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Nutrient Dynamics in Wetland Organic Vegetable Production Systems in Eastern Zambia

P. L. Mafongoya[1] & O. Jiri[1]

[1] University of KwaZulu-Natal, School of Agriculture, Earth and Environmental Science, Pietermaritzburg, 3029, South Africa

Correspondence: O. Jiri, University of KwaZulu-Natal, School of Agriculture, Earth and Environmental Science, Pietermaritzburg, 3029, South Africa. E-mail: obertjiri@yahoo.co.uk

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Abstract

The aim of this study was to determine effects of organic inputs on vegetable crops and on a subsequent maize crop grown in wetlands. The following treatments were applied to cabbage (*Brassica oleracea*) and onion (*Allium cepa*) crops: *Gliricidia sepium* (Gliricidia) biomass (8 t ha^{-1}), Gliricidia biomass (12 t ha^{-1}), cattle manure (10 t ha^{-1}) with half recommended fertilizer rate, and recommended fertilizer rate (800 kg ha^{-1} basal dressing and 250 kg ha^{-1} top dressing fertilizer). The residual effect of the treatments was tested on a subsequent maize crop. The soil at the sites had low organic matter content (average 2%) and it was acidic (average pH 4.4). Soil inorganic N increased significantly from 11 mg kg^{-1} in the unfertilized crop to 22 mg kg^{-1} in the Gliricidia treatments after cabbage, and from 10.3 mg kg^{-1} to 37.2 mg kg^{-1} after the onion crop. There were significant differences ($P<0.05$) in onion and cabbage yields and in subsequent maize yield in both cabbage and onion plots. This study concluded that the application of high quality Gliricidia prunings lead to rapid release of N and higher vegetable yields. However, there is a high amount of residual N that can be leached.

Keywords: Wetland, organic fertilizer, nutrient dynamics.

1. Introduction

Seasonally waterlogged wetlands, “dambos”, cover about 240 million hectares in sub Sahara Africa (Andriesse, 1986). The water table of dambos during most of the year is in the upper 50 – 100 cm of the soil profile from which they drain into streams (Breen et al., 1997). In southern Africa, the total area under wetlands is about 16 million hectares (Mharapara, 1995). It is estimated that in Zambia dambos cover an area of about 7.5 million hectares (Pereira, 1982).

Smallholder farmers take advantage of reliable water supply and better soil fertility (than in topland fields) that are characteristic of these ecosystems to use them for agriculture. The cultivation of dambos often leads to their degradation, justifying their prohibition for cropping use. However, dambo degradation can be avoided with design of proper land use management systems (Mharapara, 1995).

In southern Africa, smallholder vegetable production has become a fast expanding enterprise due to a rapidly increasing urban population. Vegetable crops fetch attractive prices and generate income throughout the year (Kuntashula et al., 2004; Sibanda et al., 2000).

In eastern Zambia, dambo cultivation is a very attractive enterprise (Raussen et al., 1995). The crops grown in the dambos include rape (*Brassica napus*), tomato (*Lycopersicon esculentum*), cabbage (*Brassica oleracea*), onions (*Allium cepa*) and maize (*Zea mays*) (Kuntashula et al., 2004). These crops supplement topland field cultivation (non-wetland fields) by reducing seasonal food shortages, optimizing labour use and increasing household income. The intensive use of small patches of dambos for food production must lead to sustainable intensive food production (Pretty et al., 2011; Mharapara, 1995).

Kuntashula et al. (2004) found that 75% of the households in eastern Zambia cited poor soil fertility compared to topland fields as a major constraint to crop production in dambos. This was attributed to continuous cultivation of dambos without application adequate amounts of inorganic fertilizers. The use of cattle manure was a common strategy for soil fertility replenishment in the dambos (Kuntashula et al., 2004).

One option for soil fertility replenishment under smallholder farmers is the use of leguminous leafy green manure agroforestry tree species (Mafongoya et al., 1997; Kuntashula et al., 2004). Gliricidia is a leguminous crop that is used in alley cropping and green manuring. It is commonly used in biomass transfer cropping systems. Most of the experiments on biomass transfer on vegetables in the dambos have concentrated on vegetable yields (Kuntashula et al., 2004) and there have been few studies on dynamics of soil chemical properties such pH and nutrient when organic inputs are applied on dambos.

In Zimbabwe, despite high vegetable yields obtained in dambos, application of high quality manure led to nitrate leaching in wetlands (Masaka et al., 2013). However, trade off analysis is needed since application of high quality manure increased vegetable yield but there was pollution of shallow ground water by nitrate leaching. The application of low quality organic inputs with less N content can presumably increase vegetable yield but reduce nitrate leaching. Such information is lacking in the use of wetlands in vegetable production in Zambia.

The objectives of this study were to evaluate effect of organic inputs on nutrient dynamics and risk of leaching in dambo cultivation, and to determine effects of organic inputs on cabbage and onion yields on dambos of eastern Zambia.

2. Materials and Methods

The study was conducted in the dambos of Chipata South district (latitude 13º 15'S, longitude 32º 36'E and an altitude of 1015 m above sea level) in eastern Zambia. Eastern Zambia is characterized by a flat to gently sloping landscape with altitudes ranging from 900 to 1200 m above sea level. Dambos are a common feature of the landscape (Pereira, 1982; Ngugi, 1988). Dambos have hydromorphic soils (greysols) with non-expanding clay type (illites) which makes the soil easy to work by hand (Raussen et al., 1995). Rainfall is unimodal with about 85% falling in four months from November to March. Annual rainfall in the study area averaged 1030 mm (AGROMET Office, Msekera, Zambia, 2001). Average air temperatures range from 15º to 18ºC during June-July and 21º to 26ºC during September-October (Ngugi, 1988).

Cabbage and onion seedlings were raised in nursery beds, and transplanted after 3 and 4 weeks, respectively. Cabbage, planted on 0.5 m raised beds, was spaced at 0.75 m between rows and 0.40 m within rows, and onion at 0.30 m between rows and 0.10 m within rows. In this experiment, maize was grown in plots previously grown to the vegetables.

2.1 Treatments and Experimental Design

The treatments were as follows:

1) Gliricidia biomass 8 t ha^{-1},
2) Gliricidia biomass 12 t ha^{-1},
3) cattle manure (10 t ha^{-1}) plus half recommended rate of fertilizer (common practice),
4) recommended rate of fertilizer at 800 kg ha^{-1} Compound D (N=100 g kg^{-1}, P = 90 g kg^{-1}, and K = 80 g kg^{-1}) as basal dressing and 250 kg ha^{-1} urea (46% N) as top dressing, and
5) Control (unfertilized crop).

The biomass and manure rates are given on dry matter basis.

The experiment was established in a randomized complete block design with three replications in farmers' fields. Farmer fields were used as blocks.

2.2 Soil Data Collection and Analysis

Soil samples were taken before planting from 0-20 cm (the ploughing depth) using soil augers from 4 positions in each treatment. The soil samples were air-dried and taken to the laboratory for analysis. The calorimetric method was used to determine nitrate. Total N was obtained by using the Kjeldahl method. Soil K content was determined by flame emission spectroscopy and Ca^{2+} and Mg^{2+} by atomic absorption spectroscopy. Soil pH was determined by $CaCl_2$ method and soil phosphorus by the Bray 1 method. Soil organic carbon was determined by Walkely-Black method. Details of all the methods are found in Anderson and Ingram (1993). Analysis of variance using the Statistical Package for the Social Sciences (SPSS) was done to determine treatment differences which were declared significant at $P \leq 0.05$ and means were separated using the LSD method at $P \leq 0.05$.

2.3 Treatment Application and Yield Data Collection

Dry tree biomass and dry cattle manure were incorporated in frequently watered beds one week before transplanting vegetables. Basal and top dressing inorganic fertilizers (at 800 kg ha^{-1} Compound D (N=100 g kg^{-1}, P = 90 g kg^{-1}, and K = 80 g kg^{-1}) as basal dressing and 250 kg ha^{-1} urea (46% N) as top dressing) were applied 3 days before transplanting and four weeks after transplanting, respectively. The farmers did the land preparation, weeding and watering. The researchers managed the treatment applications. Net harvestable area of 1.7 m^2 for each vegetable plot were harvested. Cabbage was harvested at full maturity after 120 days while onion was harvested after 150 days. To evaluate the residual effect of the various treatments, hybrid maize (MM604) was grown after cabbage in September 2001, while Pool 16 (an early maturing variety) was grown after onion in November 2001. Both varieties were planted at a spacing of 0.75 m between rows and 0.25 m within rows. MM604 was harvested in January 2002 and Pool 16 was harvested in February 2002. Maize grain yield from the various treatments was determined.

3. Results

3.1 Soil Chemical Characterization

The sites had low soil organic matter levels (average 2%) and 50% of sites used had very acid soils pH around 4.4 (Table 1). However, the sites had adequate levels of soil phosphorus which were above the critical of 15 mg kg^{-1} (Anderson & Ingram, 1993). The sites used were deficient in potassium, which was below critical level of 0.20 mg kg^{-1} for these crops (Anderson & Ingram, 1993).

Table 1. Average soil properties at the trial sites

Parameter	**Mean**	**Minimum**	**Maximum**
SOM (%)	2.0	1.2	4.2
pH($CaCl_2$)	4.4	4.1	4.7
Exchangeable Ca ($cmol_c kg^{-1}$)	1.3	0.4	4.8
Exchangeable Mg ($cmol_c kg^{-1}$)	0.4	0.1	1.7
Exchangeable K ($cmol_c kg^{-1}$)	0.2	0.0	0.5
Extractable P (mg kg^{-1})	24.2	10.0	35.7

LSD<0.05.

Soil pH was significantly increased by organic inputs in both cabbage and onion trials after harvest of maize in February 2002 (from 4.4 to average 4.7). Organic inputs increased soil pH in the following order:

Control = fertilizer> 8 t Gliricidia = 12 t Gliricidia = fertilizer + manure

Application of inorganic fertilizer and manure+fertilizer significantly increased extractable phosphorus compared to the control (Figure 1). However, Gliricidia leaves application did not increase P levels as compared to the control. All treatments had significant effects ($P<0.05$) on soil P at the time onions were harvested in November 2001 and in February 2002 when maize grown on residual fertility was harvested (Figure 1). In November 2001, when onions were harvested, there was no significant differences between control, fertilizer treatments, 8 t Gliricidia and 12 t Gliricidia for soil P. However, the fertilizer manure treatment had significantly higher soil P compared to other treatments. The same pattern was observed when a maize crop was harvested in February 2002.

The treatments had significant effects on soil K and Mg ($P<0.05$) but not on calcium. Soil exchangeable Mg increased in the following order: Manure + fertilizer > 8 t Gliricidia = 12 t Gliricidia > fertilizer > control. However, for exchangeable Mg the order was: Manure + fertilizer > 12 t Gliricidia > 8 t Gliricidia > control > fertilizer.

Inorganic soil N (NO_3+NH_4) was significantly increased by treatments after the harvest of the cabbage crop (Figure 2). Application of 12 t Gliricidia and 8 t Gliricidia resulted in significantly higher total inorganic N compared to rest of the treatments. Soil nitrate showed similar results.

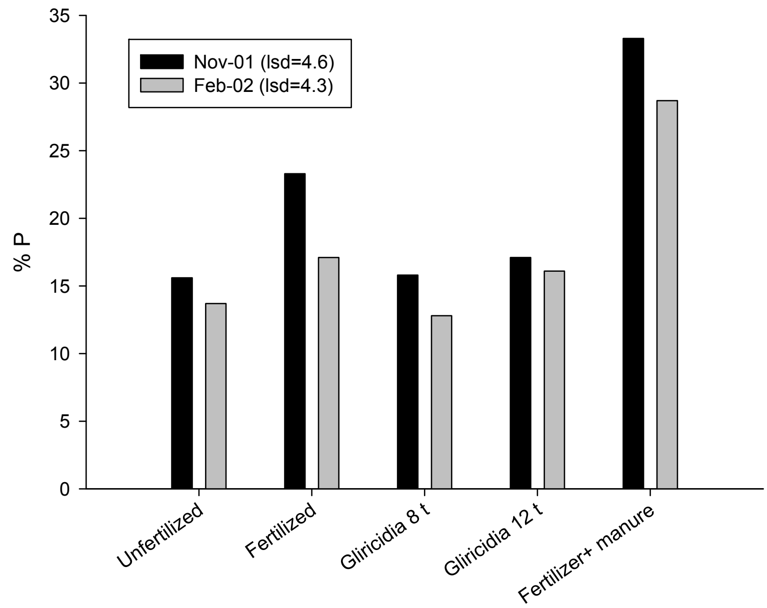

Figure 1. Phosphorus (%) levels after onion in dambos on-farm under various treatments

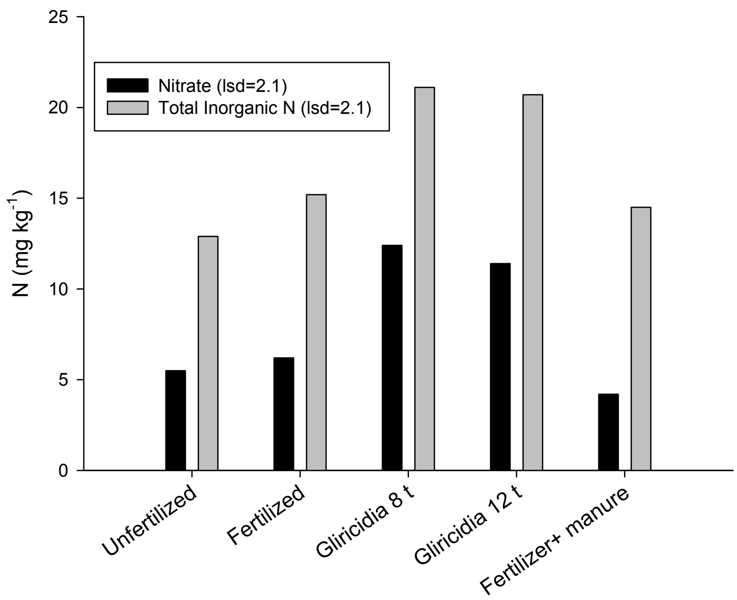

Figure 2. Nitrate and total inorganic N (mg kg^{-1}) after cabbages in dambos on-farm

Addition of organic and inorganic fertilizers increased residual inorganic N after cabbage harvest (Table 2). After onion harvests in November 2001 treatments had significant effect on soil nitrate and total inorganic N (Table 2). For soil nitrate 12 t Gliricidia > 8 t Gliricidia > manure + fertilizer = control. For total inorganic N the order was: 12 t Gliricidia > 8 t Gliricidia = manure + fertilizer = fertilizer > control. However, there were no significant effects of treatments on nitrate or total inorganic N in February 2002 (Table 2) when a maize crop was harvested.

Table 2. Nitrate and total Nitrogen in onion plots before maize planting (November 2001) and at maize harvesting (February 2002)

Treatment	Nitrate (mg kg^{-1})		Total inorganic N (mg kg^{-1})	
	November 2001	February 2002	November 2001	February 2002
No fertilizer	4.3	0.0	10.3	1.8
Full rate fertilizer	12.0	0.0	25.6	2.3
Gliricidia 8 t ha^{-1}	13.4	0.1	20.4	3.5
Gliricidia 12 t ha^{-1}	27.7	0.5	37.2	2.9
Fertilizer+manure	18.1	0.1	25.6	3.4
LSD	P<0.05	ns	P<0.05	ns

3.2 Vegetable Yields

There were significant differences in onion yields from different treatments. Onion yields were highest in manure + fertilizer, followed by Gliricidia biomass, and the fertilizer only treatment ranked fourth. The unfertilised crops had the least yield (Table 3). Similarly there were significant differences among treatments on cabbage yields. Manure + fertilizer produced the highest yield. Cabbage yield from both Gliricidia treatments and fertilizer only treatments showed no significant differences.

Table 3. Cabbages and onions yields (t ha^{-1})

Treatment	Onion	Cabbage
No fertilizer	22.0	16.0
Full rate fertilizer	43.2	43.4
Gliricidia 8 t	61.4	44.8
Gliricidia 12 t	67.2	48.8
Fertilizer+manure	85.2	63.9
LSD: P<0.05	8.5	7.9

3.3 Maize Grain Yields

There were significant differences on maize yield in both cabbage and onion plots (Table 4). On onion plots maize yields from all residual treatments except recommended fertilizer were significantly higher than yields on the control plot. On cabbage plots, 12 t ha^{-1} Gliricidia gave significantly higher yield than fully fertilized treatments and control. The other treatments did not show any significant differences between treatments.

Table 4. Subsequent maize grain yield on residual fertility after cabbage and onion harvested in Eastern Zambia (tha^{-1})

Treatment	Maize yield after cabbage	Maize yield after onion
No fertilizer	2.9	1.7
Full rate fertilizer	3.9	2.5
Gliricidia 8t	4.3	3.3
Gliricidia 12t	4.9	3.9
Fertilizer+manure	4.2	3.1
LSD: P<0.05	1.0	0.9

4. Discussion

High residual inorganic N in plots amended with Gliricidia residues could mean Gliricidia leaves are high quality materials (Mafongoya et al., 1998). They are low in lignin and polyphenols and high in N and the N mineralization is very rapid compared to animal manures (Mafongoya et al., 2000). Similar results were reported by Williumsen and Thorup-Kirstensen (2001).

The high levels of NO_3 after onion and cabbage harvest could lead to NO_3 leaching during the rainy season which follows after vegetable harvest. This leaching could lead to soil acidification in surface soil (Bolan et al., 1991). The nitrate in the dambos could be a source of N in ground water and water pollution in the streams.

There are various management options for residual inorganic N. These include proper estimation of crop N requirement, and organic fertilizer placement in order to increase its use efficiency (Mafongoya et al., 1997). Table 2 showed that the maize crop was able to take up a lot of inorganic N by February 2002 and reduced the potential leaching of nitrate.

Most agroforestry organic inputs do not have P to meet crop requirements (Palm et al., 2001). However, application of manure fertilizer increased extractable P. This can be attributed to high P content in animal manures (Palm et al., 2001) and production of organic acids which will reduce absorption of P on oxides of iron and aluminum (Nziguheba et al., 1998). However, even after the maize crop harvest there was still high levels of P in the soil especially in manure+fertilizer plots and this may pose a serious downstream problem if the P is not properly managed.

The increase in exchangeable K and Mg by application of Gliricidia residues compared to inorganic fertilizer application agree with results obtained by Zaharah et al. (1999). This is particularly important in acid soils where there are low reserves of cations due to limited cation exchange capacity.

Potassium is a highly mobile element and hence it was released very rapidly. Leaching processes were responsible for the release of K during decomposition of organic residues (Tian et al., 1999). Although Mg is relatively mobile it is expected to be released slowly compared to K since it is a constituent of more complex molecules like chlorophyll and calcium oxalate. The behaviour of calcium is more complex as it is a complex of cell wall and storage materials such as calcium oxalate (Budeman, 1988). Its decomposition may take longer and may not have a significant effect on soil pH in the short term.

Additions of crop residues, organic manures and composts to acid soils improved fertility by adding nutrients and also by increasing soil pH (Ferreras et al., 2006). This could be because organic residues contain humid type substances, which have a large number of carboxyl and phenolic groups that are able to conserve protons. These substances are formed during decomposition and are stable against further decomposition. The proton consuming properties of these substances are responsible for increase in soil pH (Wong et al., 1998).

Also, during decomposition of plant organic residues, organic acid anions are decarboxylated. This results in consumption of protons and potential rise in soil pH (Ferreras et al., 2006).

Higher vegetable yields in the manure+fertilizer (compared to the Gliricidia treatments) could be a result of better nutrients in the manure+fertilizer treatment. Combining manure with inorganic fertilizer enabled rapid release of N and other nutrients due to high quality (Mafongoya et al., 1998). This fast release of N and other nutrients could also have created asynchrony with plant nutrient demand leading to lower yields.

The increased maize grain yield from Gliricidia treatments can be attributed to higher N contribution from Gliricidia compared to manure and fertilizer which contributed lower levels on N (Table 4). In addition, residual NO_3 and NH_4 were higher in the Gliricidia treatments compared to other treatments. This situation could have created perfect synchrony for N demand by the maize crop and hence higher maize yields.

5. Conclusion

The results showed that application of Gliricidia prunings not only increase crop yield but also replenishes the soil with residual N which is used by a subsequent crop. These results also suggest the potential use of organic residues as liming materials for smallholder farmers who do not have access to expensive agricultural lime. The potential of NO_3 leaching and potential resultant eutrophication from dambos after cabbage harvest could be a potential environmental hazard in the dambos. This would need to be managed through proper cropping systems and choices of crops.

6. Recommendations

There is need to develop selection indices of organic residues such as ash alkalinity content type of organic acids content and protons consumption properties in order to screen a large number tree species for their liming potential. Further research is needed to trace N in the soil profile and in stream water, and complete N budgets in order to assess the risk of groundwater pollution quantitatively.

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