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Full Length Research Paper

Effects of different rates of compound D and cattle manure as basal dressing with different rates of ammonium nitrate as top-dressing under wetland conditions

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Smallholder farmers are facing problems of low soil fertility causing maize yield reduction of up to 1.5 tonnes per hectare (t/ha) compared to 5 t/ha obtained in the commercial sector. A maize trial was conducted on two wetlands in Natural Region IV of Zimbabwe at Zungwi vlei to determine effects of different rates of compound D and cattle manure as basal dressing with different rates of ammonium nitrate as top-dressing. The maize used was a two-way early maturing hybrid developed by Seed Co. (SC513) for marginal areas. Four basal applications were applied in the trial as treatments for two seasons with four different levels of nitrogen applied as subplots factor. The analysis revealed a highest significant increase in grain yield when 300 kilogrammes per hectare (kg/ha) of compound D was applied with 150 kg/ha of ammonium nitrate (N) as top-dressing. Significant increase in grain yield was also observed when cattle manure was applied with 150 kg/ha top-dressing of N. There was a significant yield advantage when the nitrogen was increased after applying a basal dressing in both sites for the two seasons. In order to achieve high yields, the use of compound D at 300 kg/ha as basal dressing and top-dressing at 150 kg/ha N is highly recommended to farmers. However, for the low-resourced and poor farmers, the use of cattle manure which is generally cheaper and affordable is recommended.

Key words*:* Cattle manure, ammonium nitrate, wetland, yield, maize.

INTRODUCTION

Maize is one of the world's most important cereal crops, which has the widest distribution compared to other cereals (Gibbon and Pain, 1985). It is the staple food of most African countries including Zimbabwe. Its production accounts for 70% of the total area under cereals in Zimbabwe (Gibbon and Pain, 1985). In Zimbabwe, maize production is largely driven by smallholder farmers who are spread in all five Natural Regions (Agro-ecological Zones) of Zimbabwe. However, 91% of these farmers are located in semi-arid areas and within Natural Regions 111, 1V, and V (Mataruka and Whingiri, 1988), which are characterized by low and erratic rainfall (450 to 800 mm) and relatively short seasons making them less favourable for rain-fed cropping (Vincent and Thomas, 1960).

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Abbreviations: BR/BF, Broad ridge and broad furrow or ngwarati system; **DELC,** dead end level contour systems.

Among a myriad of challenges affecting crop production in Zimbabwe, poor soil fertility in the smallholder farming sector has been of major concern particularly in maize production (Grant, 1970; Chavhunduka, 1978; Grant, 1981; Mashiringwani, 1983). The problem of low soil fertility faced by smallholder farmers has culminated in low maize yields to an average of 1.5 t/ha compared to five tonnes per hectare in the commercial sector (ARI, 2000). Maize is generally sensitive to biotic and abiotic stresses, competition for nutrition and moisture resulting in large variations in yields occurring both within and between areas of production. Low soil fertility in the smallholder farming sector has also been compounded by the quality of cattle manure used. Studies in Zimbabwe have shown that a household owns an average of 6 cattle and an average manure production per livestock unit of 1.2 tonnes per year; but the quality of manure produced is of low nutritive value (Avila, 1987; Mugwira and Murwira, 1997). The low nutrient status of manure is documented as the major factor that contributes to the low effectiveness of manure in improving crop growth and yields (Mugwira and Mukurumbira, 1986; Mugwira and Murwira, 1997). This low quality of manure is mostly attributed to imperfect storage and poor handling conditions in the kraal. However, with good post handling technologies, the quality of manure can be improved through erecting of simple storage facilities, providing shed conditions critical to avert the loss of nutritive value of manure.

Furthermore the problem of soil fertility has been accentuated by economic hardships, which have reduced inorganic fertilizer use, as most farmers can no longer afford the exorbitant prices of fertilizers on the market. Lack of knowledge on the effect of soil pH on yield has also affected maize production. The high cost of fertilizer augmented by liquidity constraints has reduced fertilizer use and perpetuated the low fertility problems in the smallholder sector (ARI, 2000). Notably however, farmers have organic manure at their disposal, which they can use to improve crop productivity. Under vlei or wetland conditions, moisture in most cases does not limit crop production, but fertility, especially in sand soils. The availability of organic manure could therefore be an option in wetland areas, whose correct application can stimulate increased production in the smallholder sector.

The objective of this study was to determine the effects of different rates of compound D and cattle manure as basal dressing with different rates of ammonium nitrate as top-dressing under wetland conditions.

MATERIALS AND METHODS

Study site and crop establishment

A trial was conducted under wetland conditions at Zungwi vlei (20° 25` S and 30° 25` E) in Zvishavane District Natural Region IV of Zimbabwe on two wetlands located about 1 km apart. The sites comprised of two cultivation systems namely Broad Ridge and Broad Furrow (BR/BF) or Ngwarati system (Mharapara, 2000) and Dead end level contour (DELC) systems. The BR/BF system consists of broad ridges and furrows that are developed on contour. They are developed in an alternating sequence starting from the highest point of the vlei. The furrows are designed in a feeder system (Mharapara, 2000) where the first furrow is filled up to a pre-determined level of 30 cm and feed the next lower furrow. The first ridge, which is called the master ridge, holds and stabilises water flowing from the catchments. Both the broad furrows and broad ridges are 2 to 4 m wide and the ridges are 60 cm high so that they can hold the water to a level of 30 cm high in the above furrow. The furrows from the top to the last bottom are all filled with water, which finally collects into the fish-pond. The BR/BF system is developed by a cut and fills method where soil from the furrow is used to build the ridge. The topsoil from the furrow forms the base of the ridge and the sub-soil forms the top of the ridge. Water movement from the catchments usually brings litter and manure and improve the furrow soil texture (Mharapara, 2000). The maize crop was grown on the ridge top.

The DELC system is composed of the rectangular trench 0.75 to 1 m deep by about 1 m wide dug along the contour. Excavated soil was placed at the lower side of the trench, the opposite of the fanya juu. The next trench followed on the next contour line being about 30 m apart. The block in-between was planted with maize. Water collected by the trench moved down slope supplying moisture to the crops. The dead end level contour was taken as a control because this system was used by local farmers as their water conservation farming method. This method did not have a self feeding mechanism like the BR/BF as far as above ground water flow was concerned. However, there was communication through underground movement. The contour released water to the lower field and subsequent contour below.

Soil samples were collected from experimental sites 0 to 45 cm using a bucket auger at random both on BR/BF system and DELC system before and after the trial from pre-marked plots. Samples taken were put in paper pockets, air dried and sieved and sent to Zimbabwe Sugar Association Experiment Station (Z.S.A.E.S) for analysis on soil texture, organic matter content, pH, clay, sand and silt, nitrogen before and after incubation, phosphate, potash, calcium, magnesium and sodium. Cattle manure that was used in the trial were taken from three farmers and sent for analysis to determine organic matter content, pH, and nitrogen before and after incubation, phosphate, potash, calcium, magnesium and sodium at Z.S.A.E.S. Rainfall data was also recorded using plastic rain gauges.

Lime was applied at the rate of 300 kg/ha to correct soil acidity. Planting holes were then made before the rains and basal fertilizers and cattle manure applied per planting station at the same time in October for the two sites. The crop was planted on the 15th and 16th of December for the first and second seasons respectively. Row spacing was 90 and 30 cm intra rows giving a plant population of 37 037 per hectare. Top-dressing was split applied at four weeks and eight weeks for both seasons.

Experimental design and treatments

The trial was set up in a split-plot design with basal dressing as the main plot and top-dressing levels as sub-plot factors and replicated three times. Basal main plots were 20.7 m long × 3.6 m wide, with 1 m pathways between main plots. Individual subplots were 4.8 m long × 3.6 m wide, with 0.5 m pathways between plots. Lime was uniformly applied at a rate of 300 kg/ha to all the plots per season making a total of 600 kg/ha in the two seasons. The experimental sites were the same both seasons for the two sites with maize variety SC 513 planted. SC 513 is a two-way early maturing hybrid developed by Seed Co. (Pvt) Ltd for marginal areas.

Four basal applications and four top-dressings were applied in the trial as treatments:

a. Main plot treatment:

1. 0 kg/ha compound D (8:14:7: N: P: K)
2. 150 kg/ha compound D
3. 300 kg/ha compound D
4. 5 t/ha of cattle manure

b. Sub-plot factor:

1. 0 kg/ha N
2. 50 kg/ha N (ammonium nitrate (34.5%N)).
3. 100 kg/ha N (ammonium nitrate (34.5%N)).
4. 150 kg/ha N (ammonium nitrate (34.5%N)).

Variables measured and Statistical analysis

Total percent emergence and stand count at harvesting were determined for each treatment. Plant heights, days to 95% flowering and physiological maturity were measured. Two middle rows with two plants on either side of the plot were discarded for yield measurements. Yield components measured were one thousand seed weight and grain yield. Total grain weight per hectare was calculated using net plot grain weight.

A Statistical package Genstat was used following procedures of a split plot design with basal as main plot and top-dressing as sub-plot factors. Least significant differences (l.s.d) were used to separate means at $p < 0.05$ as appropriate using MSTATC statistical package.

RESULTS

Rainfall data

Monthly rainfall distribution for Zungwi from December to July for the two seasons 2004/5 to 2005/6 is presented (Figure 1). The rainfall started in the second pentad of December and ended in the second pentad of March giving three months of growing season in 2004/5 and started during the fifth pentad of November and ended during the second pentad of March (3.5 months) for 2005/6 season.

Total rainfall for DELC and BR/BF were 307 and 309.5 mm for 2004/5 season and 638 and 639 mm for 2005/6 season respectively. The first season was characterised by low, erratic and poorly distributed rainfall, whilst the second season had better rainfall distribution but with very heavy rainstorms that gave 116 mm in 5 days. Distribution was highly skewed in both years with 42% of the annual total rainfall received in December in the first season and 40% in the same month in the second season. Both sites received 31 and 20% in January first and second season respectively. Rainfall was below average in 2004/5 season and above average in 2005/6 season. However there were no significant rainfall amount differences between the DELC and BR/BF system in both seasons. Significant differences occurred between seasons.

Soil data analysis from the two sites

Soil samples from two sites under study were analysed and soil texture showed that there were significant differences in clay content levels with 5% and 8% in DELC and BR/BF systems respectively (Table 1). Silt content between the two sites also showed significant differences with 13 and 2% in DELC and BR/BF respectively. Sand content was significantly different with 90 and 82% in BR/BF and DELC respectively. Organic matter content did not show any significant differences from each other with 3.99 and 4.86 in BR/BF and DELC respectively. Soil pH was both acidic but showed significantly different values statistically between sites (4.16 and 4.7 for BR/BF system and DELC system respectively) as vleis are zones of water transmission and not of accumulation (Grant et al., 1994). BR/BF was more acidic compared to DELC system. Nitrogen content did not show any significant difference between sites. Phosphate showed significant differences between systems with 25.8 and 7.2 ppm in BR/BF and DELC systems respectively. Potash was also significantly higher in BR/BF system (0.11 m.e%) as compared to DELC (0.062 m.e%). Calcium showed no significant differences between sites with 0.64 m.e% for BR/BF and 0.762 m.e% for DELC respectively. Magnesium and Sodium showed significant differences between sites with

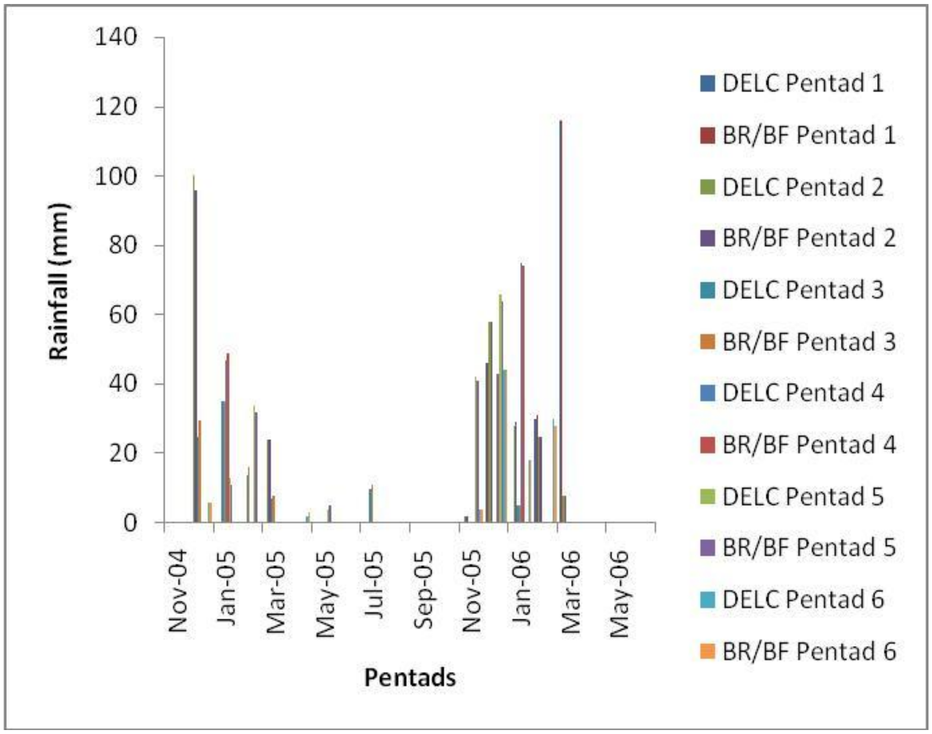

Figure 1. Rainfall over the two seasons in Zungwi vlei.

Table 1. Soil texture, organic matter, soil pH and mineral content for BR/BF and DELC system

Site	% Clay	% Silt	% Sand	OM %	pH (1:5 suspension Soil:$CaCl_2$)	Mineral N ppm after incubation	P_2O_5	Extractable cations (me/100 g)			
								K	Ca	Mg	Na
BR/BF System	8[a]	2.88[b]	89.1[a]	0.22[a]	4.37[b]	18.24[a]	32.1[a]	0.107[a]	0.92[a]	0.2[b]	0.05[c]
BR/BF System	8[a]	2.25[b]	89.6[a]	0.25[a]	3.91[c]	27.13[a]	23.6[ab]	0.13[a]	0.48[b]	0.13[b]	0.06[bc]
BR/BF System	8[a]	1.63[b]	90.3[a]	0.28[a]	4.21[b]	19.75[a]	21.8[b]	0.11[a]	0.53[b]	0.21[b]	0.11[ab]
DELC System	4.5[b]	13.1[a]	82.3[b]	0.30[a]	4.70[a]	16.63[a]	7.2[c]	0.06[a]	0.76[a]	0.6[a]	0.12[a]
Mean	7.1	4.95	87.8	0.26	4.296	20.43	21.2	0.10	0.67	0.28	0.08
LSD	0.52	2.3	2.33	0.09	0.285	17.3	9.63	0.09	0.21	0.156	0.045
S.E	0.18	0.81	0.82	0.034	0.1	6.075	3.38	0.03	0.07	0.054	0.016
CV%	5.12	32.6	1.86	25.4	4.65	59.5	31.9	60.5	21.8	37.8	39.2

0.18 m.e%, 0.60 m.e% and 0.07 m.e%, 0.12 m.e% respectively.

Trait data analysis: Grain yield, plant heights and 1000 seed weights

A general yield increasing trend appeared when there was an increase in the amount of top-dressing applied. There was also a general increase in plant height when there was an increase in the basal dressing applied without any top-dressing. Plant height in the broad ridge and broad furrow tillage system were very short with a mean of 125.76 cm as compared to DELC system with a mean plant height of 215.7 cm (Table 2). There were significant plant height differences ($p<0.05$) between treatments when basal dressing of 300kg/ha was applied as compared to no basal application. There were also significant differences between applying 5t cattle manure and no basal application.

Plant height significantly increased when nitrogen was increased from zero through to 150 kg/ha with 150 kg/ha D basal applied. Also, there was a significant increase in plant height when nitrogen was increased from zero through to 150 kg/ha with 300 kg/ha compound D as basal. Significant

Table 2. Effect of different basal dressing and nitrogen levels on plant heights and 1000 seed weight 2005/6 season.

Treatment combinations	Plant height (cm)		1000 seed weight (g)	
	BR/BF scheme	DELC scheme (Control)	BR/BF scheme	DELC scheme (Control)
1 (0kg/ha D + 0 kg N/ha)	74.7^{h}	163.0^{d}	243.3^{d}	293.3^{cd}
2 (0kg/ha D + 50 kg N/ha)	$101.1f^{g}$	236.0^{a}	280.0^{bcd}	320.0^{abcd}
3 (0kg/ha D + 100 kg N/ha)	108.3^{efg}	229.7^{ab}	266.7^{cd}	300.0^{bcd}
4 (0kg/ha D + 150 kg N/ha)	119.0^{def}	210.3^{abc}	286.7^{abcd}	306.7^{abcd}
5 (150kg/ha D + 0 kg N/ha)	86.0^{gh}	210.3^{abc}	276.7^{bcd}	290.0^{d}
6 (150kg/ha D + 50 kg N/ha)	133.0^{cde}	221.0^{abc}	303.3^{abcd}	343.3^{abc}
7 (150kg/ha D + 100 kg N/ha)	162.0^{ab}	204.3^{bc}	340.0^{ab}	336.7^{abcd}
8 (150kg/ha D + 150 kg N/ha)	170.3^{a}	198.0^{c}	343.3^{ab}	323.3^{abcd}
9 (300kg/ha D+ 0 kg N/ha)	96.0^{fgh}	207.3^{abc}	313.3^{abc}	356.7^{a}
10 (300kg/ha D+ 50 kg N/ha)	151.0^{abc}	224.0^{abc}	236.7^{d}	313.3^{abcd}
11 (300kg/ha D+ 100 kg N/ha)	146.7^{abc}	236.7^{a}	300.0^{abcd}	353.3^{a}
12 (300kg/ha D+ 150kgN/ha)	160.0^{ab}	216.0^{abc}	313.3^{abc}	350.0^{ab}
13 (5t. manure + 0 kg N/ha)	88.3^{gh}	215.3^{abc}	350.0^{a}	330.0^{ab}
14 (5t. manure + 50 kg N/ha)	118.0^{def}	220.7^{abc}	290.0^{abcd}	330.0^{abcd}
15 (5t. manure + 100 kg N/ha)	156.0^{abc}	223.7^{abc}	293.3^{abcd}	343.3^{abc}
16 (5t. manure+ 150 kg N/ha	141.7^{bcd}	235.0^{ab}	320.0^{abc}	326.7^{abcd}
Means	125.76	215.7	297.29	326.875
LSD	25.32	31.12	69.37	50.94
SE	8.90	10.94	24.38	619.9
CV	12.26	8.78	14.2	9.49

plant height differences were noted when nitrogen was applied from zero through to 150 kg/ha with cattle manure. No significant plant height differences were however observed when basal dressings were applied without top-dressing in all treatments. Significant differences were only linked to top-dressing application.

Significant plant height differences with increase in application of nitrogen were observed when no basal fertilizer was applied. There were no significant differences in plant height when 150 kg/ha of compound D was applied as basal regardless of top-dressing applied. No significant plant height differences were observed when 300 kg/ha D was applied even in the presence of top-dressing. Similarly, no significant differences were noticed when 5 tonne cattle manure was applied with any level of top-dressing. However, there were significant plant height differences between BR/BF and DELC with taller plants in DELC system. There was better filled grain in the DELC scheme than in the BR/BF scheme as shown by weight of seeds (Table 2).

Yields from the first season were generally low because it was drier as compared to the second season (Figure 3). Yields from the BR/BF system were higher in the first season than in the DELC system. However, in the second year the opposite was true because the season was extremely wet contributing to leaching of nutrients. Yield response in the DELC was better when no basal application was applied than in BR/BF in the second season. In the first season when conditions were dry, yield response for both sites were very low with no basal application. Grain yield increased significantly ($p < 0.05$) when 300 kg/ha of compound D were applied with 150 kg/ha N top-dressing as compared to no basal application or when little nitrogen was applied as top-dressing with 300 kg/ha of compound D (Figures 2 and 3). There was also a significant yield advantage when the rate of nitrogen was increased after applying a basal dressing in both sites for the two seasons as compared to no top-dressing. There was a significant yield advantage ($p < 0.05$) when the rate of nitrogen was increased after applying a basal dressing. When manure was applied as basal the response on different levels of nitrogen was positive showing significant differences at $p < 0.05$ in both systems for the two seasons. There were no significant yield advantages in applying basal dressing without top-dressing at both schemes for the two seasons. Also, there were no significant yield differences between applying 300 kg/ha compound D and 5t of manure as basal when both were top-dressed with 150 kg/ha nitrogen at DELC scheme.

DISCUSSION

The two seasons of study had different rainfall totals that were respectively below and above average. Rainfall was almost continuous in 2005/6 season with 48; 257; 126; 84 and 124 mm in November, December, January, February

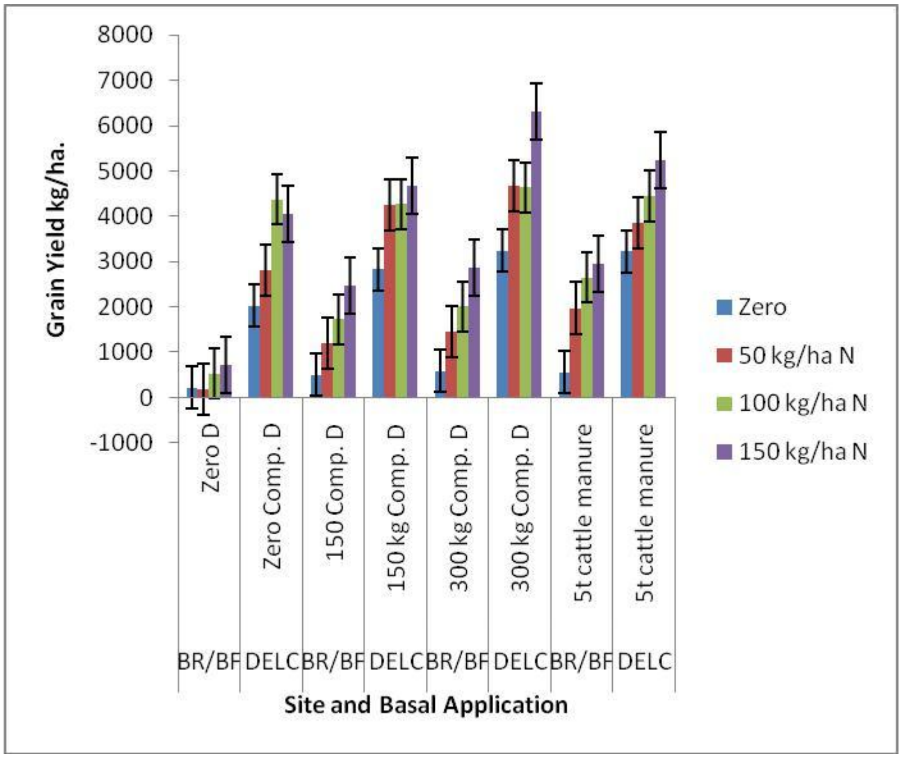

Figure 2. Comparison of yields from different types of basal dressing and top-dressings on maize planted in 2005/6 season at Zungwi (BR/BF and DELC) schemes.

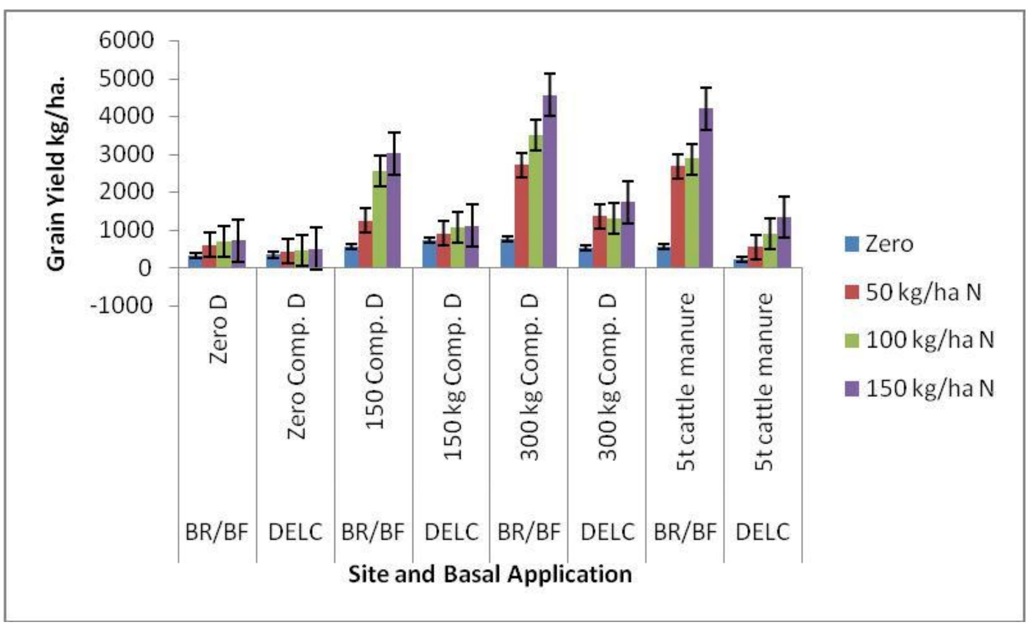

Figure 3. Comparison of yields from different types of basal application and different rates of top-dressings on maize planted in 2004/5 season at Zungwi (BR/BF and DELC) schemes.

and March resulting in high water table. The longest spell of 18 days for 2005/6 was in February, but the soils were already saturated. These conditions favoured saturated overland flow (Dunne and Black, 1970b) which would normally affect crop production and productivity. However, in the first season rainfall was erratic, low and poorly distributed with 131, 95, 48 and 32 mm in December, January, February and March respectively. Between December and January, there was a 32 day dry spell, 21 days between January and February and between February and March there was a 14 day dry spell, typical of a dry year.

In the first season, yields increased in the BR/BF system (Figure 3) because broad ridges and broad furrows harvested the little rainfall received, reducing runoff and effectively concentrated onto the growing plants (Nyamudeza et al., 1991) giving an extra advantage over the DELC system. The first year was a typical semi-arid season with rainfall distribution poor and characterized by frequent occurrence of dry spells (Vincent and Thomas, 1960). Almost all the rains fell in two occasions, the second week of December 2004; 125 mm fell in 6 consecutive days, followed by 85 mm, which also fell in 4 consecutive days in mid January. The dry spells in between adversely reduced crop yields in the DELC system in 2004/5 season because they occurred at critical stages of crop development such as flowering and grain filling (Nyamudeza, 1998). Nyamudeza and Jones (1993) reported that in Regions of low rainfall crop yields can be maximized by reducing runoff, a phenomenon which the BR/BF system confirmed in the 2004/5 season. In 2004/5 season, the differences in yields between BR/BF and DELC systems were a result of the soil and water differences reported by Nyamudeza and Jones (1993).

The 2005/6 season was characterized by well distributed rainfall with a dry spell, which occurred for 18 days between February and March. In March 124 mm fell in 4 consecutive days with 85 mm received in a single day, exacerbating leaching of applied fertilizers and causing reduction in yields (Mharapara, 1994). The fall of heavy rains saturated the soil immediately after nitrogen application subsequently causing fertilizer losses through volatilization (Grant, 1994). Hence, it also contributed to the low yield obtained under the BR/BF system. Furthermore, the low yield under the BR/BF system was exacerbated by nutrient erosion caused by water runoff from the top of the ridge to the furrows. This required more top-dressing to replenish the eroded and leached fertilizers. There was a significant response to nitrogen applied when manure was applied as basal dressing, as this had an effect on soil pH. Manure applied had pH 8.6 and this tended to increase the soil pH that was very low. According to Grant (1970), the calcium and magnesium contained in the manure replaces the exchangeable hydrogen ions. Applying 150kg/ha nitrogen with 300kg/ha D as basal fertilizer gave the highest yields in both sites. This was due to the effects of phosphate supplied by compound D that helped the capture of mineral nitrogen in soil due to increased root growth (Giller et al., 1997). Manure increased yields when nitrogen was added due to improved soil physical properties which caused better root growth, penetration and longer plant duration. This favoured improved nitrogen uptake amid increased water availability (Giller et al., 1997). The application of organic combined with chemical fertilizer improved the quality and yield of crops (Huang and Lin, 2001; Zhang and Fang, 2007; Mahmoud et al., 2009). Muller-Samann and Kotshchi (1994) reported that carbon in manure acted as a source of food to micro-organisms, which improved soil aeration, drainage and assisted in buffering pH. It also enhanced moisture-holding capacity of the soil (Rodel et al., 1980). This also improved the fertilizer use efficiency and therefore the response of yield to nitrogen increased as the nitrogen applied increased. However, the response on yield was largely affected by the loamy sand soils used in building the ridge in the case of the BR/BF system as compared to the DELC system. In the latter where the soil was not disturbed the response was a bit different, with slightly high yield responses due to topsoil, which was not trans-located. The negative effect of nutrient loss through leaching is clearly confirmed in the absence of basal dressing when BR/BF system gave significant poor yields compared to DELC system in the wet season.

Conclusion

In a drought year BR/BF exhibited significantly higher yields as compared to DELC system at any given fertility levels. However, in a wet season the reverse was true. This was because BR/BF system harvested a lot of the first rains causing leaching of supplied nutrients in the early season. It was clear that applying 5t of manure with 150 kg/ha N top-dressings had almost the same yields with applying 300 kg/ha of compound D with 150 kg N/ha. Manures are locally available and can be utilized to improve yields.

The soils need to be dressed with liming material to raise the soil pH to acceptable levels. In cases when there is too much rainfall farmers need to further split their nitrogen to replenish the leached fertilizers. With high cost of compound fertilizers the use of cattle manure can be a better option for subsistence farming. The BR/BF system is recommended as suitable for drought-prone areas preferably Natural Regions 1V and V of Zimbabwe. However, after construction of the scheme, use of nutrient amendments is vital because soils are left barren. Farmers endowed with cattle manure must apply at a rate of 5 t/ha and top-dress at the rate of 150 kg/ha N. Use of compound D at 300 kg/ha as basal dressing and top-dressing at 150 kg/ha N is highly recommended to those affording. If there is a down pour of rains after application of ammonium nitrate additional top-dressing should be done. Furthermore, if the wetland water table is saturated it is necessary to split the top-dressing to avoid leaching of all the nitrogen supplied.

REFERENCES

ARI (2000). Agronomy Research Institute, Annual report (1998-2000), AREX, Harare.

Avila M (1987). Integrating with cropping systems. In: *Cropping* in the Semi-arid Areas of Zimbabwe. Proceedings of a workshop held in Harare, 24th to 28th August 1987 and sponsored by GTZ-Cart Masvingo.

Chavhunduka DK (1978). African attitudes to conservation. Rhodesia Agric. J. 37: 234-236.

Dunne T, Black R (1970). Partial area contribution to storm runoff in a small New England Watershed. Water Resour. Res., 6 (5) 1296-1311.

Gibbon D, Pain A (1985). Crops of the Drier Regions of the Tropics (1st ed.) Longman publishing company, Singapore. Pp.155

Giller KE, Caddisch G, Ehaliotis C, Adams E, Sakala WD, Mafongoya PL (1997). Building soil nitrogen capital in Africa. In: Replenishing soil fertility in Africa. R.J. USA, pp. 151-192.

Grant PM (1970). Lime as a factor in maize production. Part 1: The efficiency of liming. Rhodesia Agric. J. 67: 73-80.

Grant RF, Juma NG, Robertson JA, Izaurralde RC, McGill WB (1994). Long-term changes in soil Carbon under Different Fertilizer, manure and Rotation. Testing the Mathematical Model ecosys with Data from Breton Plots. Kindly provide page number

Huang SN, Lin JC (2001). Current status of organic materials recycling in Southern Taiwan. Soil and Fertilizer Experiment Bulletin, 3: 43-48.

Mahmoud E, Abd EL- Kader N, Robin P, Akkal-Corfini N, Abd El-Rahman L (2009). Effects of Different Organic and Inorganic Fertilizers on Cucumber Yield and Some Soil Properties. World J. Agric. Sci., 5 (4): 408-414.

Mashiringwani NA (1983). The present nutrient status of soils in communal farming areas of Zimbabwe. Zimb Agric. J., 80 (2) 73-75.

Mataruka DF, Whingwiri EE (1988). Maize production in communal areas of Zimbabwe and the Research options for improving productivity pp 332-346 in towards self sufficiency. Proceedings of the South Eastern Central and Southern Africa Regional maize workshop, Harare; The college press.

Mharapara I (2000). Development of Wetland Cultivation System in Zimbabwe. Phd.Thesis.

Mharapara IM (1994). A fundamental Approach to Dambo utilization In: Proceedings for a workshop in Dambo farming in Zimbabwe water management cropping and soil potential for smallholder farming in wetlands. Pp. 1-8.

Mugwira LM, Mukurumbira LM (1986). Comparative effectiveness of manures from the communal areas and commercial feedlots as plant nutrient sources. Zimb. Agric. J. 81:25-29.

Mugwira LM, Murwira HK (1997). Use of cattle manure to improve soil fertility in Zimbabwe. Past, current and future research needs. SoilFertNet Network Research Results Working Paper, Number 2 CIMMYT Maize programme and Natural Resources Group, Harare, Zimbabwe. Pp. 33

Muller-Samann KM, Kotshchi J (1994). Sustaining growth-soil fertility management in tropical smallholdings. CTA & GTZ Margraf Verlag, Weikersheim. Pp. 486

Nyamudeza P (1993). The effects of growing sorghum in furrows and on the flat at three populations and three row widths in Semi-Arid Regions of Zimbabwe. Zimb. J. Agric. Res., 31: 11-21.

Nyamudeza P (1998). Water and fertility management for crop production in semi-arid Zimbabwe. Unpublished PhD thesis, University of Nottingham.

Nyamudeza P, Jones E (1993). The effects of growing sorghum in furrows and on the flat at three populations and three row widths in Semi-Arid Regions of Zimbabwe. Zimb J. Agric. Res., 31: 11-21.

Nyamudeza P, Nyakatawa EZ, Jones E, Maringa D (1991). Water and Soil Fertility Management for Increased Crop Production on the Light Soils of the South Eastern Lowveld of Zimbabwe. In: The Second Annual Scientific Conference Proceedings. October 7-9, 1991 Pp. 232-240.

Rodel MGW, Hopley JDH, Boultwood JN (1980). Effects of applied nitrogen, kraal compost and maize stover on the yield of maize grown on a poor granite soil. Zimb. Agric. J., 77(5): 229-232.

Vincent V, Thomas RG (1960). Agricultural survey of Southern Rhodesia. Part 1.Agro-Ecological Survey. Salisbury: Governments Printers. Pp.1

Zhang M, Fang L (2007). Effect of tillage, fertilizer and green manure cropping on soil quality at an abandoned brick making site. Soil Tillage Res., 93: 87-93.