthroughs in developing hybrids that could be successfully grown in the less favored areas in competition with sorghum and pearl millet, smallholders in marginal areas expanded the proportion of their cropped area and planted maize. This shifted the bulk of maize cultivation from favorable to unfavorable areas, which reduced the overall rate of growth of the national average yield.

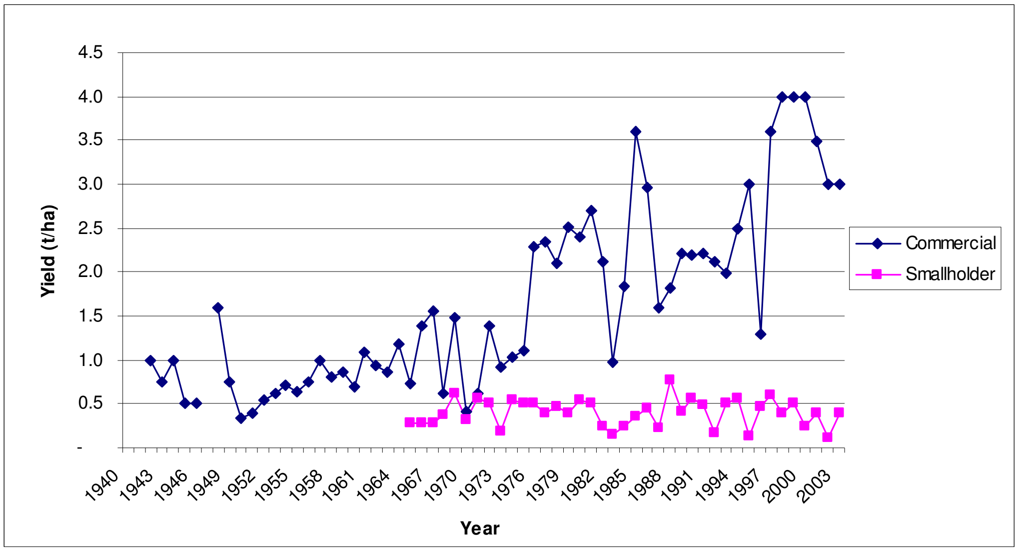
Figure 4. Maize yield trends for favourable and unfavourable smallholder area in Zimbabwe, 1980-2000



Most farmers in the unfavorable areas cultivate their fields continuously without using fertilizer, leading to a steady depletion of plant nutrients. This has been confirmed by field observations that have identified nitrogen and phosphate deficiencies, in addition to acidity in the high rainfall areas (Grant, 1967a; 1967b; 1981; Mashiringwani, 1983; Okello Oloya, 1986). Few farmers in the less favorable areas use either organic or inorganic fertilizers due to risk, lack of cash to purchase fertilizer, lack of knowledge on how to apply it, unavailability of fertilizer in convenient packages within walking distance, and poor crop response because of limited moisture (Rohrbach *et al*., 1999). Less than half of cattle-owning households use manure in their field crops because they believe that manure burns crops in dry weather. Thus, they do not perceive benefits from manure, which exceed transport and labor costs to move manure from homesteads to fields.

Yield trends of sorghum on large-scale commercial farms have more than tripled since the release of red-grain hybrids and crop management practices in the 1970s, but, in contrast, the average yield on smallholder farms have been stagnant despite high adoption of improved varieties (Figure 5). This is because of the lack of adoption of complementary crop management technologies, including tillage, time and method of planting, plant population, fertilizer, and weed, pest and disease control. Another factor is that farm households also invest their scarce resources in maize technologies, rather than sorghum and pearl millet.

Figure 5. Yield trends of sorghum for commercial and smallholder farmers, 1941-2003



4. Factors affecting farmer adoption of improved varieties and crop management technologies

Why is there broad adoption of improved varieties and yet little adoption of organic and inorganic fertilizers, especially in semi-arid areas? We estimated the fertilizer response functions of the improved maize varieties using data obtained from on-farm experiments carried out by the Department of Research and Specialist Services in different agro-ecological regions between 1986/87 and 1990/91. A quadratic response function was fitted to the experimental results for the favored and less-favored sites. The estimated response function for the maize hybrid R201 in the favored areas was:

$$Y_{bfm} = 2{,}534 + \underset{(2.25)}{23.37} - \underset{(1.03)}{0.0856N^2} + \underset{(1.59)}{8.87}\, P_2O_5$$

Where Y_{bfm} is the yield per hectare, N is the level of nitrogen in kilograms per hectare, and P_2O_5 is the level of phosphate. Values in parentheses are t-values and $R^2 = 0.24$. The estimated response equation for R201 in the less-favored areas was:

$$Y_{lfm} = 1{,}577 + \underset{(4.17)}{29.86} - \underset{(2.5)}{0.143}N^2 + \underset{(2.12)}{8.15}\,P_2O_5$$

Where Y_{lfm} is the yield per hectare and $R^2 = 0.14$.

The overall fit of the equations was reasonable and all the signs are correct. In the first equation the constant and the coefficient on nitrogen were statistically significant. All individual coefficients were statistically significant in the second equation. The estimated functions were used to estimate the derived demand for nitrogen using the annual field prices for maize and ammonium nitrate prevailing over the 1984/85 to 2001/2002 cropping seasons. The results show that there should be a consistent demand for nitrogen from farmers in favored areas for fertilizer-to-grain price ratios below 23 and from farmers in the unfavorable area for price ratios below 29. The expected per-hectare amount of nitrogen over the period was 20 kilograms per hectare for favored areas and 13 kilograms for the less-favored areas. Recommended rates for unfavorable areas are not profitable given the prevailing fertilizer-to-grain price ratios. Crop simulation modelling using the Agricultural Production Systems Simulator (APSIM) and Farmer Participatory Research trials conducted in southern Zimbabwe from 1999/2000 to 2002/2003 shows that by simply changing the variety it is possible to increase yield by 10 percent. If micro-dosing fertilizer is also added, yield increases by more than 50 percent with minimal risk. Although on-farm trials and modelling show that these low rates are profitable and reduce risks to farmers, government extension agents continue to recommend high rates targeted at maximizing yields rather than maximizing returns to a small fertilizer investment.

The yield response function for the improved sorghum variety SV2 was estimated for the less favorable areas only, because most of the crop is planted in these areas. The estimated functions for sorghum is:

$$Y_{lfs} = 1132 + \underset{(1.07)}{10.93} - \underset{(0.013)}{0.0014}N^2 + \underset{(1.91)}{11.90}\,P_2O_5$$

Where Y_{lfs} is the yield per hectare, N is the level of nitrogen in kilograms per hectare, and P_2O_5 is the level of phosphate. Values in parentheses are t-values and $R^2 = 0.20$. SV2 shows a lower response to nitrogen fertilizers and the coefficients are not statistically significant. This is because the breeding program targeted reduction in drought damages, and the quickest way to avoid drought was early maturity (Monyo *et al.*, 2002). Varieties were selected in breeding nurseries under uniform conditions (including specified fertilizer conditions) and then completed under farmer conditions. There was little emphasis on nitrogen use efficiency. Using the sorghum and nitrogen price data for the 1984/85 -and 2001/2002 seasons, the calculated per-hectare demand for nitrogen was zero, i.e. farmers will not use any nitrogen at the prevailing price ratios.

To identify farm-level factors affecting the adoption of improved varieties and crop management technologies, we estimated maize and sorghum adoption functions of improved varieties, manure use functions, and yield functions. The dependent variables are the proportions of the area of each crop planted to new varieties, the proportions of the area fertilized, and the yield per hectare (Table 3). The same explanatory variables are used in all the functions. They include farm size, family labor endowment, gender and marital status of head of household, years farming in the area, draft cattle ownership, access to extension, soil type, and location.

Table 3. Variables used in the Tobit and Logit regressions

pmaizeimprov	Proportion of maize area planted to new varieties
pmanmaz	Proportion of maize area applied manure
mazyield	Maize yield (kg/ha)
pimpsorg	Proportion of sorghum area planted to new varieties
sorgyield	Sorghum yield (kg/ha)
farmsize	Total household landholdings (ha)
Labor	Family members worked on household crops (number)
ddfefem	De facto female-headed household, dummy variable, equal to 1 if defacto female headed, 0 othwerwise
dmalehead	Male-headed household, dummy variable, equal to 1 if male headed, 0 othwerwise)
yrsfarm	Years household farmed in this area
draftcat	Draft cattle (Number)
dummf	Access to extension, dummy variable, equal to1 if household member of extension group, 0 otherwise
dsoil	Soil type, dummy variable, equal to1 if clay, 0 otherwise
dtsh	Location: Tsholotsho, annual rainfal 400-600 mm, dummy variable equal to 1 if located in Tsholotsho, 0 otherwise
dzvivi	Location: Zvishavane and Chivi area, annual rainfal 450-600mm, dummy variable 1 if located in Zvishave/Chivi, 0 otherwise

Plot and farm level data were obtained by surveying 469 farm households in southern Zimbabwe, which was the less favored region of the country. The survey was carried out at the end of the 2001/2002 cropping season, which was a severe drought year, using a questionnaire. The sample was randomly drawn from list frames of farmers in wards and districts targeted by ICRISAT for on-farm research trials. The sample included both farmers who participated in the trials and non-participants drawn from villages neighbouring those targeted for experimentation. Since the proportions of maize area under new varieties and area fertilized have limiting values between 0 and 1 and there are many zero yields, the regression models are estimated using the Tobit model. Considering that the adoption of improved sorghum varieties exhibits an “all or nothing” behaviour, the function is estimated using logit analysis.

Table 4 summarizes the results from the statistical analysis of the mean yields of new and traditional varieties. Overall average yields are very low because the 2001/2002 cropping season was characterized by difficult growing conditions resulting from the drought. Improved varieties give higher mean yield per hectare compared to farmer varieties, even though the differences are not statistically significant except for pearl millet.

Table 4. Average yields of new and farmer varieties of maize, sorghum, and pearl millets on farmers’ fields, 2001/2002, Zimbabwe (kg/ha)

Crop	Variety		T-test
	Traditional	Improved	
Maize	216 (37)	263 (411)	n.s.
Sorghum	165 (25)	190 (265)	n.s.
Pearl millet	135 (58)	208 (75)	*

Figures in parentheses are number of observations.
n.s. Denotes no statistical significance at the 0.05 confidence level.
* Denotes statistical significance at the 0.05 confidence level.

Figure 6 summarizes the yield distributions of improved varieties. Comparing improved versus traditional varieties, the probability of a zero yield is least with improved pearl millet, followed by improved sorghum and maize. Herein lies the advantage of improved varieties. Farmers are adopting them, even though they do not increase yield, because they reduce the probability of a zero or very low yield. In a drought year the gain from zero yields to 400 kilograms per hectare is significant in household food security.

Figure 6. Distribution of yields of improved maize, sorghum, and pearl millet yields on smallholder farms, 2001-2002

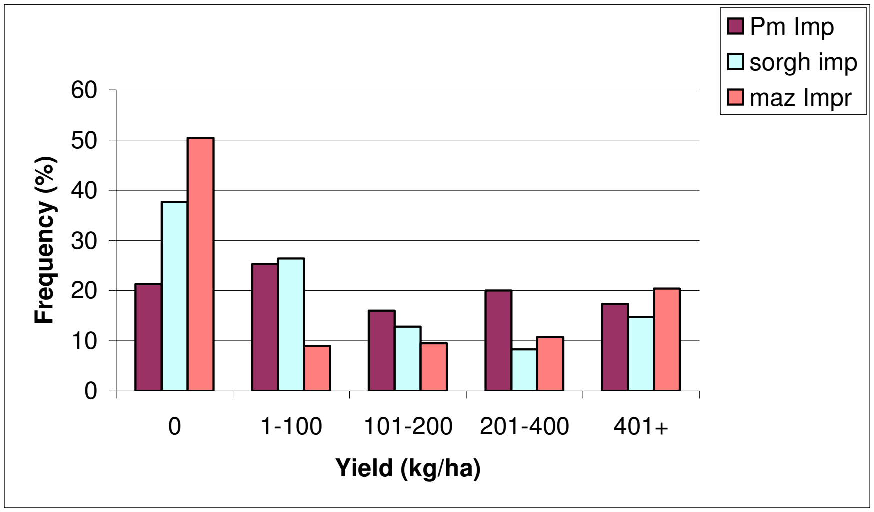


Table 5 reports the Tobit regression results for the adoption functions of improved maize varieties (pmaizeimprov), manure use (pmanmaz), and yield (mazyield). The statistically significant variables in explaining adoption of new maize varieties are soil type and draft cattle ownership. Note that traditional maize varieties are mostly recycled hybrids. Soil type indicates that farmers are more likely to invest in hybrid maize seeds for cultivating clay soil, because they perceive it as having higher inherent fertility, which gives a better payoff than sandy loams if the rainfall is good. Draft cattle-owning households that are more likely to cultivate larger maize areas have more staggered and spatially dispersed cultivation and use proportionately more recycled hybrids because they lack cash and credit to purchase sufficient hybrid seeds to plant all their maize plots.

The regression results for the adoption of manure shows that farm size, *de facto* female-headed household status, years farming, access to extension, and location dummy for Zvishavane and Chivi are the most important factors conditioning farmers' decisions to use manure for maize.[2] Households with large land holdings are likely to own more livestock and increase the quantities for field application by composting animal manure with crop residues from the larger cropped areas. *De facto* female-headed households have access to larger sums of cash from husbands in salaried employment that can be used to hire labor, draft animals and equipment for manure application. Households that have been farming for longer periods are likely to use manure because their fields are depleted of nutrients. Households participating in extension groups are more likely to use manure because extensionists place heavy emphasis on manure use in their messages. Households located in the Zvishavane and Chivi districts are more likely to use manure because of more reliable rainfall and more Master Farmers' clubs in the districts.

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[2] *De facto* households were defined as female-headed households with a titular male as household head but who is absent for six months or more during the cropping season. This category also included women married to polygamists. *De jure* houseless included female-headed households who were divorced, separated, widowed or unmarried.

Table 5. Tobit estimates of adoption functions of improved maize varieties, manure use and yield in southern Zimbabwe, 2001/2002

Dependent variable	pmaizeimprov				pmanmaz				mazyield			
Explanatory Variable	Coef.	Std. Err.	t	P>|t|	Coef.	Std. Err.	t	P>|t|	Coef.	Std. Err.	t	P>|t|
farmsize	0.0012	0.0108	0.11	0.910	0.0715	0.0230	3.11	0.002	-30.4322	30.0698	-1.01	0.31
labor	0.0098	0.0076	1.29	0.196	0.0201	0.0161	1.24	0.214	39.1070	21.1645	1.85	0.07
ddfefem	0.0746	0.0548	1.36	0.174	0.2071	0.1189	1.74	0.082	321.9500	170.5704	1.89	0.06
dmalehead	0.0064	0.0429	0.15	0.881	0.0459	0.0953	0.48	0.630	459.2718	139.9997	3.28	0.00
yrsfarm	-0.0001	0.0010	-0.01	0.936	0.0046	0.0022	2.08	0.038	-3.5361	2.9802	-1.19	0.24
draftcat	-0.0139	0.0068	-2.05	0.041	0.0124	0.0148	0.84	0.403	23.4839	19.3701	1.21	0.23
dummf	0.0299	0.0312	0.96	0.339	0.1306	0.0675	1.94	0.054	49.4517	89.2805	0.55	0.58
dsoil	0.0936	0.0301	3.11	0.002	-0.0939	0.0648	-1.45	0.148	-229.4068	85.2244	-2.69	0.01
dtsh	-0.0098	0.0479	-0.20	0.838	-0.0207	0.1084	-0.19	0.849	-55.0020	145.7375	-0.38	0.71
dzvivi	0.0226	0.0423	0.53	0.594	0.3216	0.0943	3.41	0.001	463.0372	124.5372	3.72	0.00
constant	0.7795	0.0681	11.44	0.000	-0.3565	0.1557	-2.29	0.023	-703.7109	211.0158	-3.33	0.00
Number of obs	456				456				456			
Log likelihood	-162.00				-414.03				-1946.52			
Restricted Log likelihood	-165.32				-416.91				-1949.33			
LR chi2(2)	18.54				74.06				76.22			
Prob > chi2	0.03				0.00				0.00			
Pseudo R2	0.05				0.08				0.02			

The statistically significant variables explaining yields are family labor, gender and marital status of household head, soil type, and location. The availability of family labor increases the probability of a high yield because it enables more timely land preparation, planting and weeding. *De facto* female-headed households have access to cash, and male-headed households have access to labor and livestock for investing in improve crop management. Farmer interviews revealed that they obtain higher yields on clay soil compared to sandy soil in good rainfall seasons; however, the maize performed well in sandy soil during severe droughts. To check for robustness of the coefficient, restricted models were estimated after dropping insignificant variables. The log-likelihood ratio tests and individual coefficients were stable. Therefore the model estimates are good ceteris paribus estimates, although not much of the variation is being explained.[3]

Table 6. Logit and Tobit estimates of adoption functions of improved sorghum varieties and yield in southern Zimbabwe, 2001/2002

Dependent variable	**pimpsorg**				**sorgyield**			
Explanatory Variable	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**Coef.**	**Std. Err.**	**t**	**P>|t|**
farmsize	-0.2076	0.1098	-1.89	0.059	-27.3701	27.6498	-0.99	0.323
labor	0.1812	0.0784	2.31	0.021	3.4827	16.7680	0.21	0.836
ddfefem	-0.8228	0.5643	-1.46	0.145	250.7050	130.3936	1.92	0.056
dmalehead	-1.0922	0.4543	-2.40	0.016	134.3347	103.2400	1.30	0.194
yrsfarm	-0.0091	0.0106	-0.86	0.390	-1.0903	2.6311	-0.41	0.679
draftcat	0.1189	0.0723	1.64	0.100	-5.8732	17.4909	-0.34	0.737
dummf	0.4630	0.3192	1.45	0.147	92.0723	78.5076	1.17	0.242
dsoil	0.4618	0.2937	1.57	0.116	-252.9531	72.9464	-3.47	0.001
dtsh	-0.6157	0.4439	-1.39	0.165	-105.3821	110.8140	-0.95	0.342
dzvivi	-0.1968	0.4307	-0.46	0.648	9.7212	103.3119	0.09	0.925
constant	1.6494	0.6829	2.42	0.016	125.1983	160.3280	0.78	0.436
Number of obs	295				295			
Log likelihood	-150.44				-1465.90			
Restricted Log likelihood	-159.62				-1478.31			
LR chi2(2)	27.00				23.75			
Prob > chi2	0.00				0.01			
Pseudo R2	0.08				0.01			

The Logistic regression results for the adoption function of improved sorghum varieties and Tobit estimates for yield are reported in Table 6. We did not estimate the manure use function for sorghum because very few households applied manure on their sorghum plots. Farm size, family labor, and the dummy for male-headed households are the statistically significant factors affecting decisions to adopt improved varieties. As for maize, households cultivating large sorghum areas are likely to use proportionately more traditional varieties because only small quantities are

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[3] By assuming the recursive model, we re-ran the Tobit models with pmaizeimprov in the manure use regression equation, and pmanmaiz and pmaizeimprov in the yield regression for maize. We obtained statistically significant coefficients for pmaizeimprov in the manure regression and only pmanmaiz in the maize yield regression. Thus, improved maize seems to have improved maize yield by affecting manure use.

available through government and NGO seed relief programs, and farmers lack cash and credit to purchase sufficient amount of improved seeds to plant all their fields. Male-headed households are better endowed with draft cattle and family labor, and pursue extensive rather than intensive production practices for sorghum. The availability of family labor increases the payoff to investment in new varieties because households are better able to carry out planting and weeding in a more timely manner, scare birds, and prevent losses due to predation.

The factors affecting yields are *de facto* female-head of household and soil type. *De facto* female-headed households have access to cash for intensifying production practices, which requires higher cash expenditures for purchasing new varieties of seeds and hiring labor for weeding, bird scaring and harvesting. As with maize, yields are higher in clay soil if the rainfall is good. To check robustness of the coefficient estimates, restricted models were estimated after dropping insignificant variables. The log-likelihood ratio tests and individual coefficients for the restricted models were estimated and were stable. This shows that the model estimates are good.
Results indicate that major yield gains occur with improved management. This explains why maize does better when it receives better management. Farmers plant maize early, apply manure and inorganic fertilizer, and manage it better because it is a cash and food crop, whereas pearl millet and sorghum tend not to get manure and fertilizer. Clearly the new varieties provide a foundation for moving mostly *de jure* female headed, food-insecure households who need to increase their earnings from crop production from the 0-100 to 400 kilograms per hectare level as they cannot exit farming through migration. The varieties also provide the foundation for male-headed and *de facto* female-headed, food-secure households to commercialise, by allowing them to increase yields from the current 200- 400 kilogram level to over 1,000 kilograms per hectare even in a drought year through good management.

5. Conclusions

The Zimbabwean national breeding program was particularly successful in developing improved maize varieties and hybrids, as early as the 1950s. Sorghum and pearl millet research is much more recent, and has relied largely on ICRISAT germplasm. There has been broad adoption of improved varieties in all three crops and particularly of maize hybrids, even though economic difficulties in recent years are forcing farmers to recycle hybrid seed. However, there is clear evidence that improved varieties will not lead to substantial yield gains, unless farmers also adopt improved crop management methods.

The new varieties offer one crucial advantage; they reduce the probability of zero yields. Thus, they can make a significant contribution to food security especially in drought years. Access to seeds of improved sorghum and millet varieties is a problem in some areas, and must be addressed for greater impact, but this would still leave unresolved the problem of many households still obtaining very low yields. Higher yields will require more water and better soil fertility management, and not simply a change of variety.

Fertilizer application rates recommended by the national extension service are not profitable in Zimbabwe's dryer areas, where about three-quarters of the country's smallholder farmers are concentrated. Cost-effective alternatives do exist. Farmer participatory trials, modelling and surveys have all shown that application rates as low as 10 kilograms of nitrogen per hectare (one-third to one-fourth of the recommended rate) can have a high payoff. Application of manure improves water retention, and combining manure with inorganic fertilizer can improve benefit-cost ratios and reduce risk to farmers. Research and extension agencies need to support experimentation by farmers, allowing them to become familiar with new fertilizers and crop management technologies, and also building up capacity to invest in labor and inputs to improve productivity

What are implications for ongoing research programs? First, they need to increase the emphasis on crop and fertility management. Researchers may also need more information on the behaviours of farm households in order to better target the new technologies. Different types of technologies may be needed for different sorts of households. For example, food-secure male-headed and *de facto* female-headed households can commercialise, and need technologies to move them from the current 400 kilograms to over 1,000 kilograms per hectare even in a drought year. *De facto* female-headed, sub-family farmers, who would make an exit from farming by migrating out if it was not for the economic meltdown of the Zimbabwean economy, need technologies to increase yield from 0-200 kilograms to 500 kilograms per hectare.

Overall, research can build on the inherent drought tolerance of small grains such as sorghum and pearl millet to ensure food security in drought prone areas. By increasing minimum yields (preventing zero-yield situations) and simultaneously raising average yield, even by limited amounts, there is a possibility in attaining substantial gains in rural welfare at the national level.

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