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Abstract: Upcoming technologies for maize storage have sometimes been promoted without being subjected to trials and economic analysis. In the recent past, new storage technologies, actellic super, super grain bag and the metal silo have been developed. In this paper, the results of crop loss trials are combined with measures of project worth to determine the attractiveness of investing in new storage technologies. Determination of the benefit was based on the amount of loss the new technology could abate. A one ton metal silo, with negligible % crop loss abated USD 100 in 12 months. These benefits were found to increase with time meaning that a farmer benefits by storing longer. Measures of project worth, the NPV and BCR were used to analyze the attractiveness of investing in the new technologies at a discount rate of 15% and an investment period of 15 years. Sensitivity analysis was done by varying the discount rate and the investment period. When six metal silo sizes were subjected to this analysis, the results showed that the three largest silos were attractive for all these scenarios. On the other hand, the smaller the silo size the higher the requirement that the interest rate be small and the period of investment bigger for it to be an attractive investment. Therefore, promoting larger silos would be more cost-effective to the farmer.

Keywords: Storage, LGB, economic analysis, Kenya

1. Introduction

1.1 Background: heavy storage losses

Storage is an important aspect of food security in developing countries. This is especially important since most cereals, including maize, are produced on a seasonal basis, and in many places there is only one harvest a year, which itself may be subject to failure (Proctor, 1994). Seasonal production leads to fluctuating supply at the international, regional, national or at household levels. The fluctuating supply is in sharp contrast to a stable demand throughout the year and region. Storage helps to even out fluctuations in market supply, both from one season to the next and from one year to the next, by taking produce off the market in surplus seasons, and releasing it back onto the market in lean seasons (Proctor, 1994).

Despite the realization of the importance of storage, the potential impact of stored products is however undermined by the incidence of increasingly destructive storage pests. The maize weevil and the larger grain borer (LGB) are the main and most serious pests of stored maize (Holst *et al.*, 2000, ; Proctor, 1994). The LGB is a fairly recent pest, and its introduction has caused a wave of new research. It was accidentally introduced into Africa in the late 1970s from its area of origin in Central America, where it had long been recognized as an occasional pest of stored maize. It appeared first in East and then West Africa and is now widely recognized as the most destructive pest of farm-stored maize and dried cassava in Africa (Boxall, 2002). It can be now be found in many places in many countries in Africa. In Benin, the LGB was found to have infested 54% of the experimental stores in the study (Meikle *et al.*, 2002).. In a study evaluating the existing management options for stored maize over 6 months

LGB reduces many kernels to powder (Compton *et al.,* 1998). This pest, which was observed in Togo in 1984, caused losses of up to 30.2% after six months (Pantenius, 1988). In Benin, percentage loss of stored maize amounted to around 23% after storing for six months with the LGB and the maize weevil being the major pests (Meikle *et al.*, 2002). In Tanzania, individual farmers reported suffering high losses of up to 34% (dry weight) and in extreme cases, where 70–80% of the maize grains were damaged, the commodity was totally unfit for consumption (Boxall, 2002). The LGB is equally destructive in other products and has also been reported as a prevalent insect in stored cassava in Benin (Gnonlonfin *et al.*, 2008): In Togo, mean weight losses as high as 30% were reported to be common in farm-stored dried cassava (Wright *et al.*, 1993).

Lower percentage losses had been reported before the advent of the LGB. Using the count and weigh method, losses in stored maize were found to be highest in the secondary season (8% after four months) and 6.4% in the main storage season. The highest losses were found in stored hybrids (12-13%) after storing for 6 months (Pantenius, 1988). Lower losses were also documented for Malawi; 3% for maize and 2% for sorghum after storing for 10 months (Golob, 1981). In Mali, losses were found to be 2-3% in sorghum stored for 5 months where the main pest was the lesser grain borer (Ratnadass *et al.*, 1994).

The arrival of LGB in Africa heralded an upsurge of interest in post-harvest pest management. There was increased focus on awareness creation on management, and the understanding of the biology, ecology, and economic importance of LGB. A range of different control methods, including insecticides, and a natural insect enemy were identified, tested and released in several countries (Farrell and Schulten, 2002). Farmers were also trained on new management practices of handling stored products. So far however, few of these technologies have been adopted widely, and they are either not known, or they are not economically interesting.

1.2 New storage technologies

Recently, three new storage technologies have been developed. These are actellic super, super grain bags and metal silos. Actellic super is a cocktail of 1.6% Pirimiphos-methyl and 0.3% Permethrin (Sekyembe *et al.*, Undated). It has been promoted as a chemical effective against the LGB in combination with practices like immediate shelling and treating (Farrell and Schulten, 2002, ; Sekyembe *et al.*, Undated). The Super grain bag, also known as the IRRI super bag, has been used in rice storage but is also said to be suitable for other cereal storage. The Super bag fits as a liner inside existing storage bags. The metal silo is cylindrical metal container which has been used widely in Central America for on-farm grain storage. It has also been promoted in various countries in Africa including Kenya, Malawi and Swaziland by various NGOs and the FAO (FAO, 2008). It is made of galvanized flat iron sheets. The super bag and the metal silo work on the hermitic technology concept, where the lack of air inside the container suffocates and kills insect pests.

Actellic super has been adopted by small scale farmers for grain storage in Kenya as well as other countries in Africa. In Tanzania, it was the most common control method of treating maize before storage having been reported by more than 93% of farmers in both high rainfall and low rainfall zones (Kaliba *et al.*, 1998). Adoption for the other two new technologies by small scale farmers is not well documented. For the three technologies, there is little evidence that they have been tested in a proper experiment and subjected to economic analysis before being promoted. We therefore tested the different methodologies, using heavy artificial infestation (De Groote, forthcoming).

In this paper, we present the economic analysis of the different storage options (new technologies). We calculate the expected benefits, and compare to the cost, over time, of different options under different scenarios. The benefit of each technology is equal to the expected abatement of crop loss, based on the data from the experimental trials, which represents the maximum infestation we would expect. The costs are calculated based on experimental trial, key informant interviews with silo manufactures and other technology developers so as to capture various levels and sizes of the containers. The analysis is based on measures of project worth (Gittinger, 1982).

2. Methodology

2.2. The on-station trial

The trials were set in three locations in Kenya, with differing climatic conditions and data on crop loss collected for six months (De Groote, forthcoming). Table 1 shows the six treatments that were used in the trial. These treatments were replicated three times in every trial site. The polypropylene is the common storage bag used by farmers. In one of these treatments, this bag was used without pesticide so as to act as the control. No pesticide was used for the super grain bag, while for the metal silo, the three treatments were no pesticide, actellic super and phostoxin (a fumigant). In each treatment, 90kg of maize was put, and there was artificial infestation with the LGB and the maize weevil (De Groote, forthcoming).

Table 1. Technologies used in the trial (technical description)

Treatment	Storage method	Pesticide
1	Polypropylene bag	None
2	Polypropylene bag	Actellic Super
3	Super grain bag (inside polypropylene bag)	None
4	Metal silo	None
5	Metal silo	Actellic Super
6	Metal silo	Phostoxin

2.2 Analysis of trial data

Every month, samples were taken from each container, and the percentage weight loss calculated using the Count and Weigh Method. This method has been used extensively in research to quantify the amount of storage loss in on-station and on-farm experiments (Boxall, 2002, ; Boxall, 1986, ; Compton *et al.*, 1998, ; Ratnadass and Fleurat-Lessard, 1991).

The effect of time and treatment on crop loss was analyzed based on the formula:

$$\%CL = \beta' t \, T_i$$

Where t is time and T is treatment. The right side of the equation therefore represents a matrix of cross effects of each treatment with time. Since we don not expect percentage loss at time zero, estimation of the model is done without including an intercept. The analysis was done using SPSS.

2.3. Measures of project worth

In order to determine the viability of the different technology options, methodology of economic and financial analysis as outlined by (Gittinger, 1982) is adopted. Since investment in a project will involve a future stream of costs and benefits, these must be discounted to find their present worth. We use the net present value (NPV) and the benefit-cost ratio (BCR) in this analysis. The NPV represents the present worth of the income stream generated by an investment (in this case the storage technology to the farmer). The BCR represents the present worth of the benefit stream divided by the present worth of the cost stream. We also undertake a sensitivity analysis to determine how favorable a new technology remains if some factors change.

3. Results

3.1Crop loss observed from the trials

Figure 1 shows the amount of crop loss observed for a period of six months for three sites combined. In most of the options apart from the metal silos, % crop loss increases with time and is highest in the sixth month. The polypropylene bag with no pesticide registered the highest % loss, reaching 24% in the sixth month. The second highest loss is found in the polypropylene bag with actellic super (8.4% in the sixth month) followed by the super grain bag (6.3%). Percentage loss observed in the metal silos, whether with pesticide or not, was small: 1.7% for metal silo with actellic, 1.4% for metal silo without pesticide and 0.5% for metal silo with phostoxin.

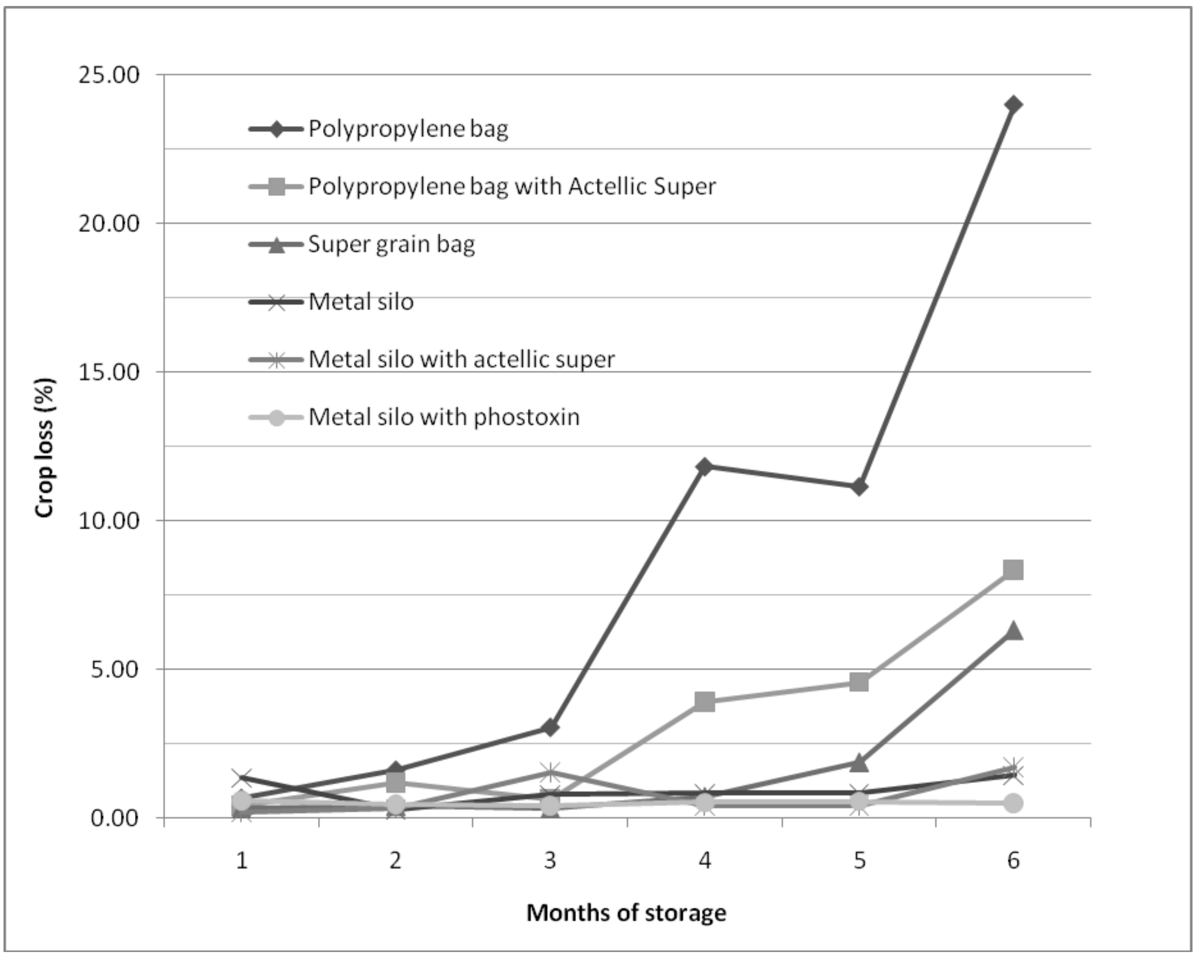

Figure 1. Crop loss in % of weight of stored maize

Table 2 shows the results after regressing the % loss with the cross effects of the treatment and time. As such, the coefficients are to be interpreted as loss, in % of initial quantity, per month. The coefficients for the polypropylene (PP) bag without pesticide (control) and super grain bag are positive and significant. Hence, percentage loss per month is 2.82% for the control, 1.03% for the polypropylene bag with actellic super and 0.54% for the super grain bag. The % losses from the metal silos are negligible

Table 2 . Regression over time, cross effects with the different treatments

Cross effect of time with	Coefficient	Std. Error	P value
Polypropylene bag, no pesticide	2.82	0.25	0.000
Polypropylene bag, actellic super	1.03	0.23	0.000
Super bag	0.54	0.25	0.035
Metal silo, no pesticide	0.21	0.26	0.416
Metal silo, actellic super	0.23	0.24	0.351
Metal silo, phostoxin	0.12	0.26	0.637
R Square	0.38		
N	258.00		

3.2 Benefits of technologies: Loss abatement – scenarios

Benefit from technology is calculated as the loss abated as compared to the control. Assuming linear loss functions based on the trial data (Table 2), we calculate the value of one ton of maize stored and priced at USD 300. The benefit form the technology is the difference from the control. Figure 2 shows the different gains from using the various technology options. In this case, the metal silos are combined since for all them, loss per month is negligible (Table 2).

The gain clearly increases with time. Storage with metal silo records highest gain, from USD 8.4 after one month of storage to 100 USD after 12 months of storage. Hence if a farmer uses a silo to store one ton for 12 months, the gain is 100 USD, which is the loss avoided as compared to the control which incurs a loss of 2.82% per month. For the super bags, the gain moves from USD 6.9 after one month of storage to USD 82.8 after 6 months.

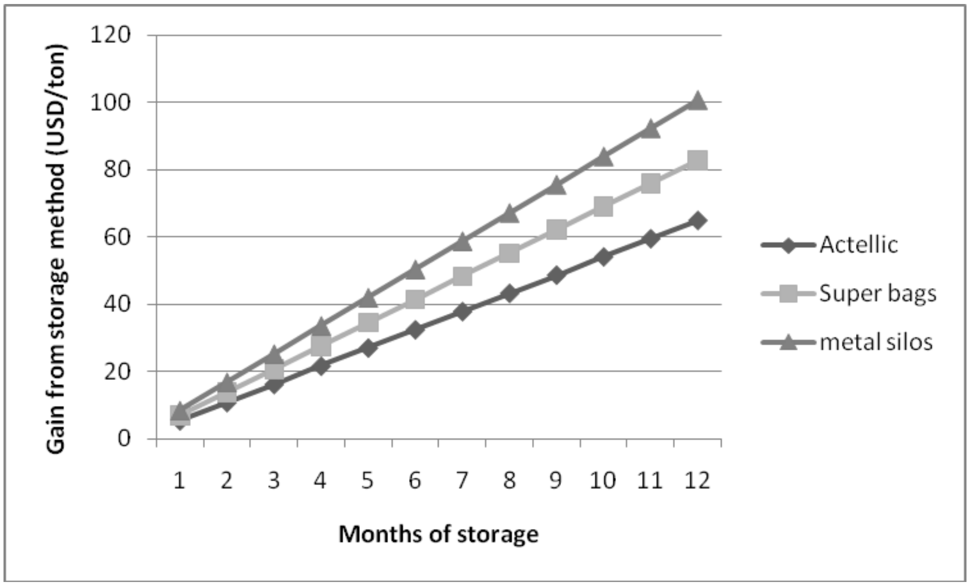

Figure 2. Benefit or crop loss abated, in USD/ton

3.3. Cost of the different technologies

Likewise costs are calculated as the incremental cost of the technology as compared to the control. Figure 3 shows the incremental cost when using the technology to store one ton for one year. The incremental cost per ton for the PP bag with actellic super is USD 30 for one year of storage. Interviews with farmers revealed that farmers undertake repeated applications of actellic super (once every 3 months), which is taken into consideration here. The cost increases to USD 52/ton for the super grain bag. In this case, we show different silo sizes since they can be made to accommodate different amounts of grain. We compare the incremental cost from the control for five silo sizes (0.36 tons to 1.8 tons). The incremental cost/ton decreases as the size of silo increases. By investing in 0.36 ton, the farmer will incur an extra 316 USD/ton compared to the control as opposed to just 171 USD/ton when the farmer invests in a 1.8 ton silo.

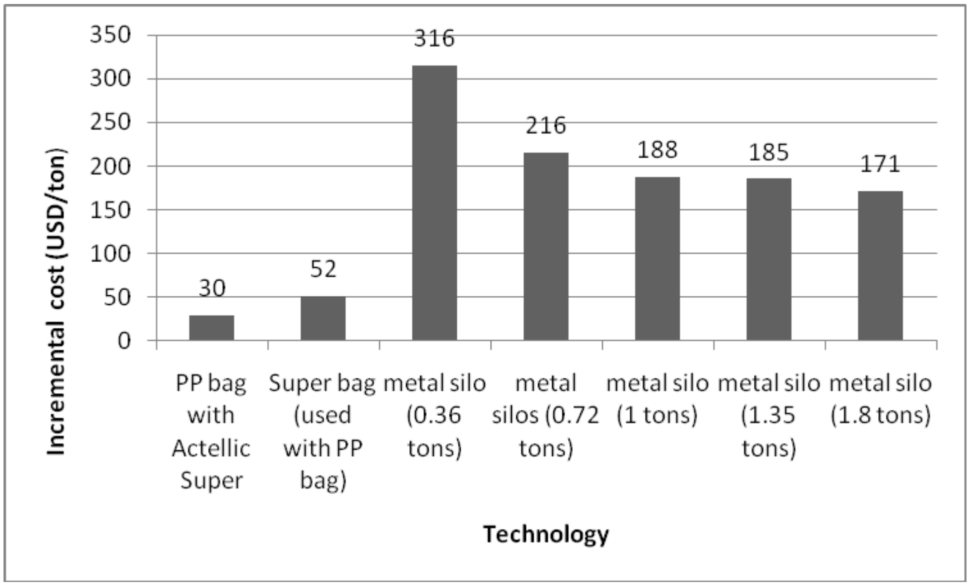

Figure 3. Incremental investment cost of different technologies used (USD/ton)

3.4 Analysis of discounted costs and benefits: different storage technologies

In this section, we discount the incremental benefits and costs over a period of 15 years. We assume a discount rate of 11%, which is the average rate of the change in consumer price index for the last 10 years in Kenya (1999 to 2008). We take the three technologies; PP bag with actellic super, super bag and the metal silo. In computation of the cost, we also add an option where a super grain bag is replaced every year (as opposed to lasting for 3 years). This is after assuming that it would be perforated by the LGB hence requires replacing every year. Therefore, we have a total of four technology options to consider. Just like the previous scenario, this analysis considers a production of one ton, with a price of maize of 300 USD/ton. Table 3 shows these technologies, their NPV in 15 years, incremental NPV and BCR. For a period of 15 years, all the technologies return a positive stream of discounted net benefits (NPV). However, BCR is highest for the PP bag with actellic super (7.1), and lowest for super grain bag of 1 year lifespan (0.5). In this paper, we argue that in order for a new technology to be attractive to a farmer, the BCR will require to be at least 2. In common practice, especially with social projects undertaken by the government, a BCR of above is considered attractive for investment. We however argue that an individual farmer would require a BCR of at least 2 since this will guarantee that the farmer recovers his investment money as opposed to just breaking even. Therefore, we use a BCR of 2 to evaluate the suitability of investing in a new storage technology. In this case therefore, the technologies (Table 3) are worth undertaking apart from a case where the super grain bag was to be replaced every other year (BCR of 0.5).

Table 3. NPV (USD) and BCR over an investment period of 15 years

Year	PP bag with actellic super	Super grain bag (3 yr lifespan)	Super grain bag (1 yr lifespan)	Metal silo
0	246	219	219	100
1	229	254	204	265
2	207	229	183	239
3	181	160	160	215
4	168	186	149	194
5	150	167	134	175
6	132	117	117	157
7	123	136	109	142
8	111	122	98	128
9	97	86	86	115
10	89	99	80	104
11	81	89	72	93
12	71	63	63	84
13	66	73	58	76
14	59	65	52	68
15	51	46	46	62
NPV	2060	2111	1828	2216
Incremental NPV (Technology less control)	465	516	233	621
Incremental PVC (Technology less control)	66	163	445	204
BCR	7.1	3.2	0.5	3.0

We undertake a sensitivity analysis by varying the period of investment and the discount rate. This is informed by the argument that a farmer would most likely than not take a shorter outlook than 15 years, and he may also face higher interest rates. Table 4 shows this analysis. At a discount rate of 11%, a metal silo ceases to be an attractive investment if the period of investment reduces below 10 years (BCR of less than 2). This is due to the high investment cost that would require considerable time to recoup. The super grain bag that lasts for 3 years is favorable in almost all the situations.

Table 4. Sensitivity analysis (BCR)

interest rate %	Time (years)	PP bag with actellic super	Super grain bag (3 yr lifespan)	Super grain bag (1 yr lifespan)	Metal silo
11	3	7.1	2.1	0.5	0.8
11	5	7.1	3.4	0.5	1.4
11	10	7.1	3.2	0.5	2.4
11	15	7.1	3.2	0.5	3.0
20	3	7.1	2.1	0.5	0.6
20	5	7.1	3.1	0.5	1.0
20	10	7.1	2.9	0.5	1.6
20	15	7.1	3.0	0.5	1.9
50	3	7.1	1.9	0.5	0.2
50	5	7.1	2.4	0.5	0.4
50	10	7.1	2.3	0.5	0.5
50	15	7.1	2.4	0.5	0.5

3.5 Analysis of discounted costs and benefits: silos of various capacities

We extend this analysis by considering the BCR of metal silos of varying capacity. This is because a farmer can invest in different size silos depending on factors like space, production, level of income and profitability. We consider six sizes, from a small one of 0.09 tons to a big one that can hold 1.8 tons. In this analysis, the benefits are the abated loss of the value of maize that silo can hold, while the cost is the actual cost of investment of the particular silo and maintenance cost over the period. We use the same criteria (BCR of at least 2) to evaluate the attractiveness of the investment. At a discount rate of 11%, the smallest silo has a BCR of less than 2 irrespective of the period of investment (whether 3, 5, 10 or to 15 years). For the shortest investment period, the second smallest silo (0.36 tons) is not an attractive investment to the farmer (Figure 4). However, the bigger silos are attractive irrespective of the period of investment considered. A sensitivity analysis is undertaken by varying the discount rate at investment periods. At 20%, we get the same results as at 11%, with the smallest silo not looking profitable while for the second smallest, the period of investment has to be at least 5 years for it to be worth investing in. Figure 5 shows the same analysis, but now discounted at a rate of 50%. Because of the higher interest rate, now the two smallest silo sizes are not profitable for the investment periods under consideration. In all these situations however, the 3 large silos are attractive investments with a BCR of above 2.

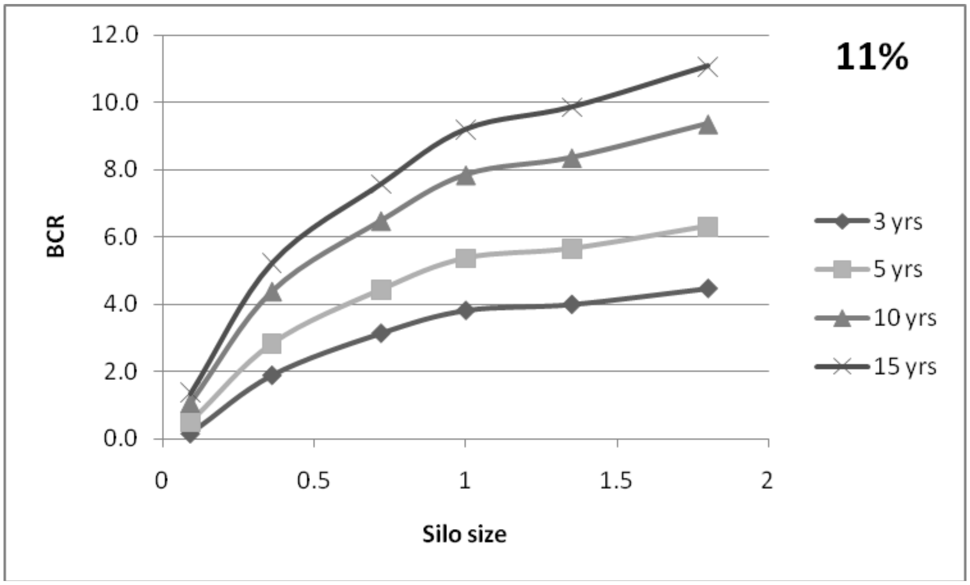

Figure 4. BCR for different silo size for different investment periods (11%)

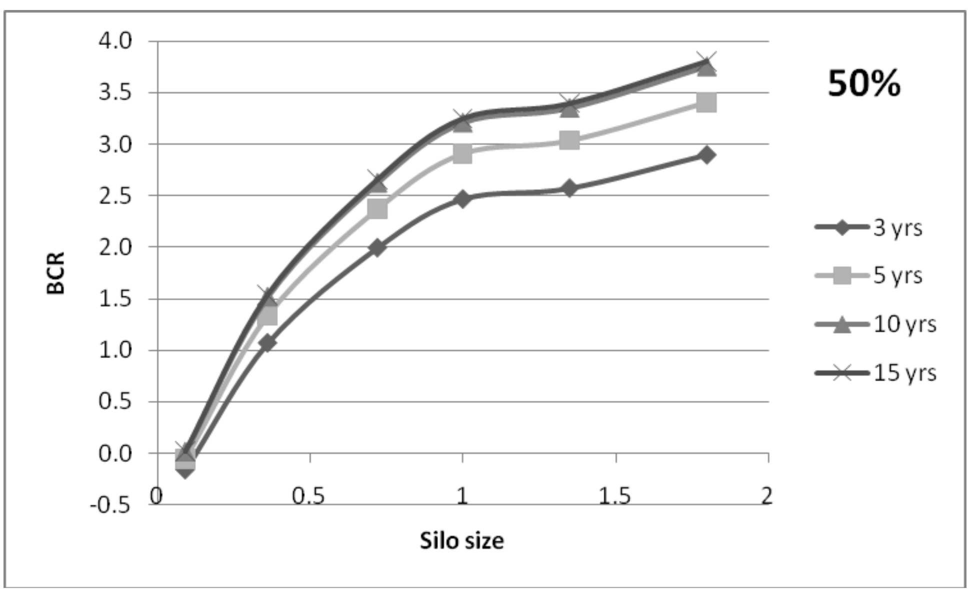

Figure 5. BCR for different silo size for different investment periods (50%)

4. Conclusions

In this study, economic analysis of new storage technologies has been undertaken. In order to get the amount of loss each technology can abate, results on crop loss were regressed cross effects of time and technology. Results showed that the highest loss from the trials was observed in the control, reaching 24% after six months. Percentage losses from the silos were minimal. Determination of the benefit was based on the amount of loss the technology could abate. For a one ton silo, the benefits were USD 100 in the first year of investment since the loss from the silo was negligible. These benefits were found to increase with time, reaching USD 82.8 after 6 months for the super bag from USD 6.9 in the first month. For the silo, they increased from USD 8.4 after one month of storage to 100 USD after 12 months of storage. The fact that the farmer gains more by storing more (unlike what happens with high losses and no improved technology) is an encouragement to those farmers who may want to invest in a silo and keep maize for longer either for household consumption or in deferring sales to wait for better maize prices. On the other hand, investment costs were found to decrease with silo size, with the small silo having a higher cost/ton as opposed to a bigger one.

Measures of project worth, mainly the NPV and BCR were used to analyze the expected future net benefits from investing in the new technologies. Using a discount rate of 11% and an investment period of 15 years, the incremental NPV from all technologies were found to be positive. In this paper, we argue that a farmer would need a BCR of at least 2 to consider investing in a new technology. This is because he would not just he would need not just break-even, but generate revenue in excess of his investment. Using this criterion at this discount rate, the technologies were found to be favorable based on a favorable BCR apart from the super grain bag where a farmer would have to replace every year. Calculating this BCR was based on incremental benefits and costs from the control.

One positive characteristic of the silo is that it can vary in size, and a farmer has a choice to buy the size that fits his conditions. In order to compare the attractiveness of investing in silos of various sizes, the analysis was extended to six silo sizes, now comparing their benefits and costs in determination of BCR. This analysis was also subjected to a sensitivity analysis by varying the interest rates and length of investment period. The results showed that the three largest silos were attractive for all the scenarios used here. The attractiveness of the smaller silos were however sensitive to the interest rate and the investment period. Hence the smaller the silo size, the higher the requirement that the interest rate be small and the period of investment bigger for it to be attractive to the farmer. This is important information to the promoters of this technology, since by promoting bigger silos, they are in essence reducing the cost to the farmer. The observation also resonates well with the message for increased production, which in effect would imply that farmer would go a bigger silo to fit his production.

This analysis has generalized the amount of crop loss reported from the trials. The authors are currently quantifying on-farm % crop loss in various agro ecological zones in Kenya. This information will help to further improve the analysis and target is to specific zones.

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