Effect of Inorganic and Organic Fertilizers on the Performance and Profitability of Grain Amaranth (*Amaranthus caudatus L.*) in Western Kenya

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Abstract

Protein malnutrition is a major cause of morbidity and mortality in developing countries where the cost and availability of animal protein remain prohibitive. Grain amaranth (*Amaranthus caudatus L*) has the potential to substitute expensive animal protein. Its production and consumption is however low in Kenya. Nitrogen is a key limiting element in grain amaranth production. This study investigated the effects of different rates of inorganic nitrogen and cattle manure on the growth and yield of grain amaranth over a period of two years. Inorganic fertilizer at the rate of 100 kg N/ha significantly delayed flowering. Grain yield showed a linear response to inorganic and organic N application. Regression analysis projected the optimum inorganic fertilizer and manure application rates of 87.5 kg N/ha and 9 t/ha respectively with yield of 1.84 t/ha. The highest profitability was achieved at the optimum manure and fertilizer rates. The projected manure and inorganic fertilize rates may however not be affordable by the small-scale farmers. Thus a follow-up study to test the combined effect of inorganic and organic fertilizers is recommended.

Keywords: Manure, Grain yield, Gross margins; Inorganic nitrogen, Protein amaranth

1. Introduction

There is widespread and severe protein malnutrition in Kenya and other developing countries due to poverty and inability of vulnerable groups to access adequate amounts of expensive animal protein foods to meet dietary requirements (WHO, 2004). Grain amaranth has the potential to substitute expensive animal protein because of its comparable protein quality and quantity (FAO/WHO/UNO, 1985; FAO, 2003). Despite its nutritional qualities, its production and consumption is still limited in Kenya. This is partly attributed to the fact that little research has been done to determine the best agronomic practices to maximize grain production and inherent low soil fertility. Furthermore, low and declining soil fertility due to continuous cultivation, soil erosion and nutrients losses through runoff and leaching is a serious problem in many parts of Kenya (Okalebo, 2002). About 30% of increases in harvests by small-scale farmers in the third world in the last three decades is due to use of chemical fertilizers (Bunch, 1996). However, in view of their escalating prices, green manure crops, compost and animal manure are increasingly being used for soil fertility management (Bernick, 2008). In Kenya, only 25% of grain amaranth farmers use either inorganic or organic fertilizer albeit in quantities less than the recommended rates. The average grain yield of grain amaranth in Kenya is 0.5- 1 t/ha compared to 2.5 t/ha to3 t/ha achieved with optimal use of fertilizers (Bernick, 2008).

Fertility needs for grain amaranth production varies significantly depending on rainfall amounts and distribution (Mposi, 1999). Studies show that nitrogen is the most limiting nutrient under most environments (Pospisil et al., 2006). Phosphorous and potassium are only applied in soils that are especially deficient in these nutrients with the rate of 50kg P/ha being considered optimum (Myers and Putnam, 1988; Ojo et al., 2007). There is limited information on soil fertility requirements for grain amaranth production in Kenya as the crop is relatively new. The current research was accordingly undertaken to investigate the appropriate levels of nitrogen fertilizer and manure application for enhanced grain amaranth production in Kenya.

2. Research Methodology

2.1 Site description

Field experiments were conducted during the short rain season of 2008 and the long rain season of 2009 at the Maseno University Research Farm (latitude N 0^0 1'-S 0^0 12' and latitude E 34^0 24'- E34^0 47'), in Western Kenya. The rainfall distribution is bimodal with the long rains occurring from March to July and short rains from September to December (Jama et al., 1997). The area receives an annual average rainfall of 1750 mm and the temperature ranges from 15^oC-31^oC (Abednego et al., 2003). During the experimental period, 1672 mm annual rainfall was received in 2008 and 710.5 mm during the months of January-July, 2009. The mean temperature during the experimental period was 20^0 C.

The major soil type of the area is classified as acrisols (FAO, 2003). The measured initial soil properties were: Moderate in total nitrogen (0.13%), low Mehlich phosphorus (3.95 ppm), high potassium (2.97 Cmol/kg), moderate organic carbon (1.37%) and moderately acidic (pH water; 5.03 and pH 0.01 $Cacl_{2;}$ 5.8). Prior to the commencement of the field experiments, the experimental plots had been under fallow for a year.

2.2 Experimental design and agronomic practices

The experiment was laid out as randomized complete block design with three replications and conducted over two seasons. Land preparation was done using a tractor powered disc plough and harrow. The plot sizes were 5x4 m with a footpath of 0.5 and 1 m between the plots and replicates, respectively. The treatments were inorganic fertilizer and cattle manure applied at the rates of 0, 30, 60 and 100 kg N/ha, and 0, 0.5, 1.0, 2.0 and 3.0 t/ha, respectively. Inorganic fertilizer was applied at half rate at planting in the form of Diammonium Phosphate (DAP 18:46:0) and the balance top dressed as Calcium Ammonium Nitrate (CAN 26% N) six weeks after sowing. Manure was incorporated in the soil before planting. Grain amaranth was planted at a spacing of 30 x 60cm using hand hoes. Weeding was done three times, 3, 6 and 9 weeks after sowing in both years.

2.3 Data collection

Plant height and inflorescence length were measured on five plants randomly sampled from the inner rows of each plot weekly starting 5 weeks after planting to harvesting. Days to 50% flowering were determined by averaging the period it took for half of the plants in each plot to flower. Days to harvest for each treatment were determined by the average period to physiological maturity. Dry matter was determined by destructive harvesting of 5 plants from the inner rows of each plot. The plants from each treatment were chopped and dried at 65^oC for 48 hours in an oven. The destructive sampling was done at harvest to avoid changing plant population in the course of plant growth. Grain yield was measured by harvesting the inner rows and the grain threshed and dried to moisture content of 12-13% and then weighed for yield analysis.

2.4 Data analysis

Data was subjected to Analysis of Variance using one way ANOVA, of Genstat statistical package (Lawes Agricultural Trust Rothamsted Experimental Station) and the differences in means compared by least significant difference at the 5% probability level. Regression analysis was done to determine the optimal application rates of inorganic fertilizer and cattle manure. Marginal Rate of Return was (MRR) used to determine the profitability of grain amaranth production. Sensitivity analysis was conducted to determine the effect of varying the rate of fertilizer, fertilizer price and grain yield on the MRR of grain amaranth.

3. Results and discussion

3.1 Effect of fertilizer application on plant height and Inflorescence length

Application of inorganic fertilizer and manure significantly ($p < 0.05$) improved crop growth as compared to the control (Figures 1 and 2). More rapid growth of grain amaranth was realized with use of chemical fertilizer compared to manure. This could be due to increased availability of soil nitrogen with application of inorganic fertilizer culminating into enhanced N uptake and hence faster growth. Release of nitrogen by manure however occurs slowly after mineralization.

These findings are in agreement with those of other researchers (Pang and Letey, 2000; Hartemink et al., 2000; Eghball et al., 2002) who found that while nitrogen supplied by inorganic fertilizer was readily available, the nitrogen supplied by manure was released slowly.

Inflorescence length increased with increasing application of fertilizer rates. The highest inflorescent length was achieved when inorganic fertilizer was applied at 100 kg N/ha and manure applied at 3 t/ha (Figures 3 and 4). Inorganic fertilizer at the rate of 100 kg N/ha significantly increased ($P< 0.05$) days to 50% flowering compared to the lower N levels of 0, 30 and 60 kg N/ha. The 50% flowering occurred after 57 days compared to the controls' 42 days. There was no significant ($P< 0.05$) difference in days to 50% flowering across the manure application rates.

Increased levels of inorganic fertilizer and manure could have led to increased availability and uptake of nitrogen which promoted vegetative growth and prolonged the period to flowering and physiological maturity. Similar findings on the effect of fertility on amaranth growth have also been reported (Materechera and Medupe, 2006; Mhlontlo et al., 2007; Myers, 1998; Spetter and Thompson, 2007; Bruce and Philipe, 2008).

3.2 Effect of fertilizer on grain amaranth yield and harvest index

Fertilizer application significantly ($p < 0.05$) improved dry matter production and yield of grain amaranth (Table 1). The rate of increase in grain yield rose steadily as the rate of nitrogen was raised from 0 kg/ha to 100kgN/ha to the optimum level of 87.5 kg N/ha. Similarly, the grain yield continued to increase at an increasing rate as the rate of manure was raised to the optimum level of 2.65 t/ha (Figure 5).

The harvest index was not significantly affected by the rate of fertilizer application (Table 1), showing that there was no change in biomass partitioning with application of the different rates of inorganic fertilizer. Gunda et al. (2005) also found no significant difference in the harvest index when N was applied at the rates of up to 120 kg N/ha.

Grain yield showed a linear response to inorganic fertilizer and manure application (Figures 5 and 6). When inorganic fertilizer was used (Figure 5), the yield response followed the regression equations $y= 0.019x + 0.29$ ($R^2=0.988$) and $y= 0.018x + 0.23$ ($R^2=0.980$) in 2008 and 2009 respectively. In the first year, the grain yield increased to 1.96 t/ha with application of 90.0 kg N/ha. In the second year, the grain yield rose to 1.71 t/ha with the application of 85.0 kg N/ha. Over the two years, the grain response to inorganic fertilizer showed an optimum inorganic fertilizer application rate of 87.5 kg N/ha with an optimum grain yield of 1.84 t/ha.

Similarly, when manure was used (Figure 6), the grain yield showed a linear response, $y= 0.0181x + 0.01$ ($R^2=0.869$) and $y= 0.227x + 0.01$ ($R^2=0.923$) in 2008 and 2009 respectively. The grain yield increased to 0.67 and 0.79 t/ha with application of manure at the rate of 3 t/ha in 2008 and 2009 respectively. Regression analysis showed that the optimum grain yield of 1.84 t/ha obtained with application of inorganic fertilizer could be obtained with a manure rate of 10.0 t/ha and 8.0 t/ha in 2008 and 2009 respectively. The optimum manure rate was therefore projected as 9.0 t/ha being the average for the two years.

These results are in agreement with the findings of Elbehri et al. (1993), Myers (1998) and Bruce and Philip (2008) who reported a linear response of grain amaranth yield to N fertilization. The increase in grain yield as fertilizer application rates increased could have been due to increased plant growth, flowering and grain filling.

This responsiveness of grain amaranth yield to nitrogen fertilization is comparable to the findings of other researchers (Myers, 1996; Jefferson Institute, 1999; Bruce and Philipe, 2008).

The increase in grain yield obtained with application of 30 kg N/ha of inorganic fertilizer and 1 t/ha of manure compared to the control appears drastic. This could be attributed to the inherent low fertility of the soil at the experimental site. According to Myers (1996), Jefferson Institute (1999) and O'Brien and Price (1983) only 45 to 90 kg N/ha was required to reach maximum yield of 2 t/ha with the lower rate used following soybeans or other legumes. Kauffman and Weber (1990) also found grain yield to increase when nitrogen was applied at rates up to 90 kg N/ha, to double at 100 kg N/ha and reduce at higher rates.

When grain amaranth was grown using manure, better grain yields were obtained in the second year across all manure rates. This is attributable to the slow release of nutrients from organic sources and hence available for prolonged periods of time. For this reason, the yields in the first year with application of manure were low compared to inorganic fertilizer application. In the second year however the yields were higher in all the manure treated plots implying sufficient nitrogen release, coupled with nitrogen carryover from the previous season, with resultant enhanced uptake and consequently higher crop yields. This is in agreement with the findings of Stute and Posner (1995) and Onwonga et al. (2008) who reported that use of manures could help build soil fertility and increase N supply for the succeeding crops.

3.3 Effect of fertilizer on grain amaranth profitability

The marginal rate of return (MRR) increased with increase in the rate of inorganic fertilizer up to the optimum rate before decreasing with further increase in fertilization (Figure 7). In the first year, the marginal rate of return increased with increase in the rate of inorganic fertilizer from 0 to 90.0 kg N/ha and thereafter declined with further increase in the rate of fertilization. During the second year, the MRR increased with increase in the rate of fertilization from 0 to 85.0 kg N/ha and thereafter decreased with increase in the rate of inorganic fertilizer (Figure 7). Averaged over the two years, the greatest MRR of 7.51 was achieved with application of inorganic fertilizer at the rate of 87.5 kg N/ha.

Similarly, the MRR increased with increase in the rate of manure application up to optimum rate of 10.0 and 8.0 t/ha in 2008 and 2009 respectively (Figure 8). In 2008, the MRR remained stable with increase in the rate of manure up to 2 t/ha before increasing steadily as the rate of manure increased to 3 t/ha. The maximum MRR was projected to 6.81 at a manure rate of 10.0 t/ha in 2008. In 2009, the MRR increased steadily with increase in the rate of application of manure from 0 to 3 t/ha. The MRR was projected to increase further with increase in the rate of fertilization up to a maximum of 8.44 at manure application rate of 8.0 t/ha (Figure 8). Averaged over the two years, the highest MRR of 7.63 would be achieved with application of manure at rate of 9.0 t/ha, a rate also obtained through regression analysis. The marginal rate of return decreased with increase in fertilizer and manure prices (Figures 9 and 10). The marginal rate of return increased with increase in grain yield following application of inorganic and organic fertilizer at various rates (Figures 11 and 12).

4. Conclusion

Application of inorganic fertilizer and manure were found to improve the growth, yield and MRR of grain amaranth. Based on the results of regression analysis and sensitivity analysis, the optimum inorganic fertilizer and manure application is estimated at of 87.5 kg N/ha and 9.0 t/ha, respectively. Better marginal rates of return were realized with higher grain yields indicating that grain amaranth production would be profitable with increased application of inorganic fertilizer and cattle manure. However, the projected manure rates of 9 tons/ha and 87.5 kg N/ha may not be affordable by the small-scale farmers. This therefore calls for a follow-up study on an integrated approach to soil fertility management through a balanced use of chemical fertilizers in combination with organic manures.

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Table 1. Effect of inorganic fertilizer and manure on yield and harvest index of grain amaranth in Western Kenya in 2008 and 2009 growing seasons

		2008			2009		
		Grain yield (t/ha)	Dry matter yield (t/ha)	Harvest index	Grain yield (t/ha)	Dry matter yield (t/ha)	Harvest index
Inorganic fertilizer	0 kg N/ha	0.29	0.74	0.28	0.23	0.65	0.26
	30 kg N/ha	0.90	2.31	0.28	0.76	2.10	0.27
	60 kg N/ha	1.55	3.61	0.30	1.47	3.71	0.28
	100kg N/ha	2.10	5.14	0.29	1.94	4.98	0.28
LSD 5%		0.573	1.220	0.044	0.347	1.012	0.059
Manure	0 t/ha	0.01	0.024	0.29	0.01	0.025	0.29
	0.5 t/ha	0.05	0.120	0.29	0.05	0.122	0.29
	1 t/ha	0.11	0.280	0.28	0.13	0.300	0.30
	2 t/ha	0.25	0.560	0.31	0.39	0.890	0.30
	3 t/ha	0.67	1.560	0.30	0.79	1.810	0.30
LSD 5%		0.093	0.179	0.051	0.210	0.531	0.042

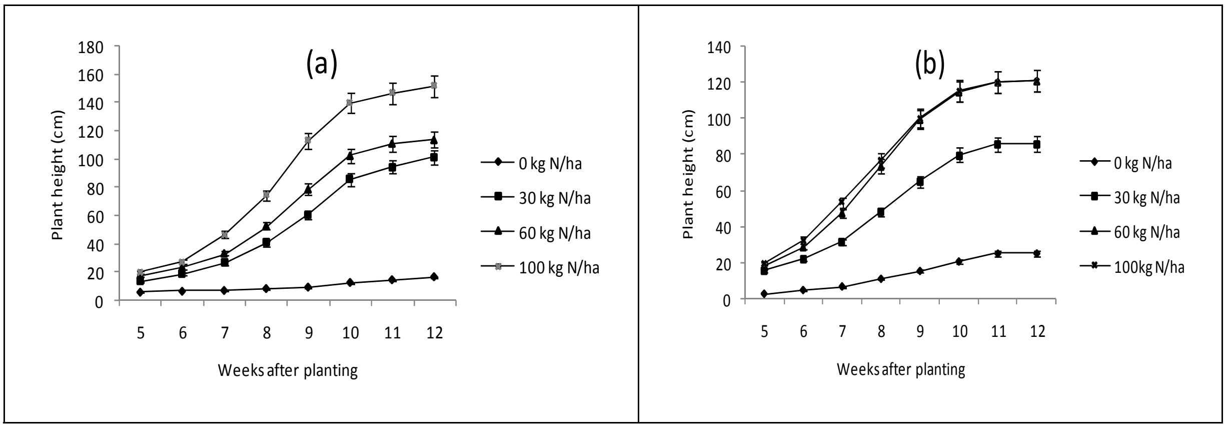

Figure 1. Effect of inorganic fertilizer on the height (cm) of grain amaranth in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

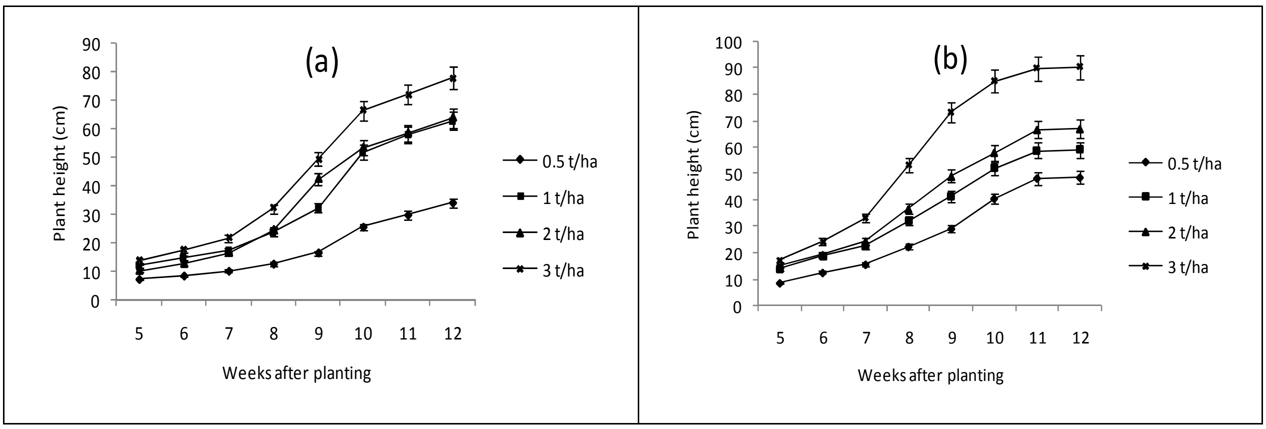

Figure 2. Effect of manure on the height (cm) of grain amaranth in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

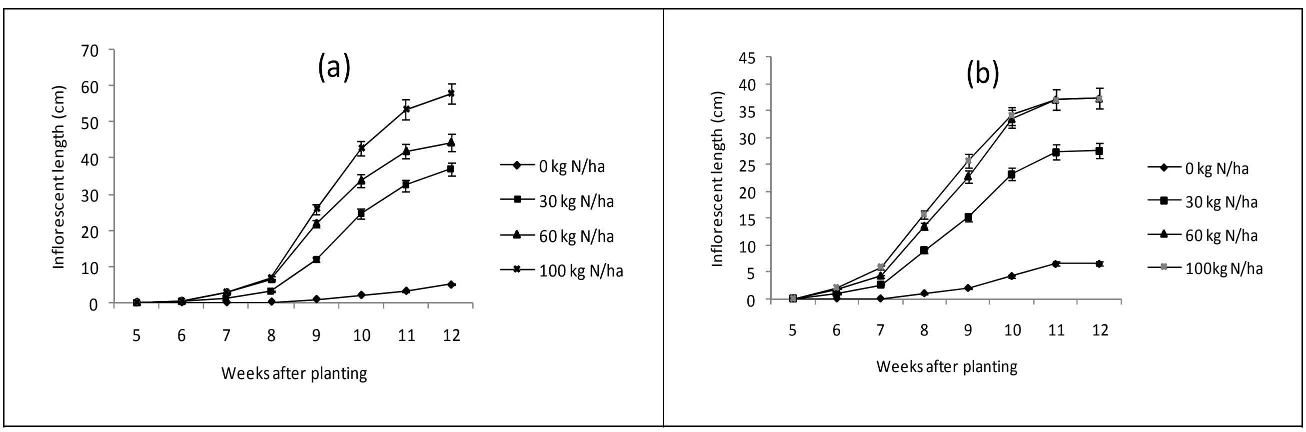

Figure 3. Effect of inorganic fertilizer on inflorescence length (cm) of grain amaranth in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

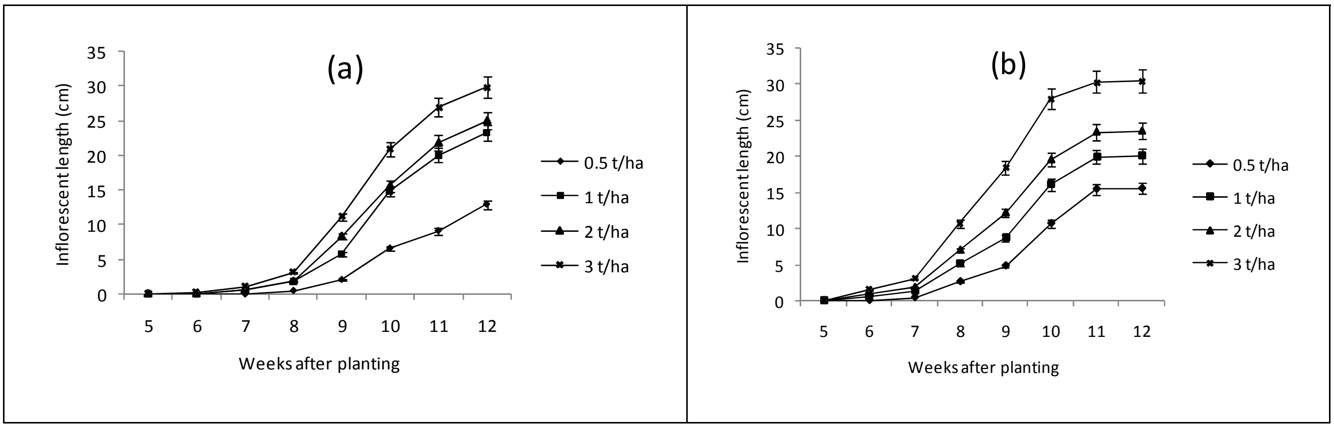

Figure 4. Effect of manure on inflorescence length (cm) of grain amaranth in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

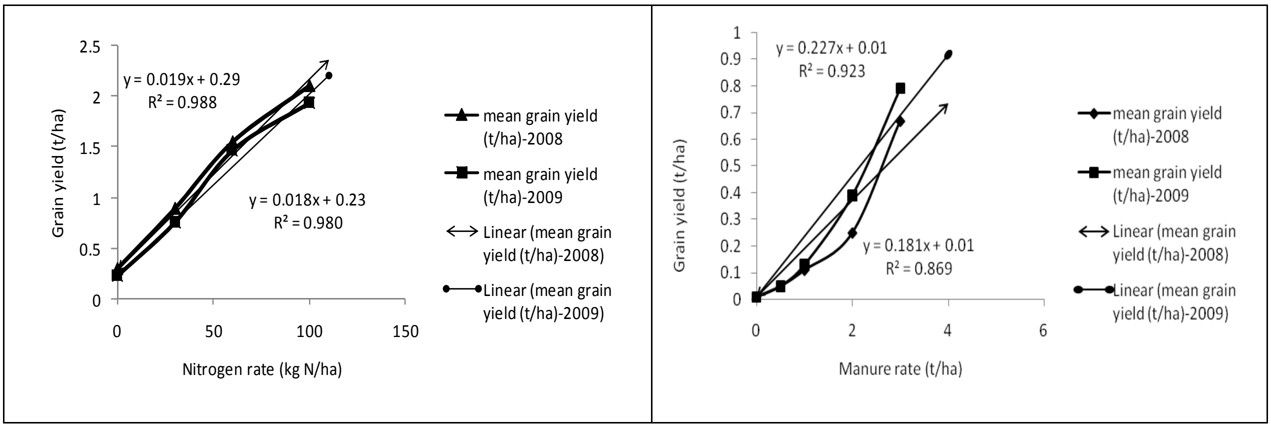

Figure 5. Regression analysis based on mean values of inorganic fertilizer and organic fertilizer on grain amaranth yield

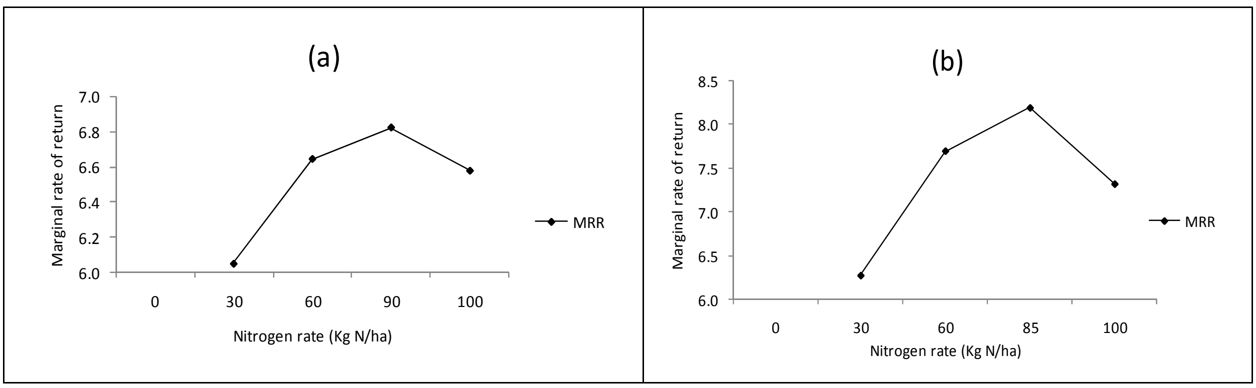

Figure 7. Effect of varying inorganic fertilizer rates on the marginal rate of return of grain amaranth in 2008 (a) and 2009 (b)

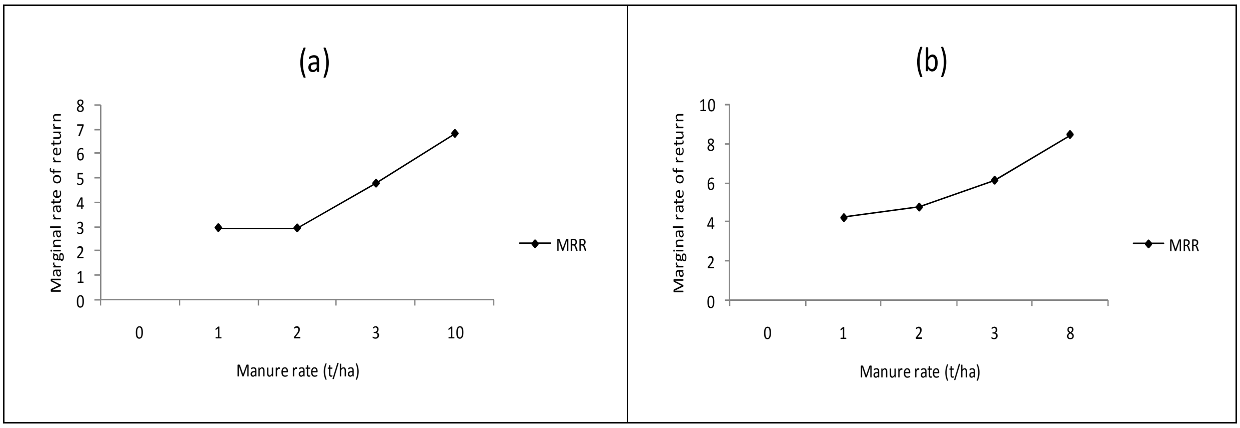

Figure 8. Effect of varying manure rates on the marginal rate of return of grain amaranth in 2008b (a) and 2009 (b)

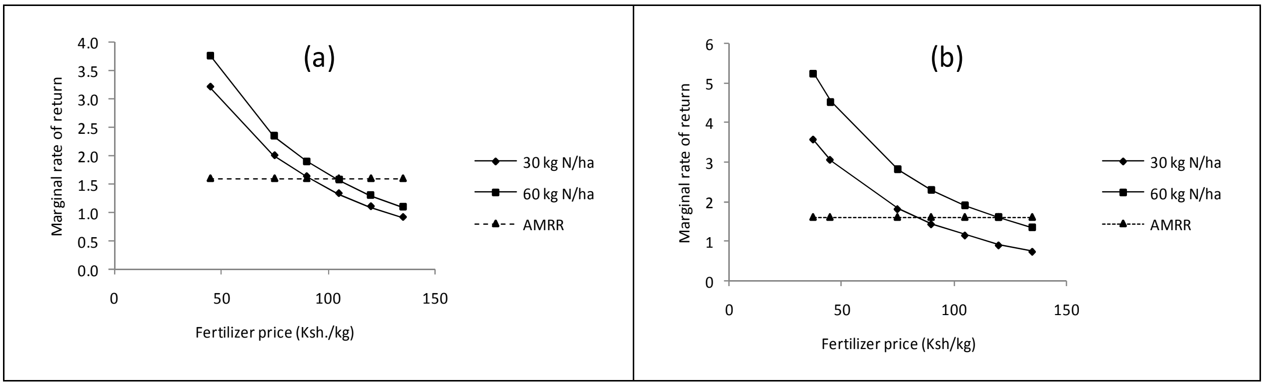

Figure 9. Effect of varying fertilizer price on the marginal rate of return of grain amaranth in 2008 (a) and 2009 (b)

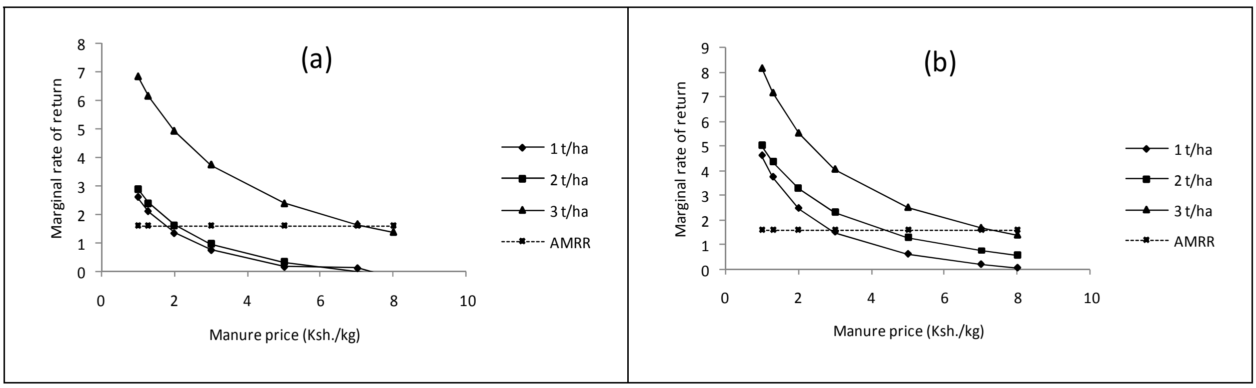

Figure 10. Effect of varying manure price on the marginal rate of return of grain amaranth in 2008 (a) and 2009 (b)

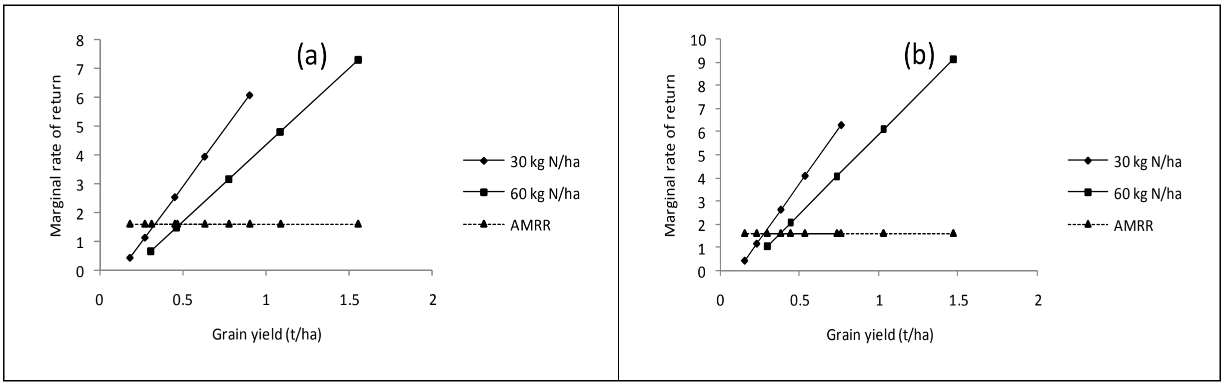

Figure 11. Effect of varying grain yield on the marginal rate of return of grain amaranth in 2008 (a) and 2009 (b)

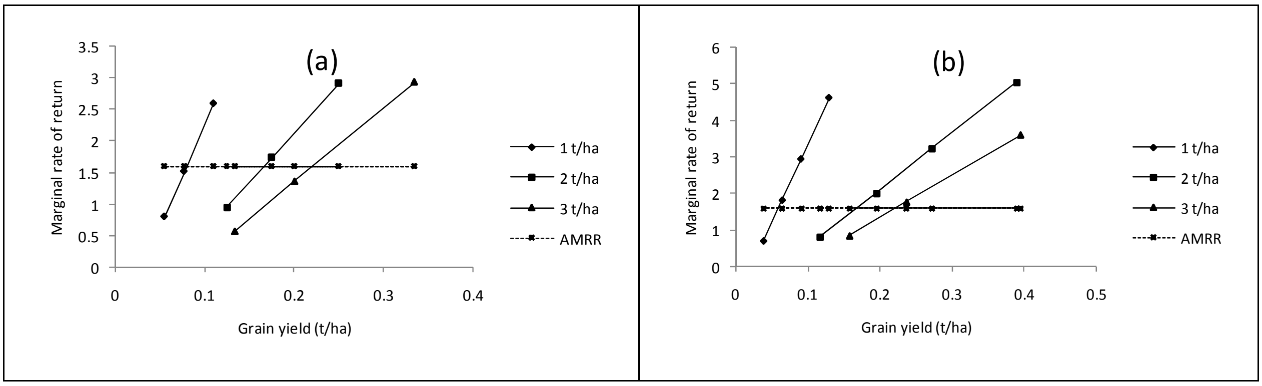

Figure 12. Effect of varying grain yield on the marginal rate of return of grain amaranth in 2008 (a) and 2009 (b)