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Effects of manure from water hyacinth on soil fertility and maize performance under controlled conditions in Rwanda

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Abstract

The aim of the present study was to evaluate the impact of manure from water hyacinth on soil properties, maize growth and yield. The soil tested was collected from Gahororo in eastern Rwanda. The maize ZM 607 variety was selected as the test plant. A Randomized Complete Block Design with three replicates and seven treatments was established. Treatments consisted of fresh and dried water hyacinths applied separately in different proportions to supply nitrogen at the level of 150, 300 and 450 kg ha^{-1}. The experiment was conducted in the glasshouse for both a soil incubation study and the maize trial. Results of soil analysis show that the test soil is a clay, slightly acid and deficient in nitrogen, phosphorus and potassium. Exchangeable bases, organic matter and cation exchange capacity are found in the medium concentration range. Fresh water hyacinth treatments give better soil properties than dry manures and the control. In general, a large increase is recorded for the soil pH, organic matter, nitrogen, phosphorus as well as the basic cations. After 90 days of incubation, results indicate a positive evolution of the ammonium nitrogen with all treatments. Nitrate nitrogen is also influenced by fresh fertilizers. However, it reaches its peak at 60 days of the incubation. The available phosphorus augments with almost all the treatments except for the control. An increase in exchangeable potassium was observed for the F300 and F450 treatments. Maize dry matter yield also increased with fresh water hyacinths. The dried amendments are less favourable for both growth and yield of maize plants, and the results show rather a depressive effect compared to the control.

Key words: Maize, manure, soil properties, water hyacinth, yield

Contents

Introduction

Background information on water hyacinth

Wetlands and water bodies are vital resources for aquatic life, farming and recreational activities. Invasive aquatic plants, both floating and submerged, cause serious challenges to these resources. Wilson *et al.* (2005) recognized the water hyacinth *Eichhornia crassipes* (Pontederiaceae, Liliales), a floating aquatic weed, as the most harmful weed in the world because of its negative effects on waterways and people's livelihoods. It forms extensive mats that cover the entire surface of the water body and poses adverse problems for fishing, swimming and boating activities (Epstein 1998; Center *et al.* 2002). The weed has arrived in many tropical and subtropical regions from the Amazon basin of Brazil and then it has been spreading to other continents around the world (Julien 2001). Today, it occurs in many parts of Central and South America (Barrett and Fono 1982), Australia and Southeast Asia (Gopal and Sharma 1981). Since its introduction in Egypt (1879), the plant has invaded most lakes and rivers in Africa (Ghabbour *et al.* 2004). By 1989 it started to become a challenge in Lake Victoria in both Kenya and Uganda (Twongo *et al.* 1995).

Due to its high invasion rate, the water hyacinth weed can come to dominate the whole habitat where it grows. Methy *et al.* (1990) and Wilson *et al.* (2005) pointed out that it can reproduce both by stolons and seeds and can double its biomass in just a few days in good conditions of the water body. The excessive growth and dissemination of water hyacinth weeds are mainly favoured by nutrient enrichments such as nitrogen and phosphorus in the water (Center *et al.* 2002; Heard and Winterton 2000), by contamination with industrial pollutants and agricultural inputs from the runoff (Ogutu *et al.* 1997). Furthermore, it is also known that its propagation is mainly influenced by water crafts, floods, human activity and aquatic animals such as hippos and crocodiles. Water hyacinth has a lot of social, economic and ecological severe impacts on aquatic ecosystems and living beings (Ghabbour *et al.* 2004; Epstein 1998). The thick leaves of this macrophyte cover the surface of water, resulting in impact on aquatic habitat values, reduction of the oxygen concentrations in the water (Hensen *et al.* 1971 cited by Center *et al.* 2002) and loss of biodiversity (Denny *et al.* 2001; Sun *et al.* 1993; Sharma *et al.* 1996; Howard and Harley 1998). Consequently, this leads to lower fish production and poor quality of drinking water. Moreover, the mats of the weed serve as good shelters and ambush points for many pests and pathogens such as snakes, mosquitoes and snails that cause human diseases (Mailu 2001; Mironga 2004; Plummer 2005). Water hyacinth invasions can also completely destroy eco-tourism sites and obstruct hydro-electric power and irrigation facilities (Epstein 1998).

In the affected areas the weed needs to be eradicated or managed to a sustainable level where it cannot pose problems to aquatic communities and lakeside residents. Three control methods are generally used to fight against water hyacinth effects, including mechanical control (Smith *et al.*1984; Harley *et al.* 1996; Babu *et al.* 2003), the use of selective herbicides (Olaleye and Akinyemiju 1996; Ram and Moolani 2000) and biological control with natural enemies such as *Neochetina eichhorniae* and *Neochetina bruchi* (Julien and Griffiths 1998; Kathiresan 2000; Mbati and Neuenschwander 2005;

Shabana and Mohamed 2005). The latter option is found to be the most effective because it is low-cost, environmentally friendly and long term although it has a slow speed of action (Center *et al.* 2002; Wilson *et al.* 2005). But on the other hand, numerous authors (*e.g.* Center *et al.* 1999; Guitiérrez *et al.* 2000) suggested that the integrated use of these control strategies could be the best effective way for water hyacinth eradication.

However, findings from many investigators have shown that the water hyacinth weeds have a useful role for other purposes. They are considered as a valuable source of macronutrients such as phosphorus, nitrogen and potassium that are essential for plant nutrition (Sahu *et al.* 2002). Poddar *et al.* (1991) indicated that the nutrient concentrations found in the water hyacinth vary with the environment where it grows such as lakes, marshlands, ponds and ditches. Water hyacinth shoots are recommended for use as soil fertilizers (Woomer *et al.* 2000; Sannigrahi *et al.* 2002; Gupta *et al.* 2004) and for making carpets, baskets, chairs, house roofing and ropes. The importance of water hyacinth leaves as animal fodder (Kivaisi and Mtila 1995; Mitra *et al.* 1997) and fish feed (Sahu *et al.* 2002) is also well known. In the past years, the use of this weed has been extended for making paper (Goswami and Saikia 1994), purifying water (Gupta 1982) and producing biogas (Moorhead and Nordstedt 1993; Ali *et al.* 2004; Kumar 2005). Lindesey and Hirt (1999) and Nguyen (1996) also reported that water hyacinth flowers can be used as vegetables for human consumption and as a medicinal plant (Oudhia 1999). The water hyacinth is also known as a phytoremediation plant in removing and accumulating some toxic substances such as lead, zinc, copper and cadmium from polluted soil and water environments through root absorption (So *et al.* 2003; Singhal and Rai 2003). Therefore, there is need to evaluate heavy metal concentrations in water hyacinth before using it as a soil organic manure.

Status of water hyacinth in Rwanda

The real history and origin of water hyacinth in Rwanda is not well known and documented. The very little and limited information in the literature says that the invasive weed was accidentally introduced as an ornamental flower in late 1987. Moorhouse *et al.* (2001) reported that it appeared for the first time in the Mukungwa River located in the northern region. The weed then rapidly spread to other water bodies, including lakes, wetlands and rivers linked to the Mukungwa water system. Ogwang and Molo (1997) pointed out that the weed that spread into Lake Victoria in 1987 was from Rwanda via Akagera River. According to Masengesho (2007), the successful spread and colonization of waterways both in Rwanda and probably elsewhere by the water hyacinth appears to be through water crafts, wind, fishing nets and man. In recent decades, most lakes of the eastern region have been invaded by water hyacinth, and as an example, Lake Gishanju has been totally put out of use while one sixth of Lake Mihindi is covered by the weed (MININFRA 1996). The presence of water hyacinth has also been observed in some small lakes of Bugesera district, namely Gashanga, Kidogo and Rumira which are related to Akagera wetland as well as in Lake Muhazi, especially on the west side (Masengesho 2007). Lakes located in Akagera National Park are the most severely infected because of their direct connection with Akagera River which is considered as the main source of infestation of Lake Victoria. Because of the highly contagious nature of this weed it is likely to invade all the lakes and swamps, if specific control strategies are not implemented and adopted. The geographical distribution map of water hyacinth in Rwanda is presented in appendix 1.

Water hyacinth management strategies and use in Rwanda

Rwanda's efforts at mitigating water hyacinth invasion have so far been in the form of a two sided management strategy consisting of physical and biological control measures. The Rwanda government has been involved in mobilizing the local communities to remove water hyacinth manually at some strategic sites such as water intake points and fish landing sites. But the efforts made to combat the water hyacinth problems were not at all successful. On the other hand, the biological control initiated in 2000 by the Clean Lakes Inc. project in collaboration with the Rwanda Agricultural Research Institute (ISAR) was also not effective. A small amount of *Neochetina eichhorniae* and *Neochetina bruchi* were imported from Uganda and three weevil rearing facilities were established at ISAR Karama and Ruhengeri, and along Lake Ihema shores. The biocontrol agents have been well established at ISAR Karama and Lake Ihema but they failed at Ruhengeri rearing site due to cold weather conditions. Multiplication, release and monitoring of weevils have been done in order to determine their establishment and distribution in the infested areas. But the amount of weevils released was very insufficient and the impact was not very large in the targeted sites (ISAR 2002).

After having noticed that it was basically difficult to eradicate water hyacinth in Rwanda water bodies using manual removal and biological control, its eradication is now being done by rational management. In the north region of Rwanda, people are using water hyacinth as pig feed (Biziyaremye 2006). In the eastern province and precisely in Gashora village, water hyacinth weeds are rationally used by widow weavers for making several products, such as mats, hats, hand bags and baskets (Masengesho 2007). Water hyacinth valorization is therefore considered as a means of fighting against this invasive plant and provides employment for the poor rural community in the affected areas. But it should be noted that any control strategy for using water hyacinth as a source of income should aim at reducing the weed invasion to a manageable level where it ceases to impede activities related to water use and/or to eradicate it completely.

Level of soil fertility in Rwanda

In Rwanda, most arable soils are acidic and poor in vital macronutrients (nitrogen, phosphorus and potassium) for plant growth. The lack of these elements leads to continuous decline of agricultural production (Mutwewingabo *et al.* 1989). In most agricultural regions of the country the pH average values range from 4.6 to 6.0 (Vander Zaag 1982). The high rates of precipitation as well as the nature of the topography of the land contribute extensively to the leaching of chemical elements and the low level of organic matter in the soils. The highest values of total nitrogen (0.60 to 1.63 percent) are restricted to the volcanic soils in the northern province of Rwanda, whereas they are lower (0.10 to 0.48 percent) in all other parts of the country (Mutwewingabo *et al.* 1989). The potassium is generally low to medium level for most of the soils except for those of the former Kibungo province that are rich in this element (Vander Zaag *et al.* 1984). The phosphorus is considered as the most limiting nutrient for most soils of Rwanda and its availability in plants is very limited (Muhawenimana 1987; Hakizimana 1998). The calcium content is less than 3 centimole cation per kilogram of soil [cmole(+)kg^{-1} of soil] in most of the soils of the former Gikongoro province and is estimated to be greater than 9 cmole(+)kg^{-1} of soil in the volcanic soils of the northern and the eastern regions of the country (Vander Zaag 1981).

Role of organic matter on soil properties

The organic matter is the resulting decomposed product from green manures, plant residues and animal wastes accumulated in the surface soil layers and microbial debris in various stages of the decay (Ndabalishye 1985; Leclerc 1995; Gupta 2007). The organic matter in all its forms (fresh substances, intermediate products and humus) improves soil fertility by influencing its physical, chemical and biological properties. It improves water circulation and soil aeration, and increases the field holding capacity (Soltner 1985). According to Nyle and Brady (2003), the organic matter also improves the soil by the formation of a clay humic complex which increases the soil adsorbent capacity of basic nutrients (calcium, magnesium and potassium) and enhances the activity of microorganisms involved in the mineralization process.

Hoyt and Turner (1975 cited by Nabahungu 2003), stated that the soil pH can also be significantly increased by adding plant residues into the soils. These results are in agreement with those of Mnkeni and MacKenzie (1985), who also obtained higher values of pH in soil solution treated with organic residues than in those amended with calcium carbonate. This was attributed to higher concentrations of basic nutrients in organic amendments used and hydrous oxides reduction in soils (Hue 1992). The increasing soil pH level causes an increase in cation exchange capacity and formation of negative charges on colloidal fractions. In addition, organic amendments can also contribute to the reduction of exchangeable aluminium and iron in soil solution and thus have a positive effect on phosphorus sorption. In addition, Iyamuremye *et al.* (1996) showed that organic amendments reduced exchangeable aluminium in soil with high phosphorus sorption. That reduction may be due to the precipitation of aluminium ions released from the exchange of ligands between organic anions and aluminium oxides or aluminium complexes by organic molecules (Hoyt and Turner 1975 cited by Nabahungu 2003).

Nutrient and soil requirements of maize

Nutrient requirements (nitrogen, phosphorus and potassium) for maize plant growth are very high compared to those of other cereals. The maize plant needs 100 to 150 kgha^{-1} of nitrogen, 40 to 60 kgha^{-1} of phosphoric acid and 100 to 150 kgha^{-1} of potassium oxide during the vegetative growth period (Singh 1998). Rouanet (1984) mentioned that the inherent fertility of some tropical soils cannot satisfy this demand for more than one year as long as the soil cannot generally ensure more than 20 to 35 percent of maize plant requirements for nitrogen, phosphorus and potassium. Besides these macronutrients the maize plant also requires some appropriate amounts of secondary nutrients (calcium, magnesium and sulphur) as well as trace elements such as iron, manganese, zinc, boron and chlorine (Singh 1998). But most cereals and especially maize require more nitrogen than other nutrients for their development and high grain yields (Soltner 1983; Rouanet 1984). The maize plant absorbs small amounts of nitrogen at the start of the growing period. At the flowering time, the plant can accumulate more than 40 percent of the total nitrogen required during the early growing period (FAO 1987). The nitrogen content decreases in the course of the plant maturity until at the harvest period, and about two thirds of the total nitrogen is found in the grains. Nitrogen deficiency leads to decreased grain yields and depresses the plant growth.

The phosphorus absorption by the maize plant occurs continuously from the emergence of young seedlings until the full maturity. The phosphorus uptake reaches the peak level between the third and fifth week after planting. The phosphorus regulates the flowering of the plant, facilitates the formation of grains and confers the rigidity to plant stems (Rouanet 1984). Ristanovic (2001) pointed out that during the first thirty days after sowing the maize plant absorbs much more potassium than nitrogen and phosphorus. The daily rate of potassium absorption is estimated to 4 $kgha^{-1}$ during the first two weeks before the panicle appearance (FAO 1987).

Maize may suffer from a number of micronutrient deficiencies. Perhaps the most widespread problem is zinc deficiency. It is associated with calcareous soils and soils of low organic matter content and may be intensified by a high level of phosphorus supply from the soil or fertilizer or both together (FAO 1984). Ngilimana (1977) reported that the maize plant grows on a range of different soils. But it can perform better on well drained and aerated soils, deep and warm loam and silt loams containing adequate organic matter and well supplied with sufficient nutrients. The maize plant can be successfully grown on soils with pH ranging from 5 to 8, but the optimum level is rating from 6 to 7.

Problem statement

In Rwanda as indicated by MINITERE (2003), wetlands and aquatic ecosystems cover about 255 000 hectares, representing 10 percent of the total land area. These humid zones play an important role in maintaining ecological balance and socio-economic development. Nevertheless, wetlands are affected by several forms of environmental degradation, such as water erosion, discharge of untreated sewage from industrial effluents, loss and mismanagement of water resources (Bizimana and Nyirimanzi 1998). Ever since the invasion of the water bodies, the water hyacinth has caused enormous socio-economic and environmental problems (Fig. 1) for the lakeshore communities and on the aquatic biodiversity. It has obstructed water transport, reduced fishing activities and created, by covering the water surface, anaerobic conditions that are detrimental to the aquatic life Furthermore, the weed has also negatively impacted on tourism as it invaded the once clear lakes of the large swamp and lake systems, which form the Akagera National Park.

If durable precautions are not taken on time, Rwanda water bodies will completely be destroyed by the water hyacinth invasion and the consequent losses will lead to an important decrease of the local and even regional biodiversity. Then, it is urgent that a sustainable solution be found to combat that menace.

Fig.1. Water hyacinth limits access to open water, Lake Shakani, Rwanda.
Photo: F. Gashamura

In Rwanda, the low agricultural production and productivity of food crops is largely attributed to low and decreasing soil fertility. Inorganic fertilizers and farmyard manure are considered as important inputs for increasing soil fertility. However, mineral fertilizers are usually expensive and available in too short supply and maybe not available at all to smallholder farmers (Bazivamo 1998 cited by Nabahungu 2003). Furthermore, the use of crop residues as soil fertilizers does not also appear very useful because they are mainly utilized as livestock fodder, fuel wood and fencing materials. The use of other technologies such as organic fertilizers from unexploited natural resources would be a better alternative to improve soil fertility and increase crop yields. Since the water hyacinth is locally available, plentiful and cost-free, its effective use as organic amendment would be an interesting method for soil restoration and would minimize partially and/or totally the negative impacts of this weed on the aquatic ecosystems and socio-economic activities. The present study was envisaged within this context. In this respect, the research questions that need to be answered were formulated as follows:

(i) What are the effects of water hyacinth fertilizers on soil properties?
(ii) Does the dried or fresh manure from water hyacinth increase crop production?

It was hypothesized that the fresh manure from water hyacinths could be more efficient in improving soil fertility and both maize growth and yield as compared to the dried manure. The overall objective of this study is to show how water hyacinth manures can contribute to improve soil fertility, and to find another alternative method of water hyacinth management by using it as an organic fertilizer in farming systems. The specific objectives were to evaluate the impact of fresh and dried manure from water hyacinth on the growth and yield of maize and to determine its effects on soil physical and physico-chemical properties.

Material and Methods

Sampling site description

The study was carried out at Gahororo experimental site belonging to the Rwanda Agricultural Research Institute (ISAR) at Ngoma research station located in the eastern province, Ngoma district, and Gashanda sector. It is found at 2°10' S latitude and 30°30' E longitude at an altitude of 1663 m above sea level. This area enjoys a semi-arid climate and is characterized by three to four months of drought. Daily average temperatures are about 21°C and mean annual precipitation ranges from 800 to 1000 mm per year (Delepierre 1982). Natural vegetation has almost disappeared and is replaced by crops, pastures and planted forests. The Gahororo site is situated in the agro-climatic zone of the eastern plateau (Appendix 2) extending from both sides of the main road between Kigali and Rusumo border, about 15 kilometres from the ISAR-Ngoma research station. In the eastern plateau the relief is largely dominated by hills with broader summits generally covered by humic soils. The steep slopes are covered by lateritic gravel and superficial soils (Delepierre 1982). The area has two growing seasons per year, a long rainy season starts from September to January and a short rainy season from February to April. It is worth noting that the experimental site was previously used as a cassava plantation, and had not received any type of fertilizers. It has a gentle slope so that runoff losses are small or insignificant.

Material

The test soil used for both the maize trial and the incubation study was collected from Gahororo site. The maize variety (ZM 607) used was provided by the Maize Research Program of ISAR. It was chosen because of its precocity (130 to 140 days of vegetative cycle), disease tolerance and a high yielding potential up to 6.5 tons per hectare and it is well suited to low and medium altitudes (1300 to 1800 m above sea level) in Rwanda (Mbonigaba 2002; Bucyana 2002).

Fresh water hyacinth shoots were collected in plastic bags (Fig. 2) and utilized as nutrient treatments for both maize and soil incubation experiments. The pot experiments were conducted in a glasshouse at the Institute of Scientific and Technological Research (IRST). The reason for carrying out this experiment in the glasshouse was related to the fact that crops can grow better under controlled environment than in natural field conditions where they can be stressed by diseases, drought and nutrient deficiency due to the leaching. On the other hand, one of the limitations of growing crops in the glasshouse experiments is that crops are grown under regulated conditions such as temperatures, watering, pot size, etc as compared to harsh environment in the farmer's fields. But at the end, the results are useful as guideline to farmers and the limitation caused in glasshouse procedures can be acknowledged.

Furthermore, it is worth to note that the period (July-October 2008) during which the study was undertaken corresponded to the dry season of the year. Then, it was basically impossible to conduct any experiment as field trials.

Fig. 2. Water hyacinth plant collection. Photo: © F. Gashamura

Methods

Sampling procedures

The soil samples were taken in topsoil at a depth of 0-30 cm with a soil auger. These samples were randomly collected from 5 different locations on fallow land and homogenized to form a representative sample. The sample was sun-dried for a week and then crushed, and sieved at 0.5 mm for carbon and nitrogen analyses, and at 2 mm for other analyses. Water hyacinth samples were collected from the southern part of Lake Ihema. The sampling was focused on the plant leaves and stems. Half of the collected material was first air-dried for a week and then put in an oven at 60°C for 48 hours and finely crushed into powder (Figs. 3 and 4) for analysis of chemical composition while the other portion of fresh biomass was cut into small pieces (Fig. 5) and incorporated in pots to serve as treatments for both the soil incubation study and the maize trial.

Treatments and experimental design

There were seven treatments with three levels of dried water hyacinth fertilizers and three levels of fresh water hyacinth biomass applied separately, and one treatment without inputs. The amounts of water hyacinth fertilizer used in pots for both the soil incubation study and the maize trial were calculated (Appendix 3) on the basis of the following nutrient treatments:

1. D150: 150 kg of nitrogen per hectare of dried water hyacinth
2. D300:300 kg of nitrogen per hectare of dried water hyacinth
3. F150: 150 kg of nitrogen per hectare of fresh water hyacinth
4. F300: 300 kg of nitrogen per hectare of fresh water hyacinth
5. D450: 450 kg of nitrogen per hectare of dried water hyacinth
6. F450: 450 kg of nitrogen per hectare of fresh water hyacinth
7. C0: Control (without any organic fertilizers).


Fig. 3. Dried water hyacinths
Photo: F. Gashamura


Fig.4. Powder from dried water hyacinths
Photo: F. Gashamura


Fig. 5. Fresh water hyacinth chopped in small pieces.
Photo: F. Gashamura

The experimental design was a Randomized Complete Block Design (RCBD) with 3 replicates (Figure 6). Treatments were randomized according to the GenStat Discovery 3 software. It should be noted that with this design results are obtained without any biases and data can easily be analyzed. It is also efficient and flexible for both glasshouse and field trials. The soil incubation period lasted for three months. During this period the mineralization optimum level of water hyacinth manure was assessed as a function of time (at 0, 30, 60 and 90 days) in order to quantify its effects on soil macronutrients.

R1	F150 □ □ □	D150 □ □ □	F300 □ □ □	D300 □ □ □	F450 □ □ □	D450 □ □ □	C0 □ □ □
R2	D300 □ □ □	F450 □ □ □	D150 □ □ □	F150 □ □ □	D450 □ □ □	C0 □ □ □	F300 □ □ □
R3	F300 □ □ □	C0 □ □ □	F450 □ □ □	D300 □ □ □	F150 □ □ □	D150 □ □ □	D450 □ □ □

Fig. 6. Experimental layout used for the soil incubation study and the maize trial.
R denotes replicates, D and F are treatments with dried and fresh water hyacinth manures and C is control.

Pot experiment management

Plastic pots of an average height of 11.3 cm and a diameter of 10 cm were used for the soil incubation experiment. Each contained about 500 grams of 2 mm sieved soil. Given the number of treatments and replicates the total number of pots was 63. For the maize crop trial, pots of 19.5 cm height and 21 cm diameter each containing the same amount of soil were also used. Their total number was 21. Two pots were used on top of each other. The upper pots contained soil substrates and treatments. Holes were made in the bottom of them to allow drainage of excess water. Water retained in the lower pots was then returned into the upper ones to avoid loss of nutrients. A permutation of pots was done every two weeks to allow them to have the same exposure time of light at a given location of the design. De-ionised water was used in order to prevent any external input of nutrients other than those provided by water hyacinth fertilizers. The field capacity was determined

as $C = \frac{VO - V}{Q}$, where

VO = Total amount of water poured into the soil in millilitre
V = Quantity of water collected two days after leaching in millilitre
Q = Quantity of soil in gram
C = Field capacity in percentage.

It was found that a pot containing 500 grams of soil needed about 39.5 millilitres of water. Pots were watered regularly after two days by de-ionized water for maintaining soil moisture at 80 percent field capacity and to prevent soil compaction. Four seeds were sown in each pot, and then it was watered at the field capacity. Maize plants were singled out a week after germination just leaving two vigorous plants per pot. Water hyacinth biomass was mixed with soil substrate two weeks before sowing.

Maize plant performance

The fertilizing effect of water hyacinth manure was determined by considering the plant growth and yield parameters such as collar diameter, total plant height, biomass dry weight and nutrient content of maize shoots and roots before flowering (at 45 days of growth). Maize plants were measured for total height at three time intervals (15, 30 and 45 days) on at least 80 percent of the plants, which were randomly selected as samples from each pot. Plant heights were measured from the collar to the tip of the plants by using a graduated ruler and measurements were recorded to the nearest 0.1 centimetre. Stem collar diameter was estimated from the same sample plants which were measured for the total height with a vernier calliper. Above ground biomass for the plants was cut from standing plants in the pots after 45 days of growth by using a knife and was at about 1 cm stem collar. Each sample plant was weighed for fresh weight with a precision electric scale and then dried in an oven at 60°C for 3 days until constant weight. The measurements were recorded to the nearest 0.1 gram. The root biomass was carefully extracted from the ground and washed with distilled water, air-dried and then weighed with the same scale. The dry matter content and nutrients removed by the maize plants were analyzed at the ISAR Rubona laboratory.

Chemical analysis

(i) Soil

Soil analyses focused on the composite sample of the soil under incubation before and after application of water hyacinth fertilizer. Physical and physico-chemical analyses of soil samples were done as follows: Particle-size distribution was measured by the siphonage method (Stoke's Law). Organic matter was determined through oxidation with hydrogen peroxide and dispersion of sodium hexametaphosphate ($NaPO_3$) in an acidified suspension with 0.1 N hydrochloric acid; three soil fractions were obtained, namely sand, silt and clay after sieving in the liquid and drying in an oven at 105°C followed by weighing. The textural class was determined using the textural triangle according to the United States Department of Agriculture (USDA) soil classification (Ryan *et al.* 2001). Bulk density was determined by the Koppecky's cylinder method (core method) from soil sample collected before incubation and after drying in an oven at 105°C for 24 hours. The soil reaction (pH**)** was determined both in suspensions of soil in water [pH (H_2O)], and in potassium chloride [pH (KCl)] at a ratio of 1:2.5 (Bonneau and Souchier 1994). Total nitrogen was determined by the Kjeldahl method (Bremner and Mulvaney 1982). Exchangeable acidity was obtained through extraction with 1 N KCl percolation and titration with 0.1 N hydrochloride acid. Cation exchange capacity (CEC) consists of saturation by agitation with 1 N ammonium acetate at pH 7 followed by distillation and titration with 0.01 N hydrochloric acid (Baize 2000). Exchangeable bases were determined with atomic absorption spectrophotometer in extract solutions obtained from 1 N ammonium acetate at pH 7. Soil organic carbon levels were obtained by the modified Walkley and

Black method. Soil organic matter was estimated by multiplying the organic carbon value with the factor 1.724 mainly used for tropical soils (Nelson and Sommers 1982 cited by Ntaneza 1988). Available phosphorus was measured by the Bray 2 method, which consists of an extraction with a mixture of 0.03 N ammonium fluoride and 0.1 N hydrochloric acid at a ratio of 1:7 and dosage with colorimeter at a wave length of 826 nm (Baize, 2000; Pieltain and Mathieu 2003). Ammonium nitrogen (NH_4^+-N) was determined by distillation with boric acid followed by distillate titration with 0.01 N hydrochloric acid. Nitrate nitrogen (NO_3^--N) was found by distillation with Devarda's alloy and titration with 0.01 N hydrochloric acid.

(ii) Water hyacinth
The chemical characterization of water hyacinth focused on five major elements considered as essential minerals in plant nutrition, namely nitrogen, phosphorus, potassium, calcium and magnesium. 0.5 gram of powder derived from oven-dried water hyacinth shoots was put into digestion tubes in a mixture of nitric acid and hydrogen peroxide as modified by Moberg (2000). An amount of 5 ml of 68 percent of nitric acid was added into each tube. The tubes were put in a digestion block at 125°C for one hour before being refrigerated. Then, five millilitres of hydrogen peroxide were added into each tube and the mixture was heated at 70°C until the reaction stopped. This procedure was repeated until the content obtained was almost colourless. The digest was again heated at 180°C to nearly dryness. Then ten millilitres of ten percent nitric acid were also added to the same digest and set to a 100 millilitres volumetric flask before being filled up to the mark with distilled water. Then, the phosphorus content was measured by the ascorbic acid molybdate blue method. Magnesium and calcium were analyzed by atomic absorption spectrophotometer, and the potassium was obtained by flame spectrophotometer. The total nitrogen was determined using the same procedure given for the nitrogen in the above section. The percentage of dry matter (DM) content was determined by sampling about 200 grams of water hyacinth leaves, dried in an oven set at 60°C for 48 hours, and then the following formula was used:

$$DM = \frac{\text{Dry weight}}{\text{Fresh weight}} x\ 100$$

Heavy element concentrations (zinc, lead, copper and cadmium) in water hyacinth were determined by atomic absorption spectrophotometer. Cutting of above ground parts of maize plants was done 45 days after emergence, and nutrient uptake (N, P, K, Ca and Mg) was analyzed by the same methods as described in the above section of this thesis. Root plants were also analyzed for the heavy elements (zinc, lead, copper and cadmium) in the same way as described above.

Statistical analysis

Statistical analyses for soil physico-chemical properties and both ammonium and nitrate nitrogen, available phosphorus, exchangeable potassium at different periods of observation (0, 30, 60 and 90 days) of the soil under incubation, and maize plant height and diameter at 15, 30 and 45 days after emergence were performed through analysis of variance (ANOVA) using the Minitab for Windows Version 15.0 statistical package. The graph presentations were performed with the Excel software.

Results

Initial soil physical properties of the experimental site

The average particle-size distribution before soil incubation is presented in Table 1. Clay was the most abundant fraction compared to silt and sand. Based on the textural triangle of soil classification system defined by the USDA, the textural class of this soil was clay. The bulk density was low and indicated that the soil studied had fine particles that make it light and loose. The fine element levels showed that the soil structure was relatively good.

Table 1. Particle size and soil bulk density before soil incubation

Properties	Mean values
Particle size distribution:	
Sand	31%
Silt	15%
Clay	54%
Silt + Clay	69%
Soil bulk density (g/cm^3)	1,25
Textural class	Clay

Soil physico-chemical properties before and after water hyacinth incorporation

Characteristics of the soil samples at the end of the experiment were compared with those obtained before water hyacinth application in order to detect the effects due to the application of the various treatments used on soil physico-chemical properties. A table summarizing all those soil parameters is presented in Appendix 4.

Soil reaction (pH) and total acidity

The soil reaction and the exchangeable acidity mean values before and after application of water hyacinth manures are shown in Table 2. The soil reaction in water and potassium chloride suspension was 5.6 and 4.5, respectively. The pH (H_2O) increased from 5.7 to 6.3 with all treatments compared with the control (5.6). The pH (KCl) was considerably raised with fresh manures (from 5.2 to 5.6), and almost similar for both the control and dried water hyacinths. The difference (ΔpH) between pH (H2O) and pH (KCl) mean values remained negative for the whole applied treatments. A decrease in the total acidity was mainly observed in fresh water hyacinths (F300 and F450). The aluminium (Al^{3+}) and hydrogen (H^+) ion concentrations were lower in F450 and F300 than in dried water hyacinths.

The analysis of variance (ANOVA) revealed significant differences among treatments after water hyacinth manure incorporation.

Table 2. Soil reaction and exchangeable acidity ($Al3^{+}$+H^{+}) mean values before and after water hyacinth manure application

	Treatment	pH (H2O)	pH (KCl)	ΔpH	Al^{3}	H^{+}	Al^{3+}+H^{+}
					cmol (+) kg^{-1} of soil		
Before manure application		5,6	4,5	-1,1	0,04	1,36	1,40
After manure application	D150	5,7	4,7	-1,0	0,04	0,25	0,29
	D300	5,9	4,8	-1,1	0,03	0,13	0,16
	F150	6,1	5,2	-0,9	0,02	0,08	0,10
	F300	6,0	5,4	-0,6	0,02	0,05	0,07
	D450	5,9	5,0	-0,9	0,02	0,10	0,12
	F450	6.3	5.6	-0.7	0,01	0,03	0,04
	CO	5,6	4,7	-0,9	0,04	0,25	0,29
F-value		10,66	6,08		14,44	13,81	13,78
P-value		0,000**	0,003**		0,000**	0,000**	0,000**

** indicates significant difference at P < 0.01 among treatments.

Nitrogen, organic carbon, organic matter, carbon:nitrogen ratio and available phosphorus

As shown in Table 3 the total nitrogen (0.13 percent) and available phosphorus [13.03 parts per million (ppm)] were found to be low in the test soil before water hyacinth incorporation while the soil organic matter (3.45 percent) was at medium level. A significant difference ($P < 0.01$) was observed for the nitrogen, phosphorus and carbon to nitrogen ratio. The fresh manures had the highest nitrogen and phosphorus contents at the highest application rates. A decrease in nitrogen content was noticed for D150 and D300 treatments compared to the control. The nitrogen and organic matter levels were found higher with F300 and F450 treatments than the control. The carbon to nitrogen ratio shows that there is a very fast mineralization potential for both fresh water hyacinth (F300 and F450) and the control. Dried fertilizers of the D150 treatment showed a considerable decrease in the available phosphorus and organic carbon compared to the control.

Table 3. Organic carbon (OC), organic matter (OM), nitrogen (N), carbon to nitrogen ratio (C;N) and available phosphorus (P) mean values

	Treatment	OC (%)	OM (%)	N (%)	C:N (%)	Available P (parts per million)
Before manure incorporation		2,00	3,45	0,13	15,38	13,03
After manure incorporation	D150	2,24	3,86	0,15	14,93	8,51
	D300	2,28	3,93	0,15	15,20	21,02
	F150	2,53	4,36	0,20	12,65	20,12
	F300	2,54	4,38	0,31	8,19	23,66
	D450	2,44	4,21	0,23	10,61	20,19
	F450	2,56	4,41	0,35	7,31	25,93
	CO	2.40	4.14	0.27	8.89	12.82
F-value		4.19	8.14	12.18	24.84	15.64
P-value		0,041 ns	0.039ns	0.004**	0.002**	0.000**

** indicates significant difference at P< 0.01 among treatments ns shows non significant difference at P< 0.01 among treatments

Exchangeable bases and cation exchange capacity

The exchangeable bases and cation exchange capacity mean values are shown in Table 4. Treatments significantly ($P < 0.01$) influenced the calcium, magnesium and potassium levels. The exchangeable calcium (8.30 cmol (+) kg^{-1} of soil) was on a medium level before water hyacinth application and rose to a higher level with fresh amendment than with other treatments and the control. Fresh water hyacinth fertilizers increased enormously the exchangeable potassium contents from 0.6 to 1.40 cmol (+) kg^{-1} of soil, whereas there was a moderate increase with dried water hyacinth from 0.6 to 0.8 cmol (+) kg^{-1} of soil. The initial low level of the magnesium was considerably enhanced with the water hyacinth residues, more so with the fresh than with the dried manures.

Table 4. Mean values of exchangeable bases (Ca^{2+} , Mg^{2+}, K^{+}) and cation exchange capacity (CEC) before and after water hyacinth manure incorporation

	Treatment	Ca^{2+}	Mg^{2+}	Ca^{2+}/Mg^{2}	K^{+}	CEC
		cmol (+) kg^{-1} of soil				meq/100 g of soil
Before manure application		8,30	2,15	3,86	0,60	8,87
After manure application	D150	13,43	2,07	6,49	0,70	16,94
	D300	13,80	2,17	6,36	0,70	17,76
	F150	14,20	3,98	3,57	1,20	18,74
	F300	14,20	2,47	5,75	1,20	18,67
	D450	14,07	3,53	3,98	0,80	18,15
	F450	14,93	2,57	5,81	1,40	18,41
	C0	13,27	1,50	8,85	0,40	18,25
F-value		13,83	9,20	22,02	8,17	2,98
P-value		0,000**	0,000**	0,000**	0,001**	0,394ns

** indicates significant difference at P< 0.01 among treatments
ns shows non significant difference at P< 0.01 among treatments

An increase in the calcium to magnesium ratio was noted with the control and the dried amendments (D150 and D300). The cation exchange capacity content was slightly more affected by the F150 and F300 treatments.

Ammonium nitrogen and nitrate nitrogen during the soil incubation period

Data showing the average results for both the ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) during the incubation period (0, 15, 30, 60 and 90 days) are found in Tables 5 and 6. Significant differences were detected among treatments.

There was a considerable decrease of the ammonium nitrogen content for most treatments from the beginning of the soil incubation up to 30 days, except for the D450 treatment, and then there was an increase between 60 and 90 days.

Table 5. Effects of treatments on ammonium nitrogen during the soil incubation period

Incubation period (days)	0	30	60	90
Treatment	NH_4^+-N (g kg^{-1})	NH_4^+-N (g kg^{-1})	NH_4^+-N (g kg^{-1})	NH_4^+-N (g kg^{-1})
D150	0,10	0,08	0,07	0,15
D300	0,14	0,06	0,08	0,10
F150	0,13	0,07	0,08	0,10
F300	0,26	0,13	0,08	0,15
D450	0,09	0,13	0,07	0,15
F450	0,20	0,12	0,11	0,22
C0	0,12	0,11	0,10	0,15
F-value	11,69	10,76	7,44	17,43
P-value	0,000**	0,001**	0,003**	0,000**

** indicates significance at P < 0.01 among treatments at each observation period.

Table 6 Effect of treatments on nitrate nitrogen (NO_3^- -N) during the soil incubation period (g kg^{-1})

Incubation period (days)	0	30	60	90
Treatment				
D150	0,05	0,09	0,18	0,17
D300	0,06	0,06	0,16	0,17
F150	0,05	0,16	0,20	0,16
F300	0,06	0,17	0,17	0,17
D450	0,07	0,14	0,17	0,16
F450	0,09	0,12	0,33	0,26
C0	0,10	0,13	0,15	0,16
F-value	12,33	0,32	9,09	11,23
P-value	0,000**	0,813^{ns}	0,001**	0,001**

** indicates significance at P < 0.01 among treatments at each observation period.
ns denotes non significance at P < 0.01 among treatments.

The ammonium nitrogen trends (Fig. 7) were almost similar between 0 and 30 days after incubation except for the D450 treatment.

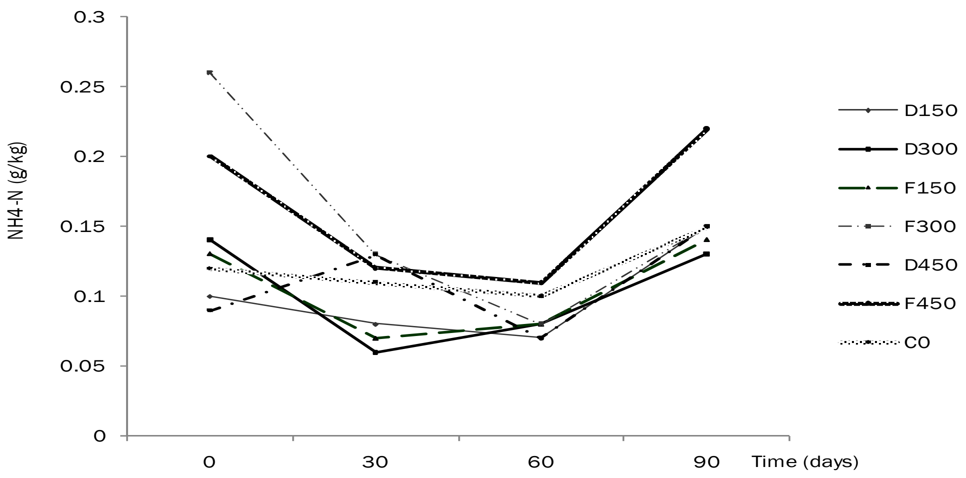

Fig. 7. Ammonium nitrogen evolution in the soil during soil incubation period.

The nitrate nitrogen contents observed at 60 and 90 days after the soil incubation indicated that the results were on the same level except for F450 treatment. The analysis of variance revealed a significant difference among treatments.

The nitrate nitrogen amounts (Fig. 8) increased between 0 and 30 days with F150 and F300 treatments and then remained constant after 60 days for some treatments. The maximum level was observed between 30 and 60 days after soil incubation with the F450 treatment. The graph shows that the trends are sharper than in the case of the ammonium nitrogen.

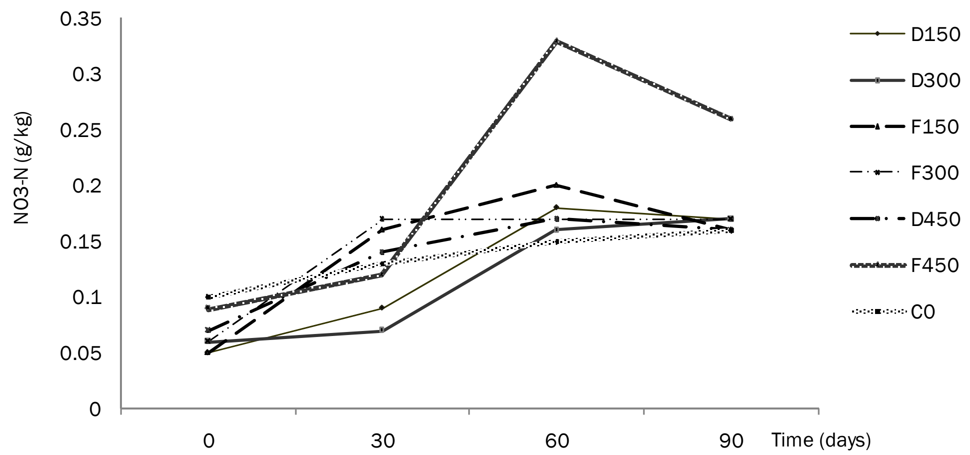

Fig. 8. Evolution of nitrate nitrogen in the soil during soil incubation period.

Total mineral nitrogen during the soil incubation period

The results of the total mineral nitrogen ($NH_4^+ + NO_3^-$) are summarized in Table 7. There were significant differences among nutrient treatments at 0 and 90 days. The mineral nitrogen ($NH_4^+ + NO_3^-$) was higher in the F450 treatment than in all other treatments at 90 days after soil incubation.

Table 7. Effect of nutrient treatments on mineral nitrogen (NH_4^++NO_3^-) during the soil incubation period (g kg^{-1})

Incubation period (days)	0	30	60	90
Treatment				
D150	0 ,15	0 ,17	0 ,25	0 ,32
D300	0 ,20	0 ,13	0 ,24	0 ,30
F150	0 ,18	0 ,23	0 ,28	0 ,30
F300	0 ,32	0 ,30	0 ,25	0 ,32
D450	0 ,16	0 ,27	0 ,24	0 ,31
F450	0 ,29	0 ,24	0 ,44	0 ,48
C0	0 ,22	0 ,24	0 ,25	0 ,31
F-value	25 ,24	4 ,05	2 ,78	17 ,23
P-value	0 ,000**	0 ,029ns	0 ,080ns	0 ,000**

** indicates significance at P < 0.01 among treatments at each observation period.
ns denotes non significance at P < 0.01 among treatments.

The trend lines of the total mineral nitrogen at various observation periods are shown in Fig. 9. The total mineral nitrogen levels were high between 60 and 90 days. There was a remarkable decrease between 0 and 30 days with F450 and F300 hyacinth fertilizers.

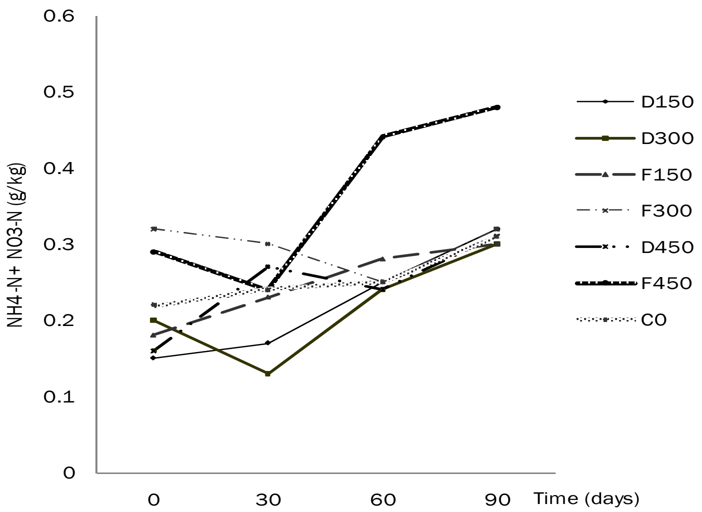

Fig. 9. Total mineral nitrogen evolution in the soil during soil incubation period.

Available phosphorus and potassium during soil incubation period

The available phosphorus and exchangeable potassium mean values for all the treatments are presented in Tables 8 and 9. The highest available phosphorus values were found in the green water hyacinth manure (F450) and the lowest in the dried ones (D150), and in the latter it was lower than the control. The analysis of variance revealed significant differences among treatments during the whole incubation period. The phosphorus amounts were significantly higher in pots amended with fresh water hyacinths than in those receiving the dried fertilizers and in the control at the end of the soil incubation.

Table 8. Effects of treatments on available phosphorus (P) during the soil incubation period (parts per million)

Incubation period (days)	0	30	60	90
Treatment				
D150	11 ,24	8 ,30	11 ,68	8 ,51
D300	9 ,78	8 ,53	13 ,65	21 ,02
F150	0 ,37	9 ,80	11 ,78	20 ,12
F300	11 ,58	11 ,87	9 ,71	23 ,66
D450	11 ,30	9 ,25	9 ,25	20 ,19
F450	14 ,30	10 ,03	12 ,78	25 ,93
C0	16 ,01	11 ,26	9 ,84	12 ,82
F-value	300 ,02	71 ,98	15 ,64	464 ,87
P-value	0 ,000**	0 ,000**	0 ,000**	0 ,000**

** indicates significance at $P < 0.01$ among treatments at each observation period.

Table 9. Effect of treatments on exchangeable potassium (K) during the soil incubation period (meq/100 g)

Incubation period (days)	0	30	60	90
Treatment				
D150	0 ,77	0 ,47	0 ,50	0 ,63
D300	0 ,70	0 ,60	0 ,70	0 ,90
F150	1 ,13	0 ,70	1 ,03	1 ,07
F300	0 ,80	0 ,76	0 ,73	1 ,33
D450	0 ,90	0 ,37	0 ,70	0 ,83
F450	1 ,30	0 ,36	0 ,87	1 ,36
C0	0 ,27	0 ,70	0 ,30	0 ,53
F-value	52 ,50	20 ,13	16 ,54	22 ,12
P-value	0 ,000**	0 ,000**	0 ,000**	0 ,000**

** indicates significance at $P < 0.01$ among treatments at each observation period.

The available phosphorus (Fig. 10) decreased for all the treatments between 0 and 30 days and then they reacted differently between 30 and 60 days. At 90 days there was a clear increase, except for the D150 treatment and the control.

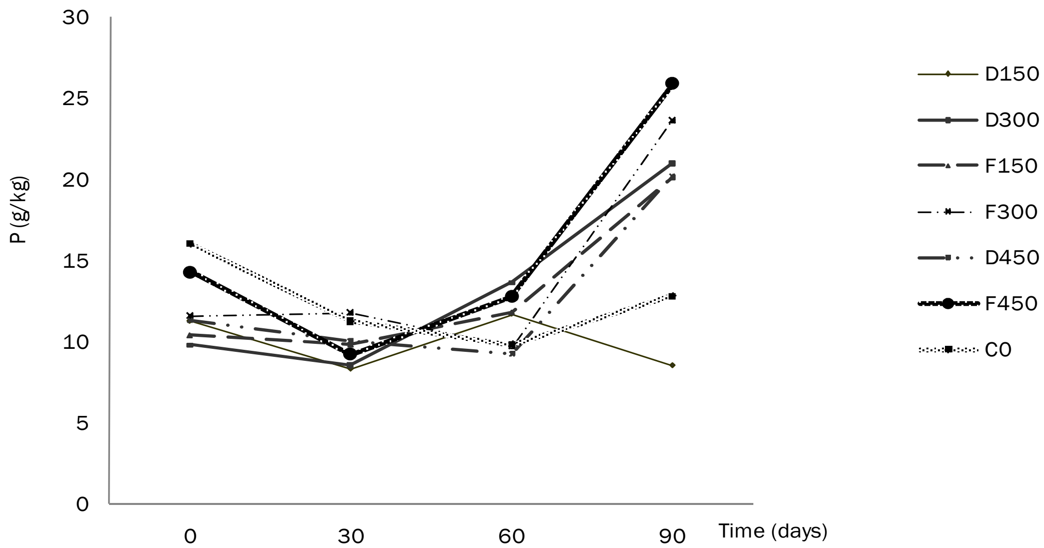

Fig. 10. Available phosphorus evolution in the soil during the soil incubation period.

The average concentrations of the exchangeable potassium (K) were higher for all treatments than the control and varied until the end of the soil incubation. A high significant difference was observed among treatments during all periods of the soil incubation.

The Fig. 11 shows that the exchangeable potassium decreased at the beginning until the thirtieth day except for the control only. Then, a slight increase was observed throughout the various observation periods for other treatments.

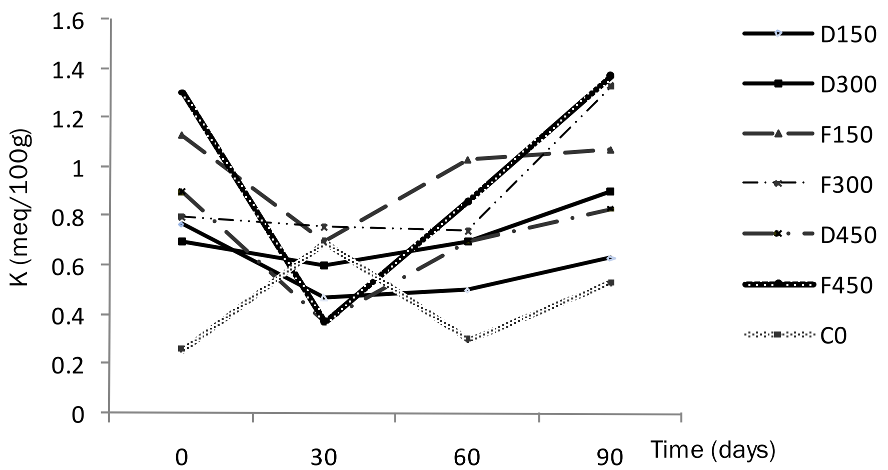

Fig. 11. Exchangeable potassium evolution in the soil during soil incubation period.

Maize growth assessment

Effect of treatments on maize height

The maize height and diameter were monitored at three time intervals (15, 30 and 45 days) after sowing. Data shown in Table 10 reveal that there is a significant difference between heights at 30 and 45 days of the plant growth.

Table 10. Mean values of maize plant heights (mean values in cm) after 15, 30 and 45 days of growth

Observation periods (days)	15	30	45
Treatment			
D150	10 ,17	13 ,00	23 ,33
D300	9 ,83	17 ,67	31 ,00
F150	14 ,33	23 ,00	26 ,00
F300	11 ,33	27 ,00	45 ,00
D450	8 ,83	15 ,57	39 ,30
F450	14 ,17	31 ,17	64 ,53
C0	9 ,50	10 ,33	37 ,50
F-value	0 ,56	8 ,49	10 ,04
P-value	0 ,649^{ns}	0 ,001**	0 ,000**

** indicates significance at P < 0.01 among treatments at each observation period.
ns denotes non significance at P < 0.01 among treatments.

The highest average plant heights (Figs. 12 and 13) were found in pots fertilized with fresh water hyacinths (F300 and F450) and the lowest in those amended with dried manures (Fig. 14).

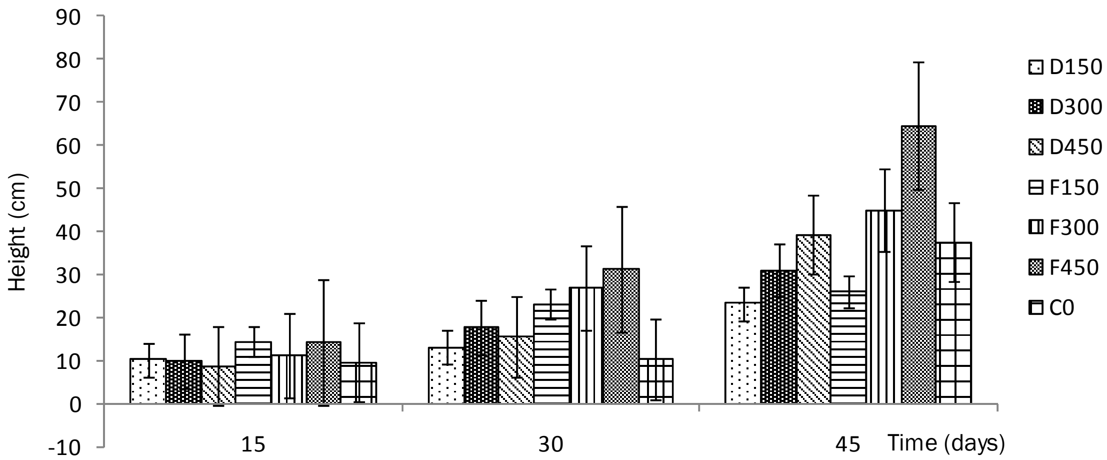

Fig. 12. Maize plant heights at various stages of growth in response to water hyacinth manure.

Fig. 13. Maize plants amended with fresh manures.
Photo: F. Gashamura

Fig. 14. Maize plants treated with dried manures.
Photo: F. Gashamura

Effect of treatments on collar diameter

The average collar diameters varied from 1.00 to 1.20 cm with fresh fertilizers and from 0.53 to 0.63 cm with dried amendments and 0.67cm for the control. The analysis of variance showed that the average diameters were significantly higher at 30 and 45 days after sowing (Table 11).

Table 11. Maize collar diameter (mean value in cm) averages at 15, 30 and 45 days after sowing

Observation periods (days)	15	30	45
Treatment			
D150	0 ,23	0 ,30	0 ,33
D300	0 ,40	0 ,50	0 ,57
F150	0 ,37	0 ,37	0 ,67
F300	0 ,50	0 ,67	1 ,00
D450	0 ,43	0 ,57	0 ,63
F450	0 ,67	1 ,03	1 ,20
C0	0 ,27	0 ,37	0 ,67
F-value	2 ,72	10 ,06	10 ,15
P-value	0 ,077^{ns}	0 ,000**	0 ,000**

** indicates significance at P < 0.01 among treatments at each observation period.
ns denotes non significance at P < 0.01 among treatments.

The maize shoots gave a better performance with fresh water hyacinths (Fig. 15) at 30 and 45 days after emergency than with the dried amendments and the control.

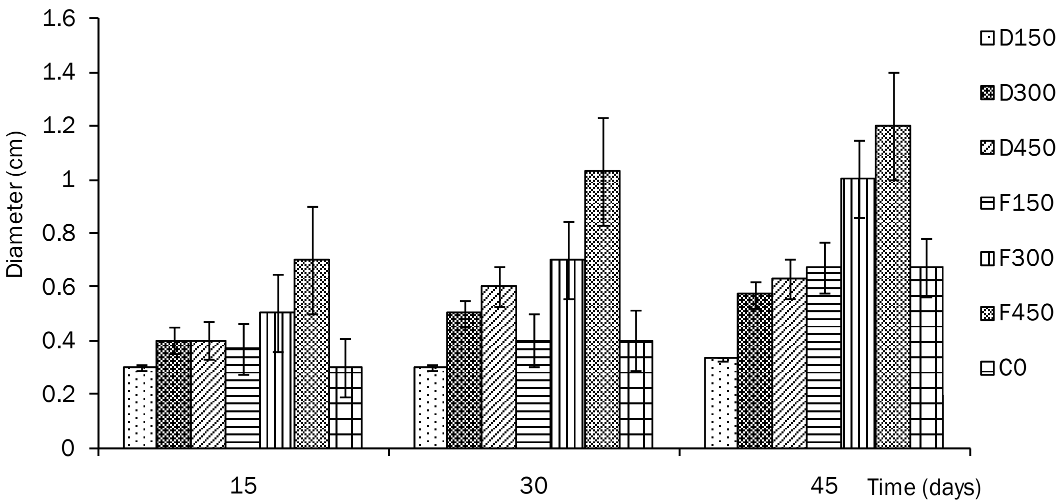

Fig. 15. Collar diameter of maize shoots at various growth stages in response to water hyacinth manure.

Maize dry matter yield

The highest yields were observed for the F300 (5.30 g) and F450 (9.37 g) treatments and the lowest for D150 (0.50 g) and D300 (1.03 g). The control yielded 4.67 g. Yields from pots treated with fresh manures were significantly different from those receiving dried fertilizers, and without inputs (Table 12).

Table 12. Dry matter yield of maize shoots after 45 days of growth (mean values in g)

Treatment	
D150	0,50
D300	1,03
F150	4,20
F300	5,13
D450	1,10
F450	9,37
C0	4,67
F-value	10,03
P-value	0,000**

** indicates significance at P < 0.01 among treatments at each observation period.

The maize dry matter yields for the different treatments at the harvest time (45 days of growth) are illustrated in Fig. 16.

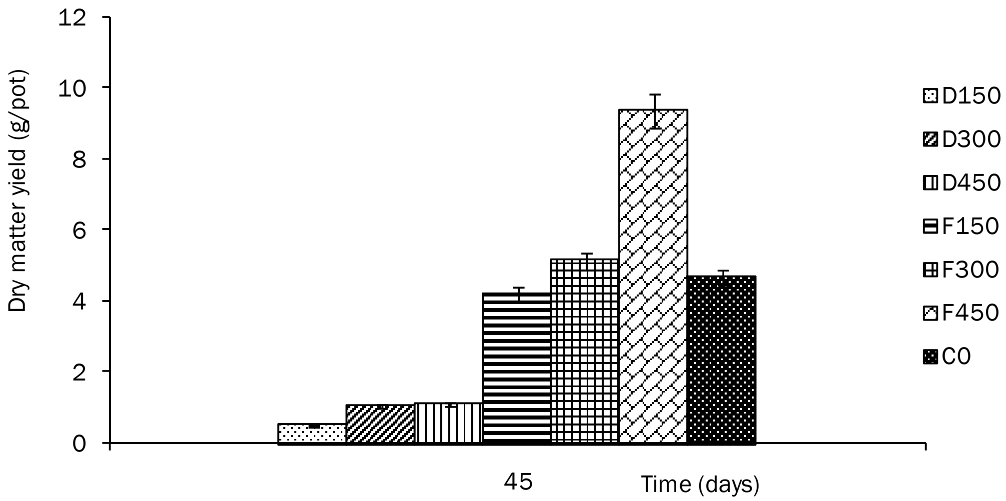

Fig. 16. Dry matter yield of maize shoots at the harvesting time.

Water hyacinth characterization

The most dominant element found in water hyacinth was the potassium whereas the magnesium was the most deficient (Table 13). The water hyacinth shoots had high carbon to nitrogen ratio showing that the mineralization could be slow for this plant.

Table 13. Chemical composition of water hyacinth shoots

Constituent Content (%)	
Calcium	1,55
Magnesium	1,12
Phosphorus	1,20
Potassium	3,81
Carbon	41,72
Nitrogen	1,67
Carbon to Nitrogen ratio	24,98
Dry matter	8,80
Cellulose	35,09

The water hyacinth shoots were also analyzed for heavy metal levels (Table 14). The highest concentrations were observed for lead and the lowest for zinc.

Table 14. Heavy element concentrations in water hyacinth shoots

Heavy elements (mg kg^{-1})	Lead	Copper	Zinc	Cadmium
Concentration	6,2	3,0	0,2	0,4
*Acceptable levels(mg kg^{-1})	50	-	25	1

*Heavy metal threshold levels in soil used for agriculture and recreation recommended by the UK Interdepartmental Committee for Restoration of Contaminated Land (ICRCL, 1987) from Nabulo *et al.* (2006).

Nutrient content of maize plants at the end of the experiment

On the whole, results showed (Table 15) that the exchangeable potassium was highly absorbed by the maize plant followed by nitrogen. The phosphorus and the magnesium were the nutrients least removed by the maize plants.

Table 15. Mean values of nutrient content of maize plants after 45 days of growth

	Nutrient content (%)				
Treatment	N	P	K	Ca	Mg
D150	1,90	0,16	3,64	0,81	0,60
D300	2,55	0,22	3,17	0,60	0,55
F150	1,41	0,18	3,03	0,49	0,45
F300	1,36	0,19	4,44	0,50	0,47
D450	2,05	0,17	1,77	0,66	0,50
F450	1,59	0,21	2,25	0,39	0,49
C0	1,19	0,17	2,29	0,68	0,46

Heavy metal content in maize roots at the end of the experiment

Results in Table 16 show that zinc and copper were taken up in larger amounts by maize shoots compared with the lead and the cadmium at the harvesting time.

Table 16. Heavy metal contents in maize roots after 45 days of growth

	Heavy metal uptake (m kg^{-1})			
Treatment	Zinc	Copper	Lead	Cadmium
D150	1,4	2,2	0	0
D300	3,3	1,6	0	0
F150	3,1	1,6	0	0
F300	3,1	1,8	0	0
D450	2,5	1,6	3,6	0
F450	3,6	1,6	0,4	0
C0	2,5	1,4	0	0

Discussion

General soil properties

The test soil has mixed grain sizes ranging from clay to sand particles and is classified as clay (Table 1). According to Mutwewingabo and Rutunga (1987 cited by Kanamugire 1993), this soil is categorised as moderate and very acidic. As shown in Table 2 the difference (ΔpH) between the two ways to measure pH is negative. Similar results were found by Sanchez (1976) who reported that this is attributed to the predominance of negative charges on the soil surface particles which allow high absorption of cations. The total nitrogen, available phosphorus and exchangeable potassium were below the critical levels (Gachengo *et al.* 1999; Palm *et al.* 1997). This means that the organic matter content was low in the soil under investigation. Compared to values reported by Mutwewingabo and Rutunga (1987 cited by Kanamugire 1993), calcium (Ca^{+2}) and magnesium (Mg^{+2}) are both in the middle concentration range. The cation exchange capacity (CEC) can help to get an idea on the soil fertility and on the nature of the adsorbent complex (Harelimana 1990). The CEC levels for the experimental soil were low (Table 4). The relatively low concentrations of organic matter (Mutwewingabo and Rutunga 1987 cited by Kanamugire 1993) show that the soil before incubation was moderately humic (Table 3). The carbon to nitrogen ratio was less than 18:1, which reflects that the mineralization was predominant over the immobilisation process in the test soil (Murray 1997).

The fresh water hyacinths increase both the pH (H_2O) and pH (KCl) and alleviate the total soil acidity as seen at the end of the experiment. This is explained by the fact that the exchangeable cations (Ca^{+2} and Mg^{+2}) were greatly influenced by the organic matter found in those fertilizers and have positive effects on the soil fertility. Furthermore, this also confirms results obtained by Mando *et al.* (2000) in Burkina-Faso that showed an increase in the soil pH by using compost from plant residues. Moreover, Munyarushoka (1983) indicated that the soil pH can also be raised by the incorporation of fresh organic matter (roots, stems) which complexes with the aluminium, manganese and iron ions. This was also stated by Bell and Bessho (1993) who observed that the application of two types of organic matter (*Caliandra calothyrsus* and *Hordeum vulgare*) reduced the levels of aluminium ions in the soil solution by this same mechanism. Here, it should also be noted that there is always a strong correlation between the soil pH and acidic cations (Al^{+3} ions). On the whole and like already mentioned in the previous section, the ΔpH results show that the test soil even after application of water hyacinth manures has many negative charges which increase the absorption of basic nutrients. Both the fresh and dry water hyacinth had a positive effect on the soil total acidity which was largely reduced with all the treatments. This is in accordance with Hargrove (1981), who mentioned that the application of organic compost can reduce the aluminium saturation in the soil surface horizons by the calcium mobilization.

The CEC also increased more with fresh water hyacinth. However, the dried water hyacinth manures gave a result almost similar to the control. It is necessary to note that the highest levels of the CEC are mostly related to the highest levels of the organic carbon found in the fresh water hyacinth fertilizers (Tables 3 and 4). This is in agreement with results obtained by Dabin (1985) who reported that there was an increase of 3 cmol (+) kg^{-1} of soil in the CEC for about 1 percent of the organic matter in the soils. The Ca^{+2} contents increased in F450 but not in any other treatment. This means that the decomposition of the organic matter provided by the F450 treatment will have largely contributed to the soil enrichment in the calcium content more than in all other treatments.

The Mg^{+2} levels increased, particularly with F150 and D450 treatments, but much less in F300 and F450. In the D150 and D300 treatments it remained fairly constant and in the control it decreased. This fact is correlated with the highest ratio of the Ca^{+2} to Mg^{+2} and may be due to the volatilization of this element during the experiment period. The exchangeable potassium (K^+) amount increased with the fresh water hyacinth treatments and remained low with the dried water hyacinth manures and in the control. The highest concentrations of the available phosphorus were observed for the F300 and F450 treatments, while they were less for D300, F150 and D450 and very low for C0 and D150. This observation results from high accumulation of the organic matter and the exchangeable Ca^{+2} in those nutrients (in F300 and F450) which stimulated the phosphorus release into the soil. This finding confirms that of Baize (2000) who indicated that the mineralization of the organic matter by the microorganisms may transform the organic phosphorus found in the soil surface horizons into the available phosphorus used by plants.

The total nitrogen content varied extensively with F300 and F450 and increased in a way almost similar for all other treatments, and exceeded the recommended acceptable level (Table 3). Holland *et al.* (1992 cited by Mbonigaba 2002) confirmed that total nitrogen levels of 0.1 to 0.2 percent are satisfactory in tropical soils. As for the organic matter, the soil with the fresh water hyacinth amendments contained more organic carbon than those of dried biomass and the control (Table 3). It is worthwhile noting that the highest or lowest organic carbon contents correspond to the highest or lowest levels of the CEC. The carbon to nitrogen ratio (C:N) is higher in the dried water hyacinths than in those of fresh fertilizers and the control. This means that the organic matter mineralization process was more favourable with the fresh water hyacinths and the control than with the dried manures.

Results show that the ammonium nitrogen decreased between 0 and 30 days after incubation. This means that the inorganic nitrogen mineralization provided through the hydrolysis to release NH_4^+ which at the end became NH_4^+-N in the soil was high during that period. It reaches its maximum evolution capacity with fresh water hyacinth fertilizers (F450) at the completion of the soil incubation. This would be facilitated by the C:N ratio, which was found to be relatively low in these cases. The ammonium nitrogen immobilization process was intense between 30 and 60 days in the D150, F300 and D450 treatments only. After this period, the NH_4^+ -N amounts increased, which shows a dynamic fast stage of the ammonium nitrogen process to the nitrate nitrogen. This immobilization is explained by the low level of the organic nitrogen found in the soil. This assertion is in agreement with that of Tisdale *et al.* (1993) who stated that the ammonium nitrogen produced can be reconverted into the organic nitrogen form to fill up the deficit recorded in the soil during the microbial activity. The nitrate nitrogen amount decreased between 60 and 90 days during the soil incubation. This period corresponds to the lowest levels of the ammonium nitrogen in the incubated soil. The maximum level of the nitrate nitrogen increased between 60 and 90 days with F450 water hyacinth manures. This shows that the low C:N ratio for this fertilizer has facilitated the mineralization in comparison with the immobilization process. Nitrate nitrogen curves are more pronounced than those of ammonium nitrogen due to the behaviour of these two different forms of mineral nitrogen in the soil. After 30 days of the soil incubation the quantity of mineral nitrogen has only decreased in F300 and D450 treatments. This can on the one hand be explained by the fact that the C:N ratio is very slow in these fertilizers and on the other hand by the immobilization process that was increased intensely in these amendments. The control treatment showed a constant evolution since the beginning up to 60 days. This indicates that the mineralisation and the immobilization processes were approximately equal during that period. It reaches its optimum level between 60 and 90 days and this is explained by the high content of mineral nitrogen in the soil during this interval of time. The mineral nitrogen results showed a positive change between 60 and 90 days for all the treatments due to the rapid mineralization of water hyacinth manures.

The available phosphorus decreased slightly with all the treatments between 0 and 30 days. The decrease observed was due to the soil pH variations, because according to Davet (1996) the mineralization can be intense at pH close to the neutral level. The potassium increase appeared only at the beginning of the soil incubation until 30 days for the control treatment. This increase corresponded to the period of the intense microbial activity during which the mineralization process of the available phosphorus is most dominant in the aforesaid treatment. However, the remarkable decrease observed between 0 and 30 days for other treatments could be explained by the immobilization process during the intense stage of the microbial activity. From 30 days the potassium release is almost stable until 60 days with F300 and D150 treatments compared to the control and very high with F450 until the end of the incubation period. This is related to the high organic matter and calcium concentrations in this amendment.

Maize growth and yield response

The maize plants became higher with high amounts of fresh fertilizers than with dried manures and in the control. This is explained by the initial conditions of the experimental site, the organic matter and the CEC induced in the soil by the fertilizer, and also by the mineralization of nitrogen and phosphorus which improved soil properties (structure and basic cations). This observation is in agreement with the finding of Singh and Jones (1976) who observed that the application of organic fertilizers continually improves soil properties and stimulates the nitrogen release and the availability of phosphorus to plants. This increase is thought to result from the gradual release of soil nutrients (N, P, K and Ca) during the organic matter decomposition and the interaction of other non-controlled elements (trace elements) in the soil. Gunnarsson and Mattsson (1997) working with water hyacinth mulch found that the maize plants were higher in plots treated with water hyacinth than in those which had not been fertilized. My results showed that maize plants amended with fresh biomass gave a higher dry matter yield than those receiving dried manures and the control. The former treatments have therefore a very high fertilizing potential. Similar results found by Jama *et al.* (2000) showed that the maize yields with *Sesbania sesban* biomass were higher than those with natural fallows on two different sites. Mukandinda (2006) also reported that the maize dry matter yields improved more with water hyacinths than with *Hagenia abyssinica* fertilizers. This increase was also noticed by Widjajanto *et al.* (2001) who mention that the dry matter yield of rice crop was enhanced after applying water hyacinth residues. Similar studies reported by Sivaprakasam and Ramaraj (1991) indicate that the water hyacinth mulch improve the yield for mushroom more than the paddy straw. There is, however, a depressive effect of dried water hyacinth on the maize dry matter yield which may be due to the poor release of nitrogen and phosphorus from organic matter decomposition that would be related on the one hand to the low fertilizing potential of those treatments and on the other hand by the likelihood of unfavourable interaction with other nutrients or by the release of organic acids produced during nitrification process which resulted in low biomass of maize plants during the growth period.

In developing countries like Rwanda where the shortage and the cost of chemical fertilizers are too high for smallholders, it is possible to use fresh water hyacinth manures in large amounts in the farmers' fields since the weed is freely available in lakes, rivers and wetlands. The more fresh manures are used by small-scale resource poor farmers the higher are the benefits they can get in terms of crop yields and incomes accordingly. This can contribute to alleviate poverty and help them to improve their livelihoods and even to mitigate the negative impacts of the water hyacinth on aquatic ecosystems and some socio-economic activities such as fishing, water quality, human health and eco-tourism. My results showed clearly that fresh water hyacinth manure applied to the rate of 450 kg of nitrogen per hectare (either 27 tons per hectare of fresh water hyacinth) is the most appropriate fertilization level in terms of increasing soil fertility, maize growth and yield. This type of fertilizer can be used at the same rate as a raw material for organic matter production and should be recommended for field experiments at the farmers' level. But when using water hyacinth for agricultural purposes the transport and the labour costs should also be taken into account due to the high water content of fresh manures. Therefore to reduce the work load, treatment of fresh water hyacinths in the form of green compost done near the harvesting place is an interesting possibility as the by-product then easier can be transported to the field. On the other hand, one of the limitations of the glasshouse experiment is that the results cannot be directly transferred to field trials. Therefore, the results from the glasshouse experiments need to be verified under field conditions for better recommendation for the farmers.

Heavy metal analysis

Results indicate that the lead is much more concentrated in water hyacinth shoots than the other heavy elements (Table 14). This observation is similar to that of Soltan and Rashed (2003) who treated the water hyacinth with different levels of heavy metals (zinc, cobalt, nickel, cadmium...) and found higher metal concentrations in the roots than in the leaves. Denny (1987) also reported that the main route of toxic substance removal mechanisms by floating plants like water hyacinth was through the roots rather than with the aerial parts.

The accumulation of heavy metals in maize roots at the end of the experiment is dependent on the type and the application rates of the water hyacinth manures. The zinc and lead contents are found to be higher in maize roots treated with both fresh and dried manures (F450 and D450) with the highest incorporation rates than with the other treatments and the control. The copper is observed in a broad range in all the treatments used whereas the cadmium is almost absent. However, the heavy metals accumulated in both water hyacinth shoots and maize roots are below the recommended maximum limits and are therefore considered to be acceptable for agricultural soils (Alloway 1990; Nabulo *et al.* 2006).

Conclusion

Results from this study allow the researcher to conclude as follows:

(i) The organic amendments (fresh and dried water hyacinths) used do not have the same fertilizing potential;

(ii) Fresh water hyacinth manures (F450 and F300 treatments) improve much more the soil properties and maize yields than the dry manures;

(iii) Use of fresh fertilizers can solve the problem of acid soils. Indeed, treatments including these manures considerably reduced the soil total acidity. The exchangeable aluminium levels fell below the recommended threshold of toxicity. The pH increased substantially,

(iv) Large quantities of nitrogen, phosphorus and potassium are obtained with fresh water hyacinth fertilizers. This is also true for the exchangeable bases (Ca^{+2}, Mg^{+2} and K^{+}), the cation exchange capacity and the organic matter;

(v) The mineralization of organic fertilizers tested shows almost the same trends in the various treatments but at different levels. They are more pronounced with fresh water hyacinth than with dried fertilizers and the control treatment;

(vi) Height and diameter of maize plants increase very much with high rates of fresh treatments;

(vii) Fresh water hyacinths improve the maize dry matter yield;

(viii) Water hyacinths can be used as a valuable input for agricultural production while at the same time the harvesting contributes to its control.

On the basis of the above results this study confirms the hypotheses initially formulated, related to the effect of fresh and or dried water hyacinth fertilizers on soil fertility, maize growth and yield. The following recommendations are proposed:

(i) In order to get concrete results that are reliable it is suggested that the experiment be carried out for more than one season in different locations of Rwanda;

(ii) It is suggested that in future experiments a combination of nutrient treatments be used to assess their influence on other food crops. For instance, water hyacinth manure versus animal manure or mineral fertilizers, and other combinations;

(iii) In future experiments more than one variety of maize should be included so that the yields can be compared;

(iv) Incorporation of fresh water hyacinth manure at different rates in more acid soils should be studied in order to determine the optimal dose per hectare and type of soils.

(v) The glasshouse experiment should be repeated in open field trials for better understanding of the role of water hyacinth as green manure in relation to crop production.

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References

Ali, N., Chaudhary, B.L. and Khandelwal, S.K. 2004. Better use of water hyacinth for fuel,manure and pollution free environment. *Indian Journal for Environtal Protection* 24: 297-303.

Alloway, B.J. 1990. *Heavy Metals in Soils.* 2sd edition, Blackie Academic and Professional, Glasgow, 339 pp.

Babu, R. M., Sajeena, A. and Seetharaman, K. 2003. Bioassay of the potentiality of *Alternaria alternate* as a bioherbicide to control water hyacinth and other aquatic weeds. *Crop Protection* 22: 1005-1013.

Baize, D. 2000. *Guide des analyses en pédologie. Choix-expréssion, Présentation- interprétation.* (*Pedology analysis Guide. Choice- expression, presentation-interpretation*). 2ème édition, INERA, Paris, 257 pp.

Barrett, S.C.H and Fono, I.W. 1982. Style morph distribution in new world populations of *Eichhornia crassipes* (Mart.) Solms-Laubach (water hyacinth). *Aquatic Botany* 13: 299-306.

Bell, L.C. and Bessho, T. 1993. An assessment of aluminum detoxification by organic materials in an Ultisol, using soil solution characterization and plant response. In *Soil organic matter dyanamics and sustainability of tropical agriculture.*Wiley Sayce co-publication, IITA/KU, Leuven, 33-35.

Biziyaremye, J. 2006. *Etude de l'impact socio- économique de la jacinthe d'eau (Eichhornia crassipes) dans la vallée de la Mukungwa, Cas des Districts de Bugarura, Mutobo et la Ville de Ruhengeri.* (Socio- economic impact study of water hyacinth (*Eichhornia crassipes*) in Mukungwa valley, a case of Bugarura and Mutobo districts and Ruhengeri city). Mémoire de Licence en Biologie, Université Nationale du Rwanda, Butare, 31 pp.

Bonneau, M. and Souchier, B. 1994. *Pédologie 2: Constituants et propriétés du sol.* (*Pedology 2: Soil properties and constituents*). 2sd ed. Masson, Paris, ORSTOM, 10: 384 pp.

Bremner, J.M. and Mulvaney, C.S. 1982. Total nitrogen. In *Methods of Soil Analysis*, Agronomy Monography 9, ASA, Madison, 595-624.

Bucyaca, B. 2002. *Effet de la fumure organo-minérale et de la densité de peuplement sur 3 variétés de maïs nouvellement introduites au Rwanda.* (*Effect of organo-mineral fertilizer and density of 3 recently introduced varieties of maize in Rwanda*). Mémoire, Université Nationale du Rwanda, Butare, 73 pp.

Center, T.D., Dray, F.A., Jubinsky, G.P. and Grodowitz, M.J. 1999. Biological control of water hyacinth under conditions of maintenance management: can herbicides and insects be integrated? *Environmental Management* 23: 241-256.

Center, T.D., Hill, M.P., Cordo, H. and Julien, M.H. 2002. Water hyacinth. In Van Driesche, R. (ed.), *Biological Control of Invasive Plants in the Eastern United States.* USDA Forest Service Publication FHTET, 41-64.

Davet, P. 1996. *Vie microbienne du sol et production vegetale.* INERA, Paris, 383 pp.

Delepierre, G. 1982. Les régions agro-climatiques en relation avec l'intensité de l'érosion du sol. (Agro-climatic zones in relation to soil erosion intensity). *Bulletin agricole du Rwanda* 2: 91- 93.

Denny, P. 1987. Mineral cycling by wetland plants. A review. *Archives of Hydrobiology* 27: 1-25.

Denny, P., Wanda, F.M. and Timothy, T. 2001. The impact of water hyacinth, *Eichhornia crassipes* (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. *Hydrobiologia* 452: 79-88.

Epstein, P. 1998. Weeds bring disease to the east African waterways. *Lancet* 351: 577 pp.

FAO 1987. *Amélioration et production du maïs, du sorgho et du mil.* Production végétale et protection des plantes / FAO 24.

Gachengo, C.N., Palm, C.A., Jama, B. and Othieno, C. 1999. Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in Western Kenya. *Agroforestry Systems* 44: 21-36

Ghabbour, E.A., Davies, D., Lam, Y.Y. and Vozzella, M.E. 2004. Metal binding by humic acids isolated from water hyacinth plants (*Eichhornia crassipes*, Mart. Solm-Laubach: Pontedericeae) in the Nile Delta, Egypt. *Environmental Pollution* 131: 445-451.

Gopal, P. and Sharma, K.P. 1981. *Water hyacinth (Eichhornia crasssipes) the most troublesome weed of the world.*, Hindasia, Delhi, 229 pp.

Goswami, T. and Saikia, C.N. 1994. Water hyacinth. A potential source of raw material for greaseproof paper, *Bioresource Technology* 50: 235-238.

Guitiérrez, E.L., Ruiz, E.F., Uribe, E.G. and Martínez, J.M. 2000. Biomass and productivity of water hyacinth and their application in control programs. In Hill, M.P. (ed.), *Proceedings of the second IOBC global working group on the biological and integrated control of water hyacinth,* ACIAR, Beijing, 102: 109-119.

Gunnarsson, C. and Mattsson, C. 1997. *Water hyacinth trying to turn an environmental problem into an agricultural resource*, Swedish University of Agricultural Sciences, Uppsala, MSc Thesis, 25 pp.

Gupta, G.C. 1982. Use of water hyacinth in wastewater treatment. *Journal of Environmental Health* 43: 80-82.

Gupta, M., Sarmah, R. and Gupta, S. 2004. Nutrient composition of Pleurotus sajor-caju grown on different substrates. *Journal of Food Science and Technology* 41: 584-586.

Hakizimana, P. 1998. *Etude des éléments minéraux limitants du sol le long d'une toposéquence et sous culture du mais. Cas de la colline de Tonga.* Mémoire d'Ingénieur en Agronomie, Université Nationale du Rwanda, Butare, 78 pp.

Harerimana, B. 1990. *Essai comparatif d'application de la chaux éteinte et du travertin dans les sols acides de haute altitude de Gikongoro.* Mémoire, Univresité Nationale du Rwanda, Butare, 189 p.

Harley, K.L.S., Julien, M.H. and Wright, A.D. 1996. *Water hyacinth: a tropical worldwide problem and methods for its control.* Proceedings of the 2nd international weed control congress, Copenhagen, 2: 639-644.

Heard, T.A. and Winterton, S.L. 2000. Interactions between nutrient status and weevil herbivore in the biological control of water hyacinth. *Journal of Applied Ecology* 37: 117-127.

Howard, G.W. and Harley, K.L.S. 1998. How do floating aquatic weeds affect wetland conservation and development? How can these effects be minimized? *Wetlands Ecology and Management* 5: 215-225.

Hue, N.V. 1992. Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. *Communications in Soil and Plant Analysis* 23: 241-264.

ISAR, Rwanda Agricultural Research Institute, 2002. *Water hyacinth weevil productivity assessment and survey about weevil establishment.* Plant Protection Program, Field trip report, 6-8.

Iyamuremye, F., Dick, R.P. and Baham, J. 1996. Organic amendments and phosphorus dynamics: Phosphorus chemistry and sorption. *Soil Science* 161: 426-435.

Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G. and Amadolo, B. 2000. *Tithonia diversifolia* as a green manure for soil fertility improvement in Western Kenya: A review. *Agroforestry Systems* 49: 201-221.

Julien, M. 2001. Biological control of water hyacinth with arthropods: a review to 2000. In Julien, M., Hill, M., Center, T. and Ding, J. (eds.), *Proceedings of the Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth,* Beijing, China, 9-12 December 2000. Australian Centre for International Agricultural Research, Canberra, 8-20.

Julien, M.H. and Griffiths, M.W. 1998. *Biological control of weeds. A world catalogue of agents and their target weeds,* 4th edition.CABI Publishing, Wallingford, 223 pp.

Kanamugire, A. 1993. *Effet du phosphore et de deux types d'aménagement anti- érosif sur le rendement de la pomme de terre au site expérimental de Tonga.* Mémoire, Université Nationale du Rwanda, Butare, 142 pp.

Kathiresan, R.M. 2000. Allelopathic potential of native plants against water hyacinth. *Crop Protection* 19:705-708.

Kivaisi, A.K. and Mtila, M. 1995. Chemical composition and in vitro degradability of whole plants and shoots of the water hyacinth (*Eicchornia crassipes*) by rumen micro-organisms. *Tanzania Veterinary Journal* 15: 121-129.

Kumar, S. 2005. Studies on efficiencies of bio-gas production in anaerobic digesters using water hyacinth and night-soil alone as well as in combination. *Asian Journal of Chemistry* 17: 934-938.

Leclerc, B. 1995. *Guide des matières organiques : Fertilité des sols-Ressources-Gestions-Fiches techniques.* 1st edition, ITAB, Paris, 245 pp.

Lindsey, K. and Hirt H.M. 1999. *Use water hyacinth! A Practical Hanbook of uses for the water hyacinth from Across the World.* Winnenden, 114 pp.

Mailu, A.M. 2001. Preliminary assessment of the social, economic and environmental impacts of water hyacinth in the Lake Victoria basin and the status of control, biological and integrated control of water hyacinth, *Eichhornia crassipes.* In Julien, M.H., Hill, M.P. Center, T.D. and Ding, J. (eds.) *Biological and integrated control of water hyacinth, Eichhornia crassipes*, ACIAR Proceedings, 102: 133-136.

Mando, E., Ouedraogo, E. and Zombre, N.P. 2000. Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agriculture, Ecosystems and Environment* 84 : 259-266.

Masengesho, A. 2007. *L'impact environnemental et socio- économique d'Eichhornia crassipes (jacinthe d'eau) sur les zones humides du Rwanda.* (*Environmental and socio- economic impact of Eichhornia crassipes (water hyacinth) on humid zones of Rwanda*). Mémoire de Licence en Géographie, Université Nationale du Rwanda, Butare, 10-14.

Mbati, G. and Neuenschwander, P. 2005. Biological control of three floating water weeds, *Eichhornia crassipes*, *Pistia stratiotes*, and *Salvinia molesta* in the Republic of Congo. *Biocontrol* 50: 635-645.

Mbonigaba, J.J. 2002. *Essai de compostage de déchets verts et évaluation des effets des composts obtenus sur des sols acides du Rwanda. (Composting test of green wastes and effects assessment of obtained composts on acid soils in Rwanda).* Thèse de maîtrise, Faculté Universitaire des Sciences Agronomiques de Gembloux, Belgique, 77 pp.

Methy, M., Alpert, P. and Roy, J. 1990. Effects of light quality and quantity on growth of the clonal plant *Eichhornia crassipes*. *Oecologia* 84 : 265-271.

MINAGRI, Ministry of Agriculture and Animal Resources, Republic of Rwanda 2006. *Altitudinal regions in Rwanda (derived from soil map at scale 1: 250,000).* http://www.minagri.gov.rw/map.php3?id_document=538id_article=60 [Cited 20 February 2009].

MININFRA, Ministry of Infrastructure, Republic of Rwanda 1996. *Rapport d'évaluation de la Jacinthe d'eau. Division hydrologie et gestion des ressources en eau. (Assessment report on water hyacinth. Hydrology department and water resources management).* Kigali, Rwanda, 10 pp.

MINITERE, Ministry of Lands Resettlement and Environment 2003. *National Strategy and Action Plan for the conservation of biodiversity in Rwanda,* Rwanda, 14 pp.

Mironga, J.M. 2004. Geographic information systems (GIS) and remote sensing in the management of shallow tropical lakes. *Applied Ecology and Environmental Research* 2: 83-103.

Mitra, T., Biswas, P., Mandal,L. and Banerjee, G.C. 1997. Effect of feeding water hyacinth (*Eichhornia crassipes*) in different forms on the palatability in buffalo calves. *Indian Veterinary Journal* 74: 935-937.

Mnkeni, P.N.S. and MacKenzie, A.F. 1985. Ortho and polyphosphates in some Quebec soils as affected by added organic residues and calcium carbonate. *Canadian Journal of Soil Science* 68: 243-250.

Moberg, J.R. 2000. *Soil and Plant Analysis Manual.* The Royal Veterinary and Agriculture University, Chemistry Department, Copenghagen, Denmark, 133 pp.

Moorhead, K.K. and Nordstedt, R.A. 1993. Batch anaerobic digestion of water hyacinth: effects of particle size, plant nitrogen content and inoculum volume. *Bioresource Technology* 44: 71-76.

Moorhouse, T.M., Agaba, P. and McNabb, T.J. 2001. Recent efforts in biological control of water hyacinth in the Kagera River headwaters of Rwanda. In Julien, M.H., Hill, M.P., Center, T.D. and Jianqing, D. (eds.), *Biological and Integrated Control of water hyacinth, Eichhornia crassipes.* Proc. Of the second meeting for the Global Working Group for the Biological and Integrated Control of water hyacinth, Beijing, China, 2000, 39-42.

Muhawenimana, A. 1987. *Caractérisation physico-chimique et minéralogique de quatre profils andosoliques du Nord-Ouest du Rwanda. Propriétés d'absorption du phosphore et du fluor,* Thèse de Doctorat, Université Local de Canada, 170 pp.

Mukandinda, A. 2006. *Evaluation de l'effet des biomasses de Hagenia abyssinica et Eichhornia crasssipes sur les propriétés physico-chimiques et la productivité du maïs dans un sol acide,* Mémoire, Université Nationale du Rwanda, Butare, 54 pp.

Munyarushoka, E., 1983. *Etude de la fertilité de quelques sols des communes Nyabisindu, Ntongwe et Ntyazo par les méthodes de laboratoires et de vases de végétation.* Mémoire, Université Nationale du Rwanda, Butare, 83 pp.

Murray, H.M. 1997. *Introduction to Soils and Soil Science. Laboratory exercises.* Fourth edition, Kendal-Hunt Publishing Company, Texas A and M University, USA, 92-97.

Mutwewingabo, B., Rutunga,V. and Ndereyehe, C. 1989. Genèse, caractéristiques et aménagements des sols acides non volcaniques de la région de haute altitude du Rwanda. (Genesis, characteristics and management of non volcanic and acidic soils of Gikongoro and high altitude region of Rwanda.) In *Séminaire régional sur la problématique de fertilisation et du revenu du paysan sur les sols acides de Gikongoro et de hautes altitudes du Rwanda, (Regional seminar on fertilization problem and peasant revenue on acid soils of Gikongoro and highlands of Rwanda*), Rwanda.

Nabahungu, N.L. 2003. *Effects of limestone, Minjingu phosphate rock and green manure application on improvement of acid soils in Tonga, Butare, Rwanda.* Master's Thesis, Sokoine University of Agriculture Morogoro, Tanzania, 28 pp.

Nabulo, G., Hannington, O.O. and Miriam, D. 2006. Assessment of lead, cadmium and zinc contamination of roadside soils, surface films and vegetables in Kampala City, Uganda, *Environmental Research* 101: 42-52.

Ndabalishye, I. 1985. Production du fumier et possibilité d'amélioration. In *Premier séminaire sur la fertilisation des sols au Rwanda,* 258-259.

Nguyen, N. X. D. 1996. *Identification and evaluation of non cultivated plants used for livestock feed in the Mekong delta of Vietnam.* MSc Thesis. Paper 1 and 2, 2-11 and 2-8 pp.

Ntaneza, D. 1988. *Examen de la fertilité des sols des périmètres semenciers de Bumbogo et Rubungo au Rwanda. (Soil fertility consideration on seed sites of Bumbogo and Rubungo in Rwanda).* Thèse (MSc), Faculté des sciences de l'agriculture et de l'alimentation, Université Laval, Canada, 194 pp.

Nyle, C. and Brady, R. 2003. *Nature and properties of soil.* 13th edition, New York, 960 pp.

Ogutu, O. R., Hecky, R.E., Cohen, A.S. and Kaufman, L. 1997. Human impacts on the African Great Lakes. *Environmental Biology of Fishes* 50: 117-131

Ogwang, J.A. and Molo, R. 1997. Biological control of water hyacinth in Uganda. *Proc. 16th Biennal Weed Science, Soc. Conf. For E. Africa*, 287-293.

Olaleye, V.F. and Akinyemiju, O.A. 1996. Effect of a glyphosate (N-(Phosphonomethyl) glycine) application to control *Eichhornia crassipes* Mart. on fish composition and abundance in Abiala Creek, Niger Delta, Nigeria*, Journal of Environmental Management* 47: 115-122.

Oudhia, P. 1999. Studies on allelopathy and medicinal weeds in chickpea fields. *International Chickpea and Pigeon pea Newsletter* 6: 29-33.

Palm, C.A., Myers, R.J.K. and Nandwa, S. 1997. Combined use of organic and inorganic nutrients sources for soil fertility maintenance and replenishment. In Buresh, R.J. and Sanchez, P.A. (eds), *Replenishing soil fertility in Africa.* Soil Science Society of America. American Society of Agronomy and Soil Science Society of America, Madison, WI, USA, 51: 193-218.

Pieltain, F. and Mathieu, C. 2003. *Analyse chimique des sols. Méthodes choisies.* Lavoisier, Paris, 379 pp.

Plummer, M.L. 2005. Impact of invasive water hyacinth (*Eichhornia crassipes*) on snail hosts of schistosomiasis in Lake Victoria, East Africa. *Ecological Health* 2: 81-86.

Poddar, K., Mandal, L. and Banerjee, G.C. 1991. Studies on water hyacinth (*Eichhornia crassipes*). Chemical composition of the plant and water from different habitats. *Indian veterinary Journal* 68: 833-837.

Ram, S. and Moolani, M.K.. 2000. Herbicidal weed control of water hyacinth under semi-arid conditions. *Pestology* 24: 69-71.

Ristanovic, D. 2001. Le maïs-Zea mays, L. In *Agriculture en Afrique tropicale*, DECI, Bruxelles, 70 pp.

Rouanet,G. 1984. *Le maïs*. (M*aize plant*). Edition Maisonneuve et Larose, Paris, 142 pp.

Ryan, J., George, E. and Abdul, R. 2001. *Soil and Plant Analysis Laboratory Manual. Second Edition. International Center for Agricultural* Research in the Dry Areas *(ICARDA).* http://www.icarda.org/Publications/Lab_Manual/PDF/part4.pdf [Accessed 6 March 2009].

Sahu, A.K., Sahoo, S.K. and Giri, S.S. 2002. Efficacy of water hyacinth compost in nursery ponds for larval rearing of Indian major carp, *Labeo rohita. Bioresource Technology* 85: 309-311.

Sanchez, A.P. 1976. *Properties and management of soil in the tropics*. New York, 618 p.

Sannigrahi, A.K., Chakrabortty, S. and Borah, B.C. 2002. Large scale utilization of water hyacinth (*Eichhornia crassipes*) as raw material for vermi composting and surface mulching in vegetable cultivation. *Ecology Environment Conservation* 8: 269-271.

Shabana, Y.M. and Mohamed, Z.A. 2005. Integrated control of water hyacinth with a mycoherbicide and a phenylpropanoid pathway inhibitor. *Biocontrol Science Technology* 15: 659-669.

Sharma, A., Gupta, M.K. and Singhal, P.K. 1996. Toxic effects of leachate of water hyacinth decay on growth of Scenedesmus obliquus (Chlorophyta). *Water Resources* 30: 281-286.

Singhal,V. and Rai, J.P. 2003. Biogas production from water hyacinth and channel grass used for phytoremediation of industrial effluents. *Bioresource Technology* 86: 221-225.

Singh, B.B. and Jones, J.P. 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. *Soil Science Society of America, Journal* 40: 389-394.

Singh, S. 1998. *Crop management*. New Delhi, India, 49 pp.

Sivaprakasam, K. and Ramaraj, B. 1991. Studies on some factors influencing the yield of oyster mushroom. In Nair, M. C. (ed.), *Indian Mushrooms*, Proc. Nat. Symp. Mushroom. Kerala Agricultural University, Trivandrum, 127-132

Smith, L.W., Williams, R.E., Shaw, M. and Green, K.R. 1984. A water hyacinth eradication campaign in New South Wales, Australia. In Thyagarajan, G. (ed.), *Proc. int. conf. water hyacinth*. UNEP, Nairobi, 925-935.

So, L.M., Chu, L.M., Wong, P.K. 2003. Microbial enhancement of Cu^{2+} removal capacity of *Eichhornia crassipes* (Mart.). *Chemosphere* 52: 1499-1503.

Soltan, M.E and Rached, M.N. 2003. Laboratory study on the survival of water hyacinth under several conditions of heavy metal concentrations. *Environmental* Resources 7: 321-334.

Soltner, D. 1983. *Les grandes productions végétales*. 13ème édition, Collection sciences et techniques, Paris, 431 pp.

Soltner, D. 1985. *Phytotechnie générale, les bases de la production végétale. Le sol.* 13th édition, Angels, France, 338 pp.

Sun, W.H., Yu, S.W., Yang, S.Y., Zhao, P.W., Yu, Z.W. and Wu, H.M. 1993. Allelochemicals from root exudates of water hyacinth. *Acta Phytophysiologia Sinica* 19: 92-96.

Tisdale, S.L., Nelson, W.L. and Beaton, J.D. and Havlin, J.L. 1993. *Soil Fertility and Fertilizers.* 5th edition. Maxwell Macmillian Inter. New York, 634 pp.

Vander Zaag, P. 1981. *La fertilité des sols du Rwanda.* (*Soil fertility in Rwanda*). Note technique nº 9, ISAR-Rubona, Rwanda, 41 pp.

Vander Zaag, P. 1982. La fertilité des sols du Rwanda. In *Bulletin agricole du Rwanda*, (Soil fertility in Rwanda). In *Rwanda agriculture bulletin*, 15ème année, MINAGRI, Kigali, 3-24.

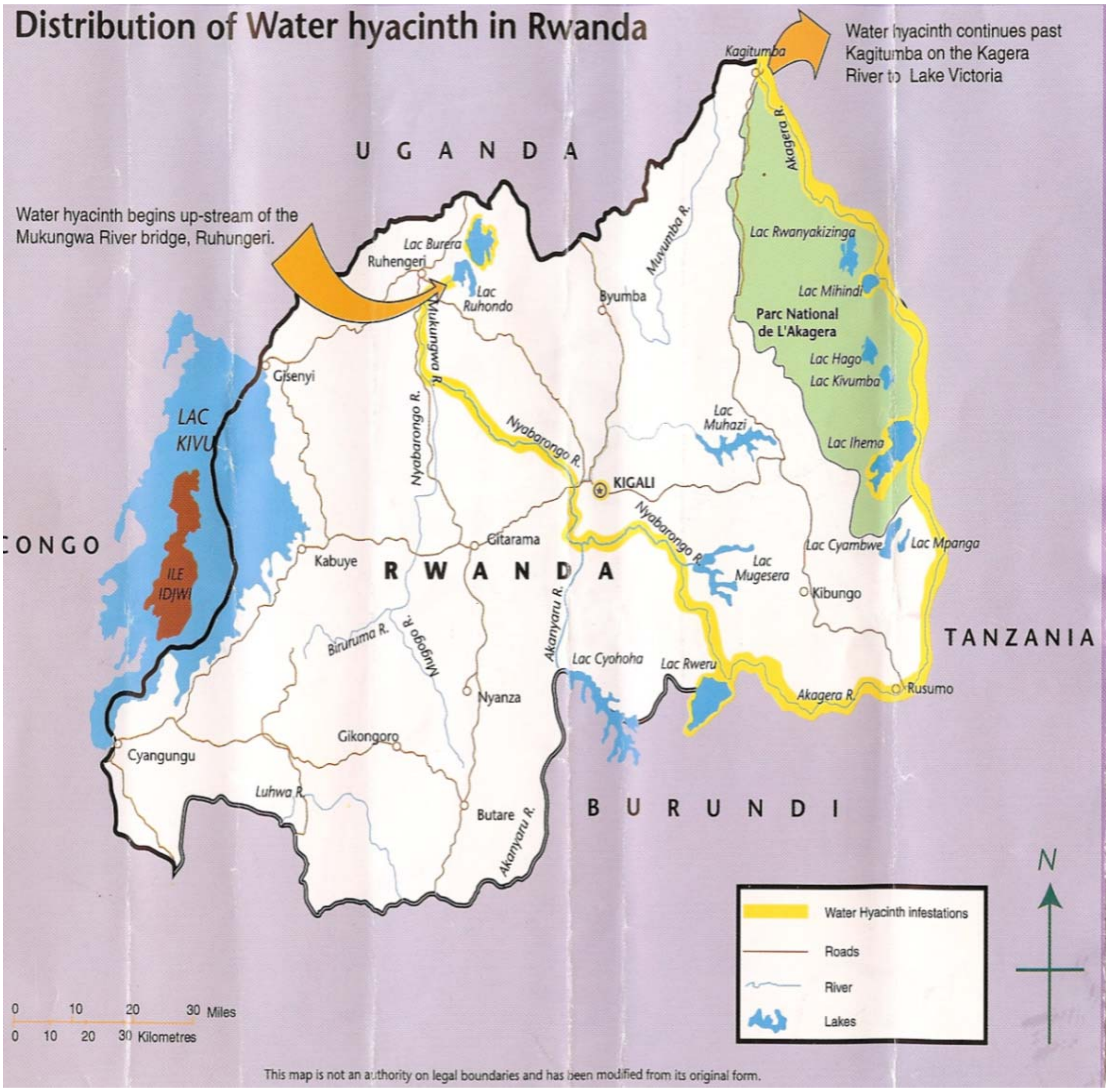
Vander Zaag, P., Yost, R.S., Trangmar, B.B., Hayashi, K. and Fox, R.L. 1984. An assessment of chemical properties for soils of Rwanda with the use of geostatistical techniques. *Geoderma* 34: 293-314.

Widjajanto, D.W., Honmura, T., Matsushita, K. and Miyauchi, N. 2001. Studies on the release of nitrogen from water hyacinth incorporated into soil-crop systems using N-Labelling techniques. *Pakistan Journal of Biological Science* 4: 175-177.

Wilson, J.R., Holst, N., Rees, M. 2005. Determinants and patterns of population growth in water hyacinth. *Aquatic Botany* 81: 51-67.

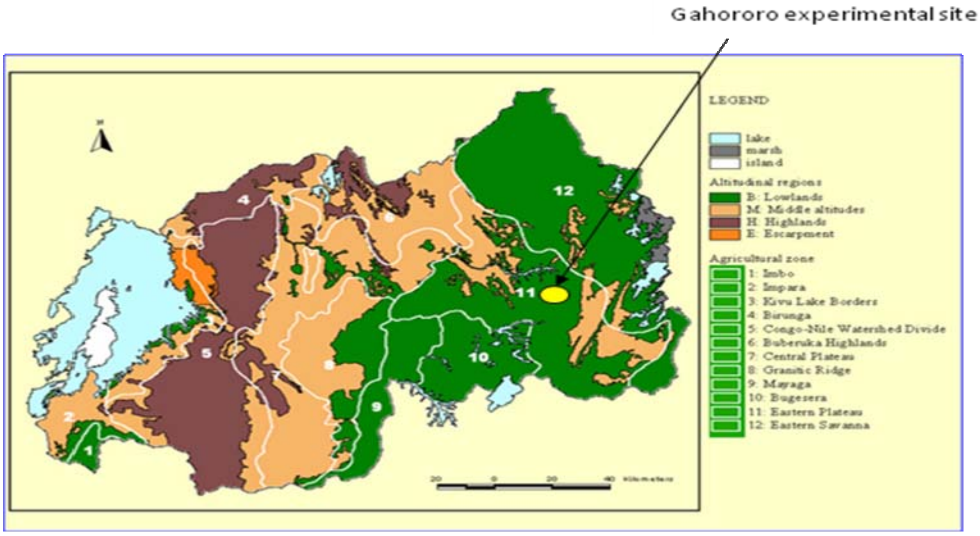
Woomer, P.L., Muzira, R., Bwamiki, D., Mutetikka, D., Amoding, A. and Bekunda, M.A. 2000. Biological management of water hyacinth waste in Uganda. *Biology Agriculture Horticulture* 17: 181-196.

Appendix 1 Distribution map of water hyacinth in Rwanda



Source: Moorhouse, T.M., Agaba, P. and McNabb, T.J. 2001. *Recent efforts in biological control of water hyacinth in the Kagera River headwaters of Rwanda.* http://www.cleanlake.com/images/Rwanda_bio_paper.pdf [adapted from Moorhouse *et al.* 2001 and accessed 20 January 2009].

Appendix 2 Altitudinal regions in Rwanda



Source: MINAGRI, Ministry of Agriculture and Animal Resources, Republic of Rwanda 2006. *Altitudinal regions in Rwanda (derived from soil map at scale 1: 250,000).* http://www.minagri.gov.rw/ map.php3?id_document=538id_article=60 [Cited 20 February 2009].

Appendix 3 Calculations of water hyacinth treatments applied in pot experiments

T1 = 150 kg of nitrogen per hectare of dried water hyacinth
Nitrogen level (N) of fresh water hyacinth = 1.67 percent
100 kg dry matter of water hyacinth biomass → 1.67 kg of N
Bulk density = 1.25 g/cm^3
Soil weight = 500 g/pot
Plant rooting depth = 0.2 m
T1= 150 kg N/ha → (100 * 150 kg/ha)/1.67 = 8 982.04 kg/ha of dry matter (DM)
8 982.03 kg/ha → 10 000 m^2 * 0.2 m * 1.25 g/cm^3= 2 000 m^3 * 1.25 * 10^6 = 25 * 10^8 g of soil
25 * 10^8 g of soil → 8982.03 kg DM of water hyacinth
500 g of soil → (8 982.03 kg * 500 g)/ (25 * 10^8 g) = 1.79 g DM of water hyacinth
T1 = 1.79 g of dried water hyacinth
The nitrogen amount added was determined as follows: 1.79 *(1.67/100) = 29.89 mg/pot
Water hyacinth dry matter = 8.8 %, this means that 8.8g dry matter of water hyacinth→ 100 g of fresh water hyacinth biomass
T2 = 300 kg N/ha = (100 * 300 kg/ha)/1.67= 17 964.07 kg/ha
17 964.07 kg/ha → 10 000 m^2 * 0.2 m * 1.25 g/cm^3 = 2.5* 10^9 g of soil
500 g of soil → (500 g * 17 964.07 kg)/2.5* 10^9 g
T2 = 3.59 g of dried water hyacinth
T3 = (1.79 g * 100) /8.8 = 20.34 g of fresh water hyacinth
T4 = (3.59 g * 100)/8.8 = 31.59 g of fresh water hyacinth
T5 = 450 kg/ha = (100* 450 kg/ha)/1.67 = 26 946.11 kg/ha
26 946.11 kg/ha → 10 000 m^2 * 0.2 m * 1.25 g/cm^3 = 2.5* 10^9 g of soil
500 g of soil → (500 g * 26 946.11 kg)/2.5 * 10^9 g
T5= 5.39 g of dried water hyacinth
T6 = (5.39 * 100)/8.8 = 61.25 g of fresh water hyacinth
T0 = no inputs used (Control treatment)

Appendix 4 Soil physico-chemical characteristics before and after water hyacinth application

		pH (H_2O)	pH (KCl)	Al^3	H^+	$Al^{3+}+H^+$	OC	OM	N	C:N	P	Ca^{2+}	Mg^{2+}	Ca^{2+}/Mg^{2+}	K^+	CEC
	Treatment				cmol(+)kg^{-1} of soil			%			ppm			cmol(+)kg^{-1} of soil		meq/100g
Before manure application		5.6	4.5	0.04	1.36	1.40	2.00	3.45	0.13	15.38	13.03	8.30	2.15	3.86	0.60	8.87
After manure application	D150	5.7	4.7	0.04	0.25	0.29	2.24	3.86	0.15	14.93	8.51	13.43	2.07	6.49	0.70	16.94
	D300	5.9	4.8	0.03	0.13	0.16	2.53	4.36	0.20	12.65	20.12	13.80	2.17	6.36	0.70	17.76
	F150	6.1	5.2	0.02	0.08	0.10	2.53	4.36	0.20	12.65	20.12	14.20	3.98	3.57	1.20	18.74
	F300	6.0	5.4	0.02	0.05	0.07	2.54	4.38	0.31	8.19	23.66	14.20	2.47	5.75	1.20	18.67
	D450	5.9	5.0	0.02	0.10	0.10	2.44	4.21	0.23	10.61	20.19	14.07	3.53	3.98	0.80	18.15
	F450	6.3	5.6	0.01	0.03	0.04	2.56	4.41	0.35	7.31	25.93	14.93	2.57	5.81	1.40	18.41
	C0	5.6	4.7	0.04	0.25	0.29	2.40	4.14	0.27	8.89	12.82	13.27	1.50	8.85	0.40	18.25
F-Value		10.66	6.08	14.44	13.81	13.78	4.19	8.14	12.18	24.84	15.64	13.83	9.20	22.02	8.17	2.98
P-Value		0.000^{**}	0.003^{**}	0.000^{**}	0.000^{**}	0.000^{**}	0.041^{ns}	0.039^{ns}	0.004^{**}	0.002^{**}	0.000^{**}	0.000^{**}	0.000^{**}	0.000^{**}	0.001^{**}	0.394^{ns}