Journal of Animal & Plant Sciences, 2010. Vol. 7, Issue 2: 801- 809.
Publication date: 29/06/2010, http://www.biosciences.elewa.org/JAPS; **ISSN 2071 - 7024**

Comparative performance of advanced generations of maize hybrids with a local maize variety: Agronomic and financial implications for smallholder farmers

C.N. Macharia[1], C.M. Njeru[1], G.A. Ombakho[2] and M.S. Shiluli[2]
[1]*Kenya Agricultural Research Institute Private Bag, Njoro*
[2]*Kenya Agricultural Research Institute P.O. Box 450, Kitale*
Corresponding author Email address: cngarimacharia@yahoo.com

Key words: Maize, Farm-saved seed, Seed Recycling, Economic Analysis, Western Kenya

1 SUMMARY

Experiments were conducted on farmers' fields in a medium altitude ecosystem in Western Kenya to determine agronomic and financial implications of using farm-saved seed selected from advanced open pollinated generations of certified maize hybrids. First generation of certified seed (G1) of two commercial hybrids (H513 and H614), a local maize variety-Ababari and their respective advanced open pollinated generations two and three (G2 and G3) were evaluated with and without inorganic fertilizer. Significant differences ($P<0.05$) in maize grain yield were observed with the G1 consistently yielding more than their respective G2 and G3 generations. Fertilizer application resulted in significantly ($P < 0.05$) higher yield. The farmers' variety revealed a marginal response to fertilizer but was significantly ($P < 0.05$) different at Ulumbi. Economic analyses showed that although certified seed with fertilizer had yield advantage of approximately one ton per hectare over unfertilized local maize, the marginal rate of return on hybrid seed and fertilizer was only 15%. This rate of return may not offer sufficient economic incentive for farmers to abandon the practice of growing local and recycled maize seeds without fertilizer given the associated costs of adopting a new technology. It is evident from this study that use of certified and inorganic fertilizer maize will significantly increase maize grain yield. However, the increase in grain yield cannot economically cushion the additional costs of certified seeds and fertilizer.

2 INTRODUCTION

Most of maize (*Zea mays* L.) production in the medium altitude ecosystems of Western Kenya is by smallholder subsistence farmers. The farming system is typified by minimal use of improved crop varieties and fertilizer. Use of farm saved maize seed also known as seed recycling is a common practice covering over 70% of arable land (Shiluli et al., 1993; Hassan and Rutto, 1994). High cost of certified seed and fertilizer is often cited as the reason for the practice. Farm saved seed is derived from local varieties and advanced generations of open pollinated certified maize hybrids. Average maize yield stands at 1.5 t per hectare, which is far below the potential of six tons per hectare with improved seed and inorganic fertilizer, nitrogen and phosphorus (Kipsat, et al., 2004). Underlying the low yield is low soil fertility, competition from weeds, insect pests and diseases. The farmers were aware of the potential benefits of improved seed and fertilizer but justified use of farm saved seed seeds on basis of high cost of seasonal seed purchases. Many farmers expressed the belief that hybrid maize performs well only under best management practices (Hassan et al., 2000). The farmers' position may have merit; Allan (1972) showed that the potential of hybrid variety is unlocked only with adequate supply of macro and micronutrients, timely planting and proper control of weeds, pests and diseases. Holistic adoption of this package is beyond the economic ability of the majority of farmers.

Reliance on farm saved seeds may compromise food security, as total crop yield in the farming system is likely to be fall below levels with first generation of certified seed. However, emphasis on the singular goal of yield maximization may often be in conflict with the farmers' economic viability at the household level where optimization of yield is only one of many factors informing decisions on input use (Nkonya and Mwangi, 2004). There is likelihood that in spite of high gross returns from using certified seed and fertilizer, the absolute benefit gained may not be justified if the fixed costs of the practice are significant (Duflo et al., 2008). These fixed costs may include time and money spent traveling to the market to buy inputs, learning how to use fertilizer, and psychic costs of changing habits (Banerjee and Duflo, 2007). Broadly, maize seed recycling may be an economically rational behavior but whether it is a backward practice or innovative response to adverse conditions is a pertinent question. (Wanyama et al., 2006). Sacrificing potential yield for the sake of economic and social benefits is thus not unusual or irrational in low input subsistence agriculture. When resources are limiting, spending on inorganic fertiliser rather than certified seed may give better returns on investment (Zambesi et al., 1994; Morris et al., 1999; Beck and Torres, 2005).

Significant yield loss is evident when seed is derived from segregating generations of certified hybrid varieties. The yield loss is attributed to genetic breakdown and low quality of such seeds (Hallauer and Miranda, 1981; Zambesi et al; 1994). Yield loss varies with the type of hybrid with single and three-way crosses showing higher losses compared to varietal crosses and top cross hybrids (Beck and Torres, 2005, Morris et al., 1999). Losses are higher under poor crop management. The origin of the maize seed commonly recycled by farmers in Western Kenya is traceable to single, top and varietal crosses. **A** wide range of hybrid and local varieties is grown in close proximity allowing unrestricted cross-pollination on small-scale farms. It is likely that the local varieties and farm saved seeds have benefited from infusion of superior genes through cross pollination and subsequent selection of superior plants in terms of ear size, grain texture, seed size and quality and other attributes desired by the farmer.

Typically, a rudimentary form of mass selection is practiced by farmers based on selection of superior ears and bulking of seed to form the seed stock for the next generation (Welsh, 1981). If practiced season after season, mass selection if properly executed has the potential to improve a crop population if large populations are used to avoid loss of vigour due to inbreeding depression (Cleveland et al; 1999). The farmers' method is also akin to selecting elite segregates and echoes a technique applied by breeders to develop second cycle inbred lines from elite S1 of commercial hybrids (Ipsilandis et al., 2006, Tokatlidis et al., 2005). Second cycle maize hybrids have a high yield potential per plant resulting in high grain yield at lower plant density while farmer initiated selection based on yield components (e.g., ear size, ear shape, kernel number, kernel size) tends to favor genotypes that are most productive under local conditions (Tokatlidis et al., 2005; Louette and Smale, 2000)). By repeatedly selecting and preserving seeds with preferred traits ~~the~~ farmers may inadvertently increase the frequency of genes conferring tolerance to biotic and abiotic stresses characteristic of the local environment due to genetic drift.

The preference for farm-saved seed in resource poor farming systems is in spite of likelihood of loss of yield due to build up of diseases such as head smut and hence the need to train farmers on own seed production (Almikinders *et al.*,). The broad objective of this study was to examine the agronomic and financial implications for smallholders who use farm-saved seed derived from advanced generations of certified maize hybrids. Specifically the study determined maize grain yield and evaluated financial implications of growing farm saved seed under low and high fertility on smallholder farms in Western Kenya.

3 MATERIALS AND METHODS

On-farm experiments were conducted in East Gem, Siaya District in Western Kenya which is Upper Midlands Zone 1 (UM1) and Lower Midlands Zone 1 (LM1) (Jaetzold and Schimdt, 1982). In order to closely simulate the farmers' practice the following procedures were followed in the development of advanced second generation (G2) and third generations (G3) of the original certified seed (G1).

1. Certified seed of hybrids H513 and H614 were grown without isolation in a farmer's field in the long rains season of 2004. Unrestricted self and cross pollination was allowed to occur naturally as would be the case under farmers' conditions. The best ears of each variety were selected with the assistance of the farmers and preserved as the second advanced generation (G2) of H513 and H614.
2. In the short rains of 2004 some seed of first segregating generation (SG1) of H513 and H614 was grown without isolation in a farmer's field and also allowed to self and cross pollinate naturally as would be the case under farmers' conditions. The best ears of each variety were again selected with the assistance of the farmers and preserved as the third generation (G3) of H513 and H614.
3. The farmers provided the local variety-Ababari while a commercial seed stockist provided the certified seeds of H513 and H614 (G1).

Planting was done during the long rains (March-August) of 2005 and 2006. Certified seed of the commercial maize hybrids (H513 and H614) and their respective advanced generations were grown under low fertility (no inorganic fertilizer) and high fertility (with inorganic fertilizer) on five row plots measuring 4.8m x 3.75m. A local variety (Ababari) whose pedigree is unknown was adopted as the control representing the farmers' practice. The experimental design was the Randomised Complete Block with three replications. A basal application of compound fertilizer, N: P: K =20:20:0 at a rate of 300kgha^{-1} supplied the equivalent of 60 kg N ha^{-1} and 26 kg P ha^{-1}. Hybrid H513 is a single cross hybrid (Are you sure?) while hybrid H614 is a top cross. In accordance with the farmers' practice, four seeds per hole were planted at inter and intra row spacing of 75 cm and 60 cm respectively. Thinning to two plants per hill was done at 14 days after emergence to attain a crop density of 44,444 plants ha^{-1}.

The net harvested area consisted of three inner rows (10.8 m^2) of each plot, which provided data on yield. Soil samples drawn from the 0 - 20cm profile were analysed according to the procedures of Mehlich**,** **(**1953) to determine the soil chemical properties (Table I).

Table 1: Soil chemical properties of four experimental sites in Western Kenya.

Site	pH	Na	K	Ca (cmols/Kg)	Mg	Mn	N %	C %	P ug/g soil
Jina	4.8	0.2	0.2	0.5	0.7	3.5	0.2	1.8	20.0
Lihanda	5.2	0.3	0.2	0.6	0.7	3.7	0.2	1.7	12.0
Marenyo	6.4	0.3	0.4	1.5	2.6	0.4	0.1	1.5	14.0
Ulumbi	5.3	0.4	0.6	0.8	1.0	1.9	0.2	1.3	4.0

Routine field management other than application of treatments was the farmers' practice. Ears were harvested at physiological maturity, sun dried and shelled for yield determination at 12.5% moisture content. Monitoring of prices in the local markets and interviews with local farmers and traders provided the necessary economic data on prices of maize grain and associated production and marketing costs. All biological data were analysed according to the analysis of variance procedure (Steel and Torrie; 1982) using the General Linear Model (SAS Institute 2002). Mean separation to identify significant treatment difference was according to Tukey's Honestly Significant Difference test. Percent yield losses for G1 and G2 were calculated respectively as follows:

(i) Percent yield losses of G2=100*(yG1 minus yG2)/yG1
(ii) Percent yield losses of G3= 100*(yG1 minus yG3)/yG1

Where: yG1 = mean yield of certified seed; YG2 = Mean yield of second generation and yG3 = Mean yield of third generation

To determine the financial costs and benefits associated with seed recycling and application of fertilizer, the partial budget procedure as described by CIMMYT (1988) was applied on the results. The variables of the partial budget procedure were: the mean grain yield (tons ha^{-1}) of each treatment based on three replications; the field price kg^{-1} of maize grain which was ~~is~~ the point-of-sale retail price minus the costs of harvesting, bagging and transporting while the gross field benefit (GFB) ha^{-1} was the product of field price and mean yield for each treatment. The field price of fertilizer kg^{-1} was the nutrient's retail cost kg^{-1} plus the cost of transport from the point of sale to the farm; the field cost ha^{-1} fertilizer is the product of the quantity applied and the field cost of fertilizer while the cost of fertilizer application is the product of person-days used and wage rate. The Total Variable Costs (TVC) was the sum of field cost of fertilizer and its cost of application while the Net Benefit (NB) ha^{1} for each treatment was the difference between the Gross Benefit GFB and the TVC.

4 RESULTS

The results of the study are for individual sites are presented in tables 2, 3 and 4. Grain yields varied significantly (P> 0.05) among sites with significant on fertility level by seed generation by location interaction (data not shown). Differences in maize grain yield between H513 and H614 were not significantly (P> 0.05) different. The mean grain yield across sites for H513 and H614 was 2641 and 2846 kg per hectare respectively. Grain yield varied significantly (P<0.05) depending on the generation of seed with the first generation certified seed (G1) of maize hybrids H513 and H614 yielding consistently more than their respective advanced generations across all sites. Yield losses were 14.5% at Marenyo, 21.5% at Ulumbi, and 22.6% at Lihanda and Jina when G2 seeds of H513 were used (Table II).. Yield losses were 23.5% at Marenyo, 21.6% at Lihanda, 18.3% at Ulumbi and 27.8% at Jina when G2 seeds of H614 were used. Grain yield losses were higher with the third generation (G2) of H513 yielding 43.9 percent less than its corresponding G1 seed at Lihanda. The yield loss observed for G3 of H614 was 38.8 percent at the same site (Table II). The yield reduction for third generation seeds ranged from 6.1% to 27.4 % for hybrid H513 and from 7.0 % to 15.2 % for hybrid H614.

Table2: Grain yield (kg/ha) of advanced generations at Marenyo, Lihanda Ulumbi and Jina

Location		**Grain yield kg ha^{-1}**			**Percent Yield Loss**		
	Hybrid	**G1**	**G2**	**G3**	**(G1 minus G2)[1]**	**(G1 minus G3)[2]**	**(G2 minus G3)[3]**
Mareyo	H513	2544ab	2146bc	1917c	14.5	29.7	10.7
	H614	2752a	2105c	1848c	23.5	32.8	12.2
SE ±			**92.95**				
CV %:			**10.2**				
Lihanda	H513	2453ab	1899c	1377d	22.6	43.9	27.4
	H614	2747a	2151bc	1822bc	21.6	33.8	15.2
SE ±			**96.53**				
CV %:			**9.4**				
Ulumbi	H513	2913ab	2287c	2122c	21.5	27.5	7.2
	H614	3147a	2572bc	2330c	18.3	26.0	9.4
SE ±			**113.10**				
CV %			**12.6**				
Jina	H513	2552a	1974b	1853b	22.6	27.4	6.1
	H614	2738a	1976b	1837b	27.8	32.9	7.0
SE ±			**70.16**				
CV %:			**7.9**				

Means sharing the same letters are not significantly different (P<0.05) Tukey's Honestly Significant difference Test

(G1 minus G2) = Percentage Yield of G1 over G2
(G1 minus G3) = Percentage Yield of G1 over G3
(G2 minus G3) = Percentage Yield of G2over G3

Journal of Animal & Plant Sciences, 2010. Vol. 7, Issue 2: 801- 809.
Publication date: 29/06/2010, *http://www.biosciences.elewa.org/JAPS;* **ISSN 2071 - 7024**

Table 3: Effect of fertilizer and generations on grain yield at Marenyo, Lihanda Ulumbi and Jina

Location	Grain yield kg ha^{-1}				Percent Yield Loss		
Marenyo	Local	G1	G2	G3	(G1 minus G2)[1]	(G1 minus G3)[2]	(G2 minus G3)[3]
No fertilizer	2142bc	2178bc	1792cd	1425d	17.7	34.6	20.4
Fertilizer	2437b	3119a	2450b	2440b	21.4	24.9	4.4
SE ±			**92.95**				
CV %			**10.2**				
Lihanda	Local	CG1	SG1	SG2	(CG1 minus SG1)[1]	(CG1 minus SG2)[2]	(SG1 minus SG2)[3]
No fertilizer	3140b	2125c	1758cd	1401d	17.3	34.1	20.3
Fertilizer	3274b	3934a	3173b	3050b	19.0	22.5	4.4
SE ±			**96.53**				
CV %			**9.4**				
Ulumbi	Local	CG1	SG1	SG2	(CG1 minus SG1)[1]	(CG1 minus SG2)[2]	(SG1 minus SG2)[3]
No fertilizer	2240c	1818cd	1428d	1337d	21.5	26.5	6.3
Fertilizer	2692b	3381a	2622b	2335bc	22.4	30.9	10.9
SE ±			**113.1**				
CV %			**12.6**				
Jina	Local	CG1	SG1	SG2	(CG1 minus SG1)[1]	(CG1 minus SG2)[2]	(SG1 minus SG2)[3]
No fertilizer	2142bc	2178bc	1792cd	1425d	17.7	34.6	20.4
Fertilizer	2437b	3119a	2450b	2440b	21.4	24.9	4.4
SE ±			**92.95**				
CV %			**10.2**				

Means sharing the same letters are not significantly different ($P<0.05$) Tukey's Honestly Significant difference Test

(G1 minus G2)[1] = Percentage Yield of G1 over G2
(G1 minus G3)[2] = Percentage Yield of G1 over G3
(G2 minus G3)[3] = Percentage Yield of G2over G3

Journal of Animal & Plant Sciences, 2010. Vol. 7, Issue 2: 801- 809.
Publication date: 29/06/2010, http://www.biosciences.elewa.org/JAPS; **ISSN 2071 - 7024**

TABLE 4: Partial Budget (Current Prices) computed across locations

Treatment	G1 No Fertilizer	G1 with Fertilizer	G2 No Fertilizer	G2 With Fertilizer	G3No Fertilizer	G3with Fertilizer	Local No Fertilizer	Local With Fertilizer
Mean Yield kg/ha	**2019**	**3454**	**1629**	**2667**	**1375**	**2544**	**2482**	**2713**
Gross benefit (Ksh)	**51484**	**86545**	**40720**	**68008**	**35062**	**64872**	**62291**	**69181**
Field cost of fertilizer	0	12000	0	12000	0	12000	0	12000
Field cost of seed (Ksh)	4375	4375	0	0	0	0	0	0
Fertilizer application cost (Ksh)	0	400	0	400	0	400	0	400
Harvesting	4038	6408	3258	5334	2750	5108	5426	4964
Shelling (Ksh)	3028	5181	2444	4001	2063	3831	4070	3273
Transport cost (Ksh)	3129	5508	2225	4133	2131	3943	4205	3847
Total Variable Costs (Ksh)	**14570**	**33872**	**7927**	**25868**	**6944**	**25282**	**13701**	**24484**
Net Benefits (Ksh)	**36914**	**52673**	**32793**	**42140**	**28118**	**39590**	**48590**	**44697**

Notes

Field price of Fertilizer :Sh.135 per kg of N-P_2O_5
Wage rate = Sh.200 per day
Fertilizer application per ha = 2 man-days

Field price of hybrid seed Sh. 175 per kg
Transport:Sh.1.55 per kg
Price of grain: Sh. 25.50 per kg

Shelling Sh.50 per kg
Harvesting: Sh. 2.0 per kg

5 DISCUSSION

Fertilizer use increased grain yield of both certified seeds and their respective advanced generations when compared with the unfertilized plots. The local variety responded marginally to fertilization except at Ulumbi where grain yield was significantly ($P<0.05$) different (Table III). Grain yield losses for the second and third generations grown without fertilizer and high fertility (with fertilizer) were 18% and 9.2% respectively (Table III). The decline was generally higher with fertilizer percent than without fertilizer. Application of fertilizer increased yield by between 941 kg at Marenyo and 1809 kg at Lihanda. On average, a yield decline of 936 kg was recorded when G2 seeds were grown with fertilizer while 415kg was lost when G3 seeds were grown without fertilizer. Loss of yield for certified seeds (G1) grown without fertilizer was between 272 kg/ha and 1048 kg/ha lower than the yield of G2 SG1 grown with fertilizer (Table III). The third generation (G3) seed grown with fertilizer had a mean grain yield difference ranging between 62 and 925 kg/ha relative to certified seed (G1) grown without fertilizer.

Economic analysis showed applying fertilizer at 60 kg N ha-1 and 26 kg P ha-1 on certified first generation (CG1) and first segregating generation seed (SG1) of hybrid varieties resulted in a marginal rate of return (MRR) of 15.2% over the farmers practice (ie growing the local maize variety without fertilizer). The net benefits were Ksh 52,673 (US $ 658.4) and Ksh 48,590 ((US $ 569.9) for certified grown with fertilizer and farmers variety without fertilizer respectively (Table IV). Applying fertilizer to the certified seeds and also to the farmers' variety (ababari) has more benefit than the farmers practice in terms of yield. The farmers practice however is financially superior to the two treatments. All other treatments are dominated by the farmers practice.

The necessity of fertilizer in unlocking the genetic potential of hybrid maize varieties in Kenya is widely documented (Allan, 1972; Smaling et al., 1992; Kipsat, et al., 2004). Inorganic fertilizers complement other inputs and practices (e.g., improved seeds and better weed control) resulting in higher yields on infertile soils (Heisey and Mwangi, (1996). This study clearly revealed that using certified hybrid seed and inorganic fertilizer has distinct agronomic advantage. Maize grain yield increased significantly ($P < 0.05$) when certified seed was grown with fertilizer thus confirming the work of Pixley and Banzinger, (2001) that maize hybrids grown from certified first generation (G1) seed yield approximately 18% more than the best local varieties. The lack of response to fertilization by the local variety whose yields peaked at 2.7 tons per hectare (0.23 tons, more than the unfertilized control) makes fertilizer use on local maize irrelevant and may discourage partial adoption of recommended technology components. Using fertilizer on farm-saved seed (G2 and SG3) in the locality of this study is not economically viable since the resultant yield gain is not sufficient to offset cost. The local variety without fertilizer is economically superior to all other treatments except certified seeds grown with fertilizer (Table IV). The yield losses over both low and high fertility were similar which confirms the work of Beck and Torres (2009).

Evidence from experimental farms indicates that fertilizer and hybrid seeds increase yield from 40% to 100% (KA R I; 1993). Based on awareness of this fact and the assumption that farmers are rational profit maximisers, the extension service has promoted the use of chemical fertilizers for many years. However, in Western Kenya estimated uptake of fertilizer by maize farmers is only 3% and 5% of recommended rates for nitrogen and phosphorus respectively (Mugunieri et al., 1997). Only 37% and 35.5% of farmers report of ever using fertilizer or hybrid seed respectively (Duflo et al., 2008). These reports point to existence of overriding concerns on input use by farmers. Mugunieri et al., (1997) found that farmers whose objective is producing for food do not increase fertilizer use if they are otherwise able to produce enough to meet their subsistence needs. The primary concern of the small-scale farmer is to produce food for household consumption and for sale in case of surplus, which calls for measures to minimise risk (Nyagito et al., 1997).

Yield advantage is important only if it translates into competitive socio-economic gains for the farmer. Economic analysis in this study revealed that though certified first generation (G1) seed under high fertility had yield advantage of approximately one ton of grain per hectare over the farmer's practice, the marginal rate of return in based on prices current at the time the maize harvest came to market was only 15.2% over the net benefit under the farmers practice. Studies by CIMMYT, (1988), indicate that on basis experience and empirical evidence, a marginal rate of return of between 50 and 100 % is necessary to give the farmers a sufficient incentive to take the risk of investing in a new technology. Where the new technology requires acquisition of new skills by the farmer, then a marginal rate of return of 100% (equivalent to a "2 to 1" return) is preferable. Based on these guidelines, it is evident that no treatment is sufficiently superior to the farmers practice to justify adoption of the new practice based on economic rationale.

This foregoing scenario raises pertinent issues. The farmers' practice is economically superior to other practices. However since it is typified by minimal use of fertilizers, it erodes sustainability by degrading farmland, which is a non-renewable resource. Maize yield under the farmers practice peaks at about 2.4 tons hectare, thus limiting potential productivity of the cropping system. Food security is compromised in the locality of this study where the potential yield exceeds six tons per hectare if certified hybrid seed and fertilizer are used (Jaetzold and Schimdt, 1982; Kipsat, et al., 2004). In the liberalized market economy maize farmers are facing diminishing producer prices due and high cost of inputs and when confronted with the challenge of producing sufficient food for the family they tend to compromise long-term sustainability by abandoning best management practises. Fertilizer prices and profitability influence farmers' choice of seed. This is because many farmers believe that hybrid seed requires fertilizer (Smale and Phiri, 1998). In the light of current fertilizer-maize price ratio and expected maize response to fertilizer, use of fertilizer at the levels tested in this study is unprofitable for smallholders. This scenario raises significant implications for researchers and policy makers. The challenge facing the maize sector is to safeguard national food security through increased productivity at farm and ecosystem level. Concurrently, ensuring economic viability of the smallholder and sustainable exploitation of non-renewable resources e.g. farmland is critical. In the short term, smallholders cannot use improved seed and fertilizer profitably; yet non-use of these inputs limits overall productivity, degrades farmland and threatens food security. Intervention at policy level e.g. use of targeted subsidies for seed and fertilizer may be necessary to safeguard national interests and public good. Researchers need to develop maize varieties that are amenable to seed recycling such as synthetics, efficient in nutrient uptake and utilization and are superior to local varieties at low levels of inorganic fertilizer. Extension agents and farmers need to devise ways to stem soil degradation and institute management practices that ensure sustainability.

6 ACNOWLEGEMENT

The Kenya Agricultural Research Institute (KARI), Egerton University and the International Maize and Wheat Improvement Centre (CIMMYT) provided support for this work through the Crop Management Research Training Project (CMRT). The authors gladly acknowledge the support. The authors also acknowledge the support provided by the centre director, Kenya Agricultural Research Institute, Njoro.

7 REFERENCES

Allan, A.Y. (1972). The Influence of Agronomic factors on Maize Yield in Western Kenya with Special Emphasis on Time of Planting; PhD Thesis. Makerere University

Banerjee, A.V. and Duflo, E. (2007). "The Economic Lives of the Poor." Journal of Economic Perspectives, 21 (1): 141-167.

Beck, D. and Torres J.L. Inbreeding Depression in Recycled Seed of Highland Hybrids Sown Under Optimal and Nitrogen Stressed Conditions. Available online at www.cimmyt.org. Accessed on 12/4/2009

CIMMYT, (1988). From agronomic Data to Farmer Recommendations; An Economics training manual: - Completely revised edition. Mexico, D.F.

Cleveland, D.A., Soleri D. and Smith, S.E. (1999). Farmer Plant Breeding from a Biological Perspective: Implications for Collaborative Plant Breeding CIMMYT Economics Working Paper No.10. Mexico, D.F.: CIMMYT.

CMRT, (1993). The maize-bean farming systems of Yala division, Siaya District; Kenya-Informal survey report.

Duflo, E., Kremer, M. and Robinson J. (2008). How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya; American Economic Review vol.98 p 482-488

FAO-UNESCO, (1974). Soil map of the world 1:500000 vol. 1 Legend UNESCO Paris.

Fehr, W. R; (1987). Principles of cultivar development, Vol. 1 Collier Macmillan (London)

Hallauer, A. R. and Miranda, J.B. (1981). Quantitative genetics in Maize breeding; Iowa State University Press, Ames, Iowa

Heisey, P.W. and Mwangi, W. (1996). Fertilizer Use and Maize Production in Sub-Saharan Africa; CIMMYT Economics Working Paper 96-01; Mexico, D.F.: CIMMYT

Ipsilandis, CG, Tokatlidis, I.S. Vafias B. and Stefanis, D. (2006). Criteria for developing second-cycle hybrids in maize Criteria for developing second-cycle hybrids in maize; Asian Journal of Plant Sciences 5 (4) 680-685

Jaetzold, R. Schimdt, H. (1982). Farm management handbook of Kenya: - Natural conditions and farm management information Vol. II/A Pubs: Ministry of Agriculture Nairobi, Kenya.

Kenya Agricultural Research Institute (KARI) (1993). Strategic plan for cereals in Kenya 1993-2013; Nairobi, Kenya.

Kenya Agricultural Research Institute (1994). Fertilizer Use Recommendations Program, Vol. 1-23. Nairobi, Kenya:

Kipsat, M. J., Maritim, H.K. and Okalebo, J.R. (2004). Economic Analysis of Non-Covention Fertilizers in Vihiga District, Western Kenya; In Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa, (Ed.) Andre Bationo, pp.535-544.

Loutte, D and Smale, M. (2000). Farmer's seed selection practices and traditional maize varieties in Cuzalapa, Mexico, Euphytica 113: 25–41.

MacRobert A., Kosina, P. Jones, J. (2007). What is hybrid maize? IRRI-CIMMYT alliance fact sheet; Available online at www.knowledgebank.irri.org. Accessed on 12/4/2009.

Maize Data Base Project (MDB) (1993). Final Report, KARI Regional Research Centre Kakamega:,Kenya.

Mehlich, A. (1953). Determination of P, Ca, Mg, K, Na and NH4 by North Carolina soil testing laboratories, Mimeo; North Carolina Department of Agriculture

Ministry of Agriculture and Livestock Development (M.O.A) Kenya, (1994) - Annual report for Yala Division

Morris, M.L., Rigopoulos J. and Beck, D. (1999). Genetic Change in Farmer-Recycled Maize Seed: A Review of the Evidence; CIMMYT Economics Working Paper No. 99-07; Mexico, D.F.: CIMMYT

Mugunieri, G.L., Nyangito, H.O and Mose, L.O. (1997). Agronomic and socioeconomic factors determining maize yield response to fertilizers in western Kenya; African Crop Science Conference Proceedings 3, pp. 1465-1471

Nkonya, E., and Mwangi, W. (2004). The economic rationale of recycling hybrid: Agricultural and Resource Economics, 25(2)

Nyagito H., L. Mose and Mugunieri, L. (1997). Farmer circumstances and their effects on fertilizer use in Western Kenya; African Crop Science Conference Proceedings 3 pp 1413-1420

Pixley, K. and Banziger M. (2001). Open-pollinated maize varieties: a backward step or valuable option for farmers? In proceedings of the seventh Eastern and Central Africa maize conference, Nairobi, Kenya

SAS Institute Inc. NC. USA (1989). SAS Statistics Guide

Smale, M., and Phiri, A. (1998). Institutional Change and Discontinuities in Farmers' Use of Hybrid Maize Seed and Fertilizer in Malawi: Findings Economics Working Paper 98-01. Mexico, D.F.: CIMMYT.

Smaling, E.M.A., Nandwa, S.M, Prestele, H., Roetter R. and Muchena, F.N. (1992). Yield response of maize to fertilizers and manure under different agro-ecological conditions in Kenya; Agriculture, Ecosystems and Environment Vol. 41, Pg 231-372

Steel, R.G.D., and Torrie J.H. (1982). Principles and Procedures of Statistics McGraw-Hill Book Co., New York

Wanyama, J. W., De Groote, H., Mose, L., Kengo, D. and Mohammed L.(2006). Recycling Hybrid Maize Varieties: Is It Backward Practice or Innovative Response to Adverse Conditions in Kenya? Paper presented at the 2006 Annual Meeting, of the International Association of Agricultural Economists August 12-18, 2006, Queensland, Australia

Welsh, J. R. (1981). Fundamentals of plant genetics and breeding, New York; John Wiley & Sons:

Zambezi B.T., Nyondo F.K., Nkhono, G., Mbigwani G.F and Chikhuta, T.F. (1996). Evaluation of recycled maize hybrids at three levels of Nitrogen in Malawi :- In proceedings of the Fifth Eastern and Central Africa regional conference, Arusha Tanzania 3-7 June 1996. Addis Ababa; Ethiopia: CIMMYT