



USE OF WATER HYACINTH (*Eichornia crassipes*) IN AMELIORATION OF A SANDY SOIL

[16]

Mubarak*¹, A.R.; Fattoma. A.M. Rezik¹ and S.A. Afiah²

1- Department of Soil and Environment Sciences, Faculty of Agriculture, University of Khartoum, Shambat P.O. Box 32, Sudan

*Present Address: Desertification and Desert Cultivation Studies Institute, University of Khartoum, Shambat, Sudan. (e mail: mubarakaba@yahoo.com)

2- Desert Research Centre, El-Mataria, Cairo, P.O. Box 11753, Egypt

Keywords: Arid soils; Decomposition; Sudan; Water hyacinth

ABSTRACT

Soil fertility management is a key issue for sustaining agricultural production in dry lands. Organic resources are important for nutrient availability and maintenance of soil organic matter. Sustaining fertility of arid soils necessitates increasing inputs of organic residues. Two experiments with water hyacinth were carried out to monitor (in the first; field study with litter bags) decomposition and changes in N, P, K, Ca and Mg as influenced by method of application where, in the second (greenhouse study) short-term effect on some properties of a sandy soil and early establishment of fodder sorghum (*Sorghum bicolor*). Results of the first experiment showed that residues incorporated in the top 0-30cm soil depth had significantly ($P \leq 0.01$) increased loss of dry matter weight compared to surface application. Decomposition rate constants of surface and sub-surface application were $0.029\% \text{ week}^{-1}$ and $0.041\% \text{ week}^{-1}$, respectively. Potassium was the fastest nutrient released with 50% loss attained after the 2nd and 6th week from incorporation and surface application, respectively. Nitrogen, P, Ca, and Mg releases from water hyacinth incorporated in the sub-soil were significantly ($P \leq$ range from 0.0001 to 0.008) high compared to surface application. Nutrients loss was in the order of $K = \text{Mg} > P > N > \text{Ca}$. However, results of the second experiment showed that incorporation of water hyacinth residues significantly ($P \leq 0.001$) decreased pH (by about 27%) and hydraulic conductivity (by 40-

46%). Also, cation exchange capacity and organic C were significantly increased by about 23 and 100%, respectively. The study concluded that application of water hyacinth could be one of the good alternatives for improving quality of arid soils.

INTRODUCTION

Aquatic plants like water hyacinth have invaded rivers and lakes of many East African countries. **Woomer (1997)** estimated that it accumulated at power plants of approximately 900 Mg dry weight and mechanically removed every 14 to 20 weeks interval. Disposal of water hyacinth during cleaning of rivers may have direct change of attention to its use as a soil amendment. This plant was used on vermicomposting for growth and flowering of the angiosperm crossandra (*Crassandra undulaefolia*) (**Gajalakshmi and Abbasi, 2002**). Similarly, it was used in phytoremediation experiments such as removal of heavy metals from effluents (**Macek et al 2000; Susarla et al 2002; Xia and Ma, 2006**).

In Sudan, water hyacinth is mainly found along the White Nile causing navigation problems, counteracting with pumping water from the Nile and increasing water loss. A local study found that incorporation of water hyacinth improved the leaching capacity of salt-affected soils and it was attributed to better aggregation. (**Ahmed, 1995**). Since this plant contains more than 95% water, drying besides removing areas would benefits small farms with degraded lands (**Bekunda and Woomer, 1996**). Incorporation of any organic residues needs information on nutrient cycling in the specific ecosystem.

(Received December 6 2007)

(Accepted January 21, 2008)

Researches on decomposition and mineralization rates of added organic matter to the soils were concentrated in humid ecosystems with high biotic activities (e.g. **Cochran 1990; Taylor et al 1991; Issac and Nair, 2005**). Studies on extreme dry conditions of arid and semiarid were carried in North America (e.g. **Whiteford et al 1988**) and the Negeve Desert (**Hamadi et al 2000**). Attempts to study decomposition and nutrient release under desert conditions of Africa are greatly lacking. Therefore, the objectives of this study were (1) to determine decomposition and nutrients dynamics of a decomposing water hyacinth under arid conditions and (2) to determine the effect of incorporation of dried water hyacinth on some selected properties of a sandy loam soil.

MATERIALS AND METHODS

Experiment 1: Decomposition and Nutrient Release from Water Hyacinth

This experiment (21 November, 2005 to 21 March, 2006) was carried out in a farm located in the peripheries of the capital (Khartoum, lat-15°73' N, long-32°13'E). According to **Soil Survey Staff (1996)**, the soil (pH 7.3, TN 0.1 g kg⁻¹, O.C. 0.3 g kg⁻¹, CEC cmole (+) kg⁻¹, ECe 1.6 dS m⁻¹, hydraulic conductivity 10.2 cm hr⁻¹, soluble Ca, Mg, Na and K are 3.4, 0.8, 0.9 and 0.12 meq L⁻¹, respectively, Sand 72%, Silt 9.7%, clay 18.3%) of the site was classified as hyperthermic, sandy loam, mixed, gypsic cambis orthid. The climate is semi-arid with total annual rainfall (July – September) of about 155.5mm, average maximum and minimum temperatures are 41.6 and 15 °C, respectively (**Fig. 1**).

Plant Materials

Water hyacinth (*Eichornia crassipes*) was collected from the White Nile in the village of Gezira Aba, White Nile province (about 300 km south Khartoum). The whole plant material (roots, pseudo-stem and leaves) were removed from the White Nile, air-dried on mats beside the Nile, packed and transported to the study site. Immediately after they were received, a sub sample was taken, oven-dried (60-70°C) for 48 hrs, crushed (0.5 mm sieve) and stored dry for characterization. Analysis of C, N, K, P, Ca and Mg were done by the Institute of Plant Nutrition, University of Gießen, Germany. Plant material contained 1.07% TN, 25.8% total C (C/N: 24.1), 0.199% total P,

1.9% K, 1.69% Ca, 0.77% Mg, ash content 39.5%, lignin of 7.5% and pH (1g in 10 ml distilled water) of 6.0.

Field Decomposition

Decomposition (mass loss) of the water hyacinth and nutrient release were monitored between 21/11/2005 and 21/3/2006 using the litter bags method (**Anderson and Ingram, 1993**). Nylon bags of 15 X 20 cm dimensions with mesh size of the 2 mm were used. One side of the bag was left open for faunal activity. Exactly 30.8 g air dried weight from water hyacinth was placed into each bag. A total number of bags were 24 and were buried in the top 30 cm depth (sub-surface) and a similar number (i.e. 24 bags) were placed on the soil surface in the same site with a label inserted inside the bag. Water was sprayed on the field and soil moisture content (gravimetric) during decomposition was determined. Soil temperature of the 0-30 cm depth was measured every two weeks using soil thermometers during the experiment and it was recorded to vary from 22 to 30°C (average of 25) whereas soil moisture content varied from 2 to 7% (average of 4%). At each sampling date 2, 4, 6, 8, 10, 12, 14, and 16 weeks, three bags were retrieved, and the soil attached was carefully removed then after, each bag was placed inside a paper envelope and transferred to the laboratory for analysis. The remaining residues were oven dried at 65-75°C until constant weight. The soil attached to the dried material was carefully brushed out and the weight of the remaining residue was recorded, ground to pass 0.5 mm sieve and analyzed for remaining C, N, K, P, Ca and Mg contents.

Experiment Two: Short-term effect of incorporation of water hyacinth on some properties of a sandy soil and early establishment of fodder sorghum (*Sorghum bicolor*).

The hypothesis of this experiment was based on the results of the first experiment. Accordingly, it was decided to incubate the water hyacinth for 12 weeks before studying the establishment of the crop.

Experimental Layout

This experiment was setup in the glasshouse of the Faculty of Agriculture, University of Khartoum, Sudan. The soil (2 mm sieve) was obtained from the surface (0-30 cm) of the same farm

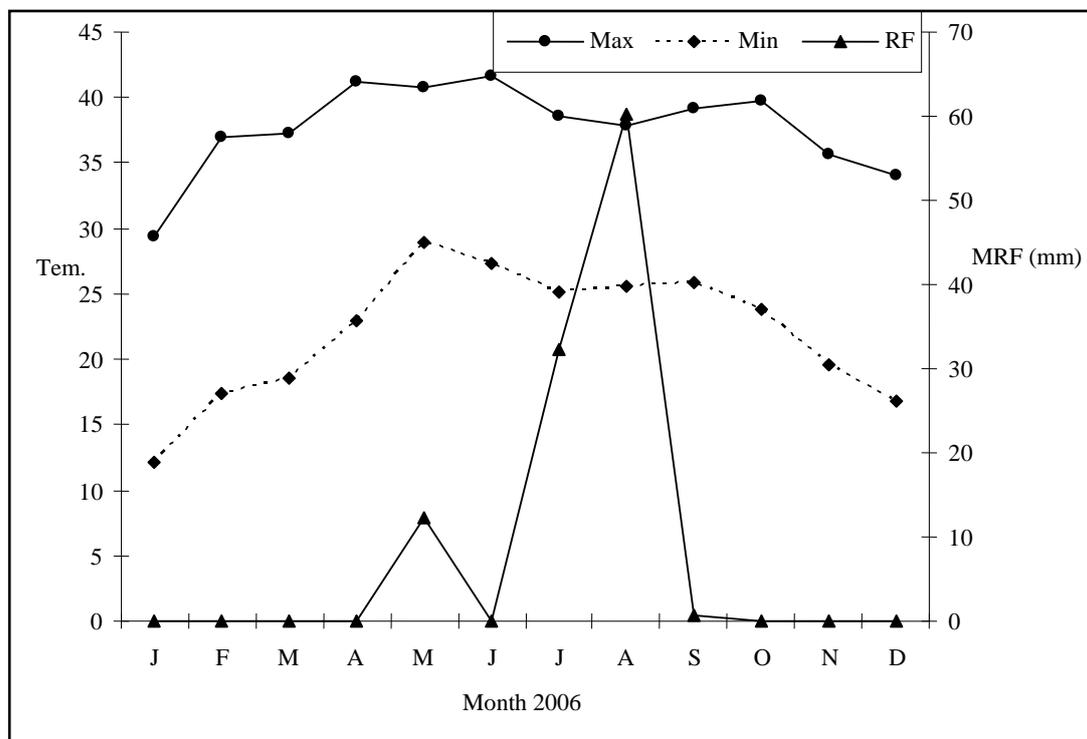


Fig. 1. Mean monthly rainfall (mm), maximum and minimum temperatures (°C) during the decomposition period (experiment 1)

where experiment was done. Water hyacinth of experiment one was used in this study. Plant material was oven-dried (65-70°C for two days) and crushed (1 mm size) before even incorporation into the whole soil of polyethylene bag. Exactly 5 kg soil was added to a polyethylene bag (18 cm wide) with the following treatments:

1. Control (no fertilizer no water hyacinth)
2. Recommended inorganic fertilizer (87 kg N as urea, 45kg P₂O₅ as TSP / ha)
3. Water hyacinth (6.7 t DM ha⁻¹; equivalent amount of recommended N)

The experiment was arranged in Randomized Complete Blocks Design (RCBD) with 3 replications (18 experimental units). Bags were placed in the glasshouse (1 May 2006) and only those with plant materials were regularly irrigated (every 7 days) with amount of tap water that was equivalent to the field capacity of the soil (26.7%). After 12 weeks (1 August 2006), the recommended inorganic fertilizer dose was applied and all bags were sown with 3 seeds of fodder sorghum (*Sorghum bicolor*) and irrigation (every 3 days). After 4 weeks from sowing, plants were cut (2 cm above the soil surface) with a blade, placed inside an envelope and dry matter was recorded after drying

at 65-70°C for two days. The soil of each bag was air-dried, roots were removed and transferred to the laboratory for determination of pH, CEC, OC, TN, hydraulic conductivity, E_ce and soluble cations (K, Ca, Mg and Na) as previously described. ANOVA analysis with Least Significant Difference (LSD) was performed for determination of statistical variations between treatments (**Gomez and Gomez, 1984**).

Plant and Soil analysis

Total N in the soil and plant was determined using the semi-macro Kjeldahl method described by **Bremner and Mulvaney (1982)**. Soil and plant organic C was determined by the modified Walkley Black method (**Walkley and Black, 1934**). Plant samples were ashed at 150°C first, then at 550°C and dissolved in 5N HCL and analyzed for K (also soil soluble) by flame photometer, P by spectrophotometer and Ca, Mg and Na (also soil soluble) by titration against ethylene diamine tetra acetic acid (**Chapman and Pratt, 1982**) and lignin was determined by the acid detergent fiber method (**Goering and Van Soest, 1970**). Electrical conductivity of the saturation

extract (EC_e) was measured according to **Richard (1954)**, Soil pH (paste) was measured using knick digital pH-meter, and hydraulic conductivity was measured according to **Kirkham and Powers (1972)**.

Statistical Analysis

Rates of mass loss and nutrient release of residues (expressed as percent remaining of initial contents) were calculated using the single exponential model $W_t = W_0 e^{-kt}$ proposed by **Olson (1963)** where W_t is the mass loss at time (t) in weeks, W_0 is the initial dry matter or nutrient pool and k is the rate constant (% week⁻¹). The time required for 50% ($T_{0.5}$) and 95% ($T_{0.95}$) were equal to $0.693/k$ and $3/k$, respectively. Statistical differences between surface application and incorporation were determined by subjecting the data to the analysis of variance (ANOVA) and means separation was conducted using T-Test (**SAS, 1985**).

RESULTS AND DISCUSSION

Decay and nutrient release

Weight loss

Remaining dry matter weight (%) during 16 weeks of incubation period is shown in **Fig. (2)**. Statistical analysis showed that during all samplings, loss from sub-surface application was significantly ($P \leq 0.01-0.0005$) greater than those of surface application. After the end of the incubation (16th week) DM that remained in sub-surface application (47.2%) was significantly ($P \leq 0.0005$) lower than that determined in surface application (60.9%) by about 22%. Decomposition rate constant (k) and time to 50%, 95% weight loss were significantly higher when plant materials were buried than left on the surface (**Table 1**). Aerobic decay of fresh water hyacinth was very fast in the study carried out by **Woomer et al (2000)** in the semi-arid tropics of Kenya (total annual rain-fall during the study period of 214-373 mm) compared to 0 mm in this study. However, regular sprinkling of water raised soil moisture to 5-8% which was far below the optimum for biological activities. In the study of **Woomer et al (2000)**, time to 50% weight loss in mulch application found to be 3 weeks compared to 24 weeks in our's. This big difference shows that under arid conditions, soil moisture availability and organic matter content are important for biotic activity. Better soil-plant

contact would possibly justify fast decay in incorporated water hyacinth compared to surface application (**Jama and Nair, 1996**) or improved moisture content (**Hamadi et al 2000**). However, this slow decomposition especially at surface application would provide good opportunity for use in protecting surface soils against erosion. Sub-surface placement of bags resembles residue incorporation by tillage. The latter was earlier considered as a regulator or driving variable enhancing elemental cycling in agroecosystem (**Buchanan and King, 1993**).

Nutrients dynamics

Nitrogen remained during decomposition showed a consistent release in both placements (**Fig. 3a**). **Table (1)** shows that N release rate from sub-surface (0.074) was significantly ($P \leq 0.08-0.0001$) higher than that from surface placement (0.049). By the end of the incubation period, about 29% and 44% remained in sub-surface and surface placements, respectively. Percent N remained during the incubation period did not exceeded 100% which indicates absence of immobilization. Moreover, N concentrations measured during all samplings were lower than the initial content (**Table 2**). Kinetic rate constants showed that after half of the material was finished expressed as $T_{(0.5)}$, loss of N from sub-surface placement was more pronounced compared to surface application. This is clear as when 50% depletion occurred in surface application, longer time was needed for apparent 95% fate of the material. **Goyal et al (2005)** showed that during 90 days composting of water hyacinth, N concentration was never higher than the initial. Other study found reported that non composted water hyacinth was found to be a viable substrate for mushroom cultivation despite the fact that their C/N ratio (24) was above the threshold (20) of N mineralization (**Murugesan et al 1995**). In this study, absence of N immobilization could possibly be due to the low lignin: N ratio. Lignin: N ratio was reported to be highly correlated with litter decay (**Cortez et al 1996 and Mafongoya et al 1998**). **Maithani et al (1998)** reported that due to low lignin and C/N ratio, N was found to be released from a decomposing tropical tree (*Schima khasiana*) leaves (%N of 1.09%). This pattern of N release reflects that recycling of such plant materials would not cause N starvation to growing plants and hence offers better alternative for amelioration of poor desert sandy soils. Both treatments showed that actual

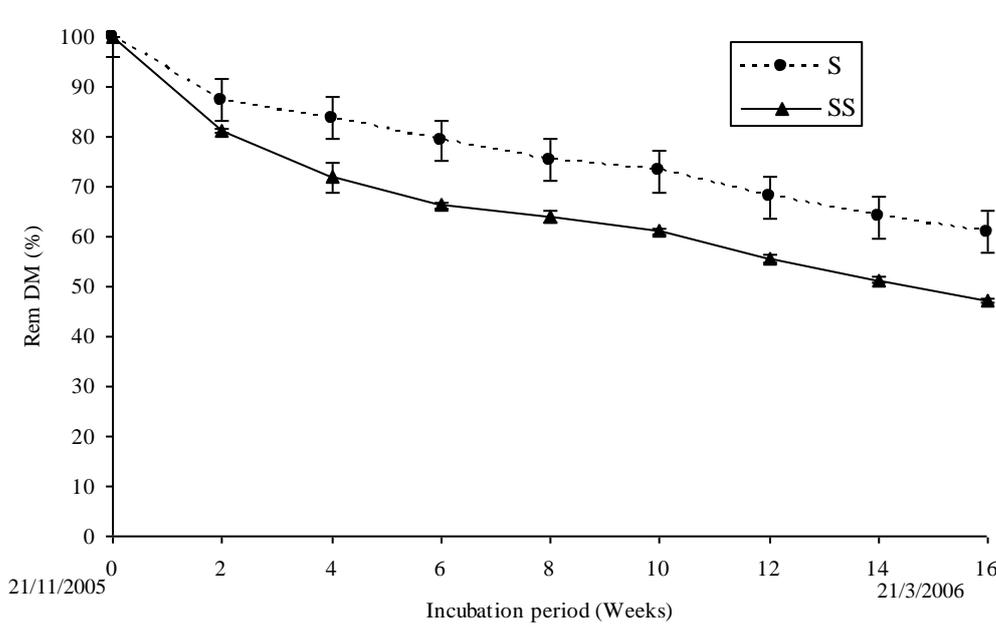


Fig. 2. Remaining dry matter weight (%) during decomposition of water hyacinth in surface (S) and sub-surface (SS) application. (Vertical bars are standard deviations)

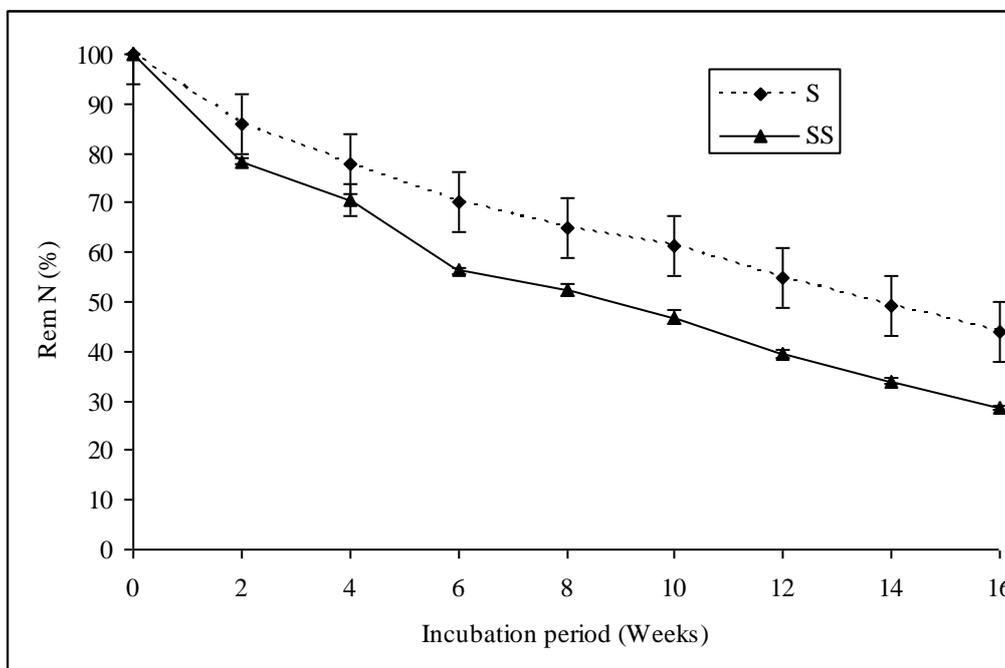


Fig. 3a. Changes in N during decomposition of water hyacinth in surface (S) and sub-surface (SS) application. (Vertical bars are standard deviations)

Table 1. Decomposition rate constant (k, week⁻¹), half-time (T_{0.5}) and time required for 95% (T_{0.95}) loss of dry matter and nutrients

| Parameter | k | | | r ² | T _(0.5) | | T _(0.95) | |
|-----------|--------|--------|-------------|----------------|--------------------|----|---------------------|----|
| | S | SS | Probability | | S | SS | S | SS |
| DM | 0.0285 | 0.0414 | 0.0007 | 0.96 | 24 | 17 | 105 | 72 |
| N | 0.0485 | 0.0737 | 0.0005 | 0.99 | 14 | 9 | 62 | 41 |
| P | 0.1179 | 0.1753 | 0.008 | 0.96 | 6 | 4 | 25 | 17 |
| K | 0.0580 | 0.0686 | 0.0002 | 0.89 | 12 | 10 | 52 | 44 |
| Ca | 0.0444 | 0.0679 | 0.0009 | 0.94 | 16 | 10 | 68 | 44 |
| Mg | 0.0779 | 0.1063 | 0.0001 | 0.96 | 9 | 6 | 39 | 28 |

K decomposition rate constant, DM dry matter, S surface application, SS sub-surface incorporation

P remained by the end on the period (5-15% was less than the corresponding amount of N (**Fig. 3b**). Also, P concentration did not show that P was limiting element during decomposition (**Table 2**). Nutrients changes showed that P is the most element released with quite higher rates (**Table 2**). Earlier **Woomer et al (2000)** calculated that 50% loss of P from whole plant of water hyacinth was attained after about 2 weeks compared to 4 to 6 weeks in this study. Although K is well known as a non structural element, its release from the decomposing water hyacinth was not very rapid as expected. However, initially (i.e. after 2 weeks), K was the only element determined to have higher mobility, i.e 35 - 48% loss (**Fig. 3c**). It is quite clear that K concentration in the remained material (**Table 2**) was abruptly decreased after 2 weeks while there was a steady release during later stages. It might possibly be that regular water spraying was not enough to leach K during later stages as occurred at the beginning of the experiment. We can not say that K release from water hyacinth is a function of its distribution among plant parties. However, it is important that mobility of nutrients from decomposing organic materials applied to sandy soils with low adsorption capacities should be slow to decrease chances of K leaching. Generally, in both placements, Ca was the least nutrient released. By the end of the incubation period, about 78% of the initial concentration remained (**Fig. 3d**). The order of nutrient release could be as follows: P > Mg > K > N = Ca (surface application) and P > Mg > N > K = Ca (sub-surface placement) **Fig. (3a, b, c, d and e)**. Quite similar

release pattern was earlier found elsewhere (**Luna-Orea et al 1996; Rutigliano et al 1998**).

Effects on soil properties

Short-term effects of incorporation of water hyacinth on soil properties are shown in **Table (3)**. Addition of water hyacinth residues decreased final soil pH (after 12 weeks) from 7.3 to 5.3 (i.e. 27% reduction). Previous researches on impact of residue application on soil pH shows different results (**Xu et al 2006**). They varied from increase (**Marschner and Noble, 2000**) or decrease, increase or remained unchanged (**Xu et al 2006**). It is well known that almost all results showed pH increase of acid soils. However, it seems that initial soil pH will greatly influence the direction of change. Within the acid range, **Xu et al (2006)** observed that pH of a sandy soil (initial pH 5.06) decreased by application of many residues. Similarly, **Tang and Yu (1999)** found pH decrease in soils with moderate acidity. Although, in this study excess cations of water hyacinth were not determined, we speculate that pH decrease could possibly be due to residue type of acidic nature (6.0) and initial soil pH. Since in our experiment, plants were sown in the bags, NH₄ uptake is associated with the excretion of H⁺ (**Bolan et al 1991**). Cation exchange capacity and organic C were significantly (P ≤ 0.0001) increased by about 23 and 100%, respectively. On the other hand, hydraulic conductivity was significantly (P ≤ 0.0001) decreased by 46%. It is clear that temporary incorporation of water hyacinth improved soil organic matter content which eventually increased water

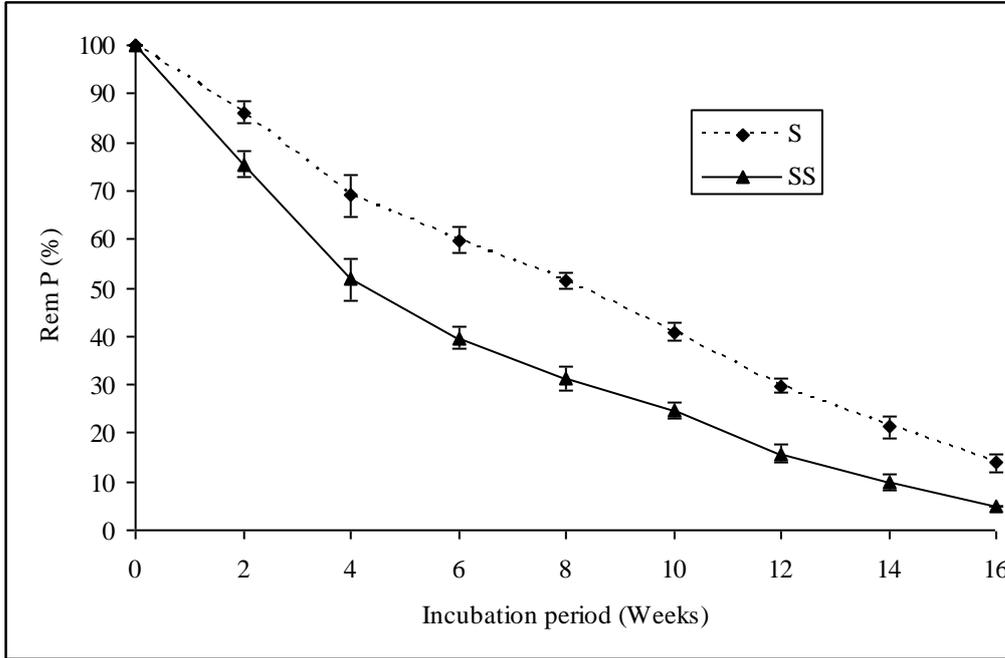


Fig. 3b. Changes in P during decomposition of water hyacinth in surface (S) and sub-surface (SS) application. (Vertical bars are standard deviations)

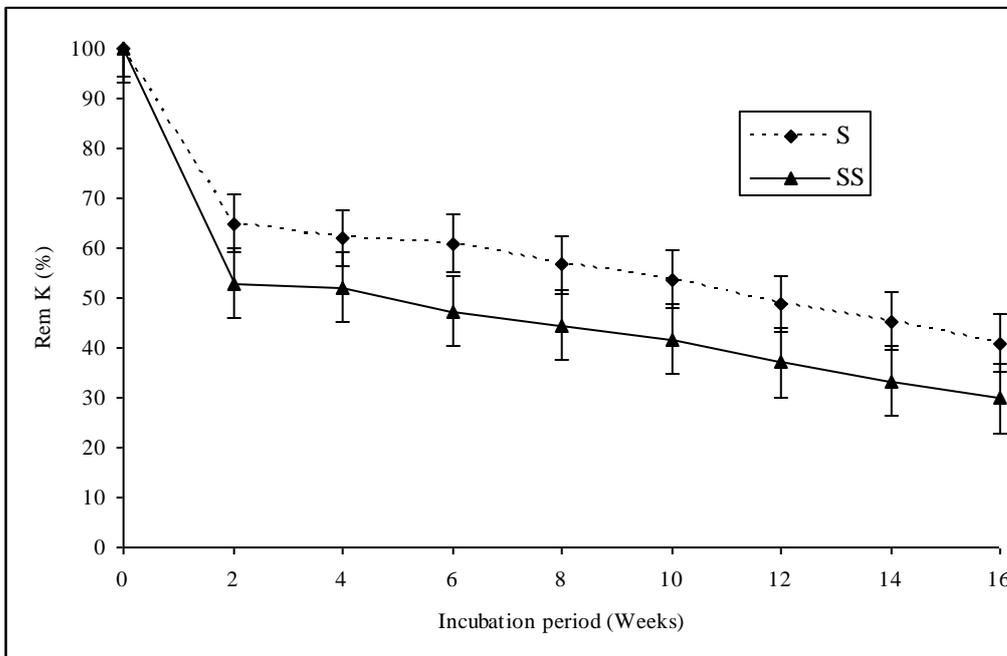


Fig. 3c. Changes in K during decomposition of water hyacinth in surface (S) and sub-surface (SS) application. (Vertical bars are standard deviations)

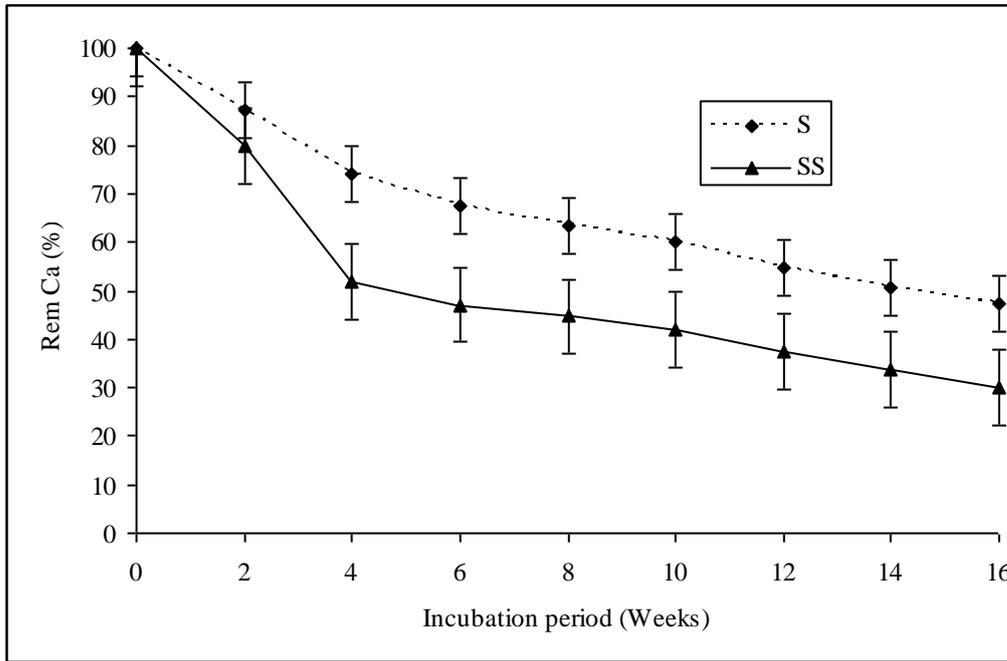


Fig. 3d. Changes in Ca during decomposition of water hyacinth in surface (S) and sub-surface (SS) application. (Vertical bars are standard deviations)

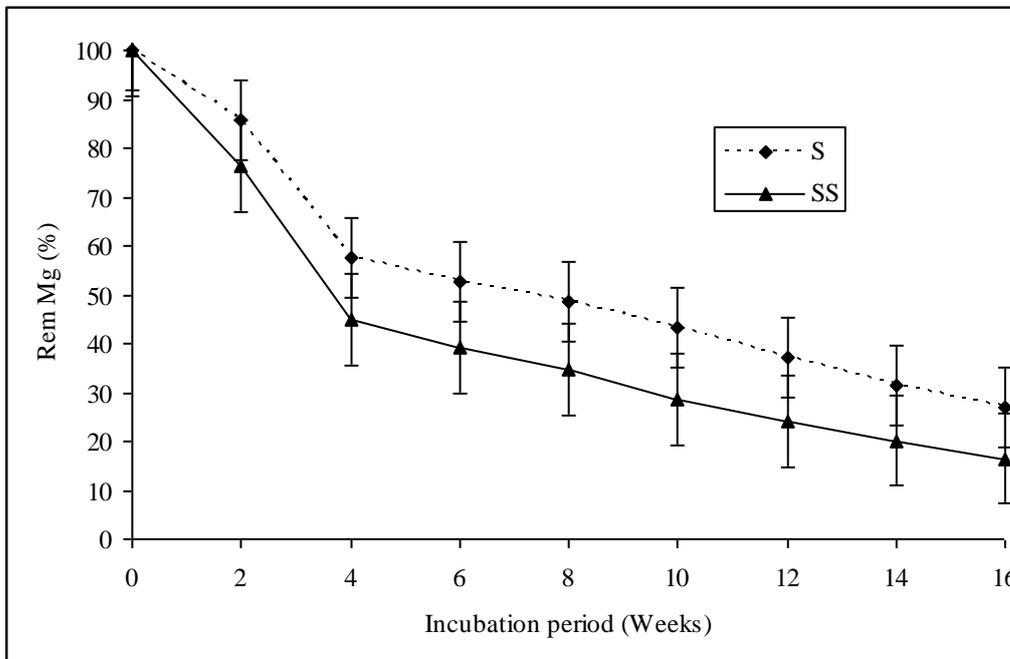


Fig. 3e. Changes in Mg during decomposition of water hyacinth in surface (S) and sub-surface (SS) application. (Vertical bars are standard deviations)

Table 2. Concentration of remaining nutrients during decomposition (g kg^{-1})

| Incubation period (Weeks) | Nutrients concentrations (g kg^{-1}) | | | | |
|-------------------------------------|---|-----|------|------|-----|
| | N | P | K | Ca | Mg |
| Surface application (S) | | | | | |
| 0 | 10.9 | 1.9 | 18.7 | 16.8 | 7.8 |
| 2 | 10.7 | 1.9 | 14.6 | 16.8 | 7.6 |
| 4 | 10.1 | 1.6 | 14.3 | 14.8 | 5.4 |
| 6 | 9.6 | 1.4 | 14.1 | 14.3 | 5.2 |
| 8 | 9.4 | 1.3 | 13.7 | 14.1 | 5 |
| 10 | 9.1 | 1.1 | 13.4 | 13.8 | 4.6 |
| 12 | 8.8 | 0.8 | 13.2 | 13.6 | 4.3 |
| 14 | 8.4 | 0.6 | 12.5 | 13.3 | 3.8 |
| 16 | 7.4 | 0.4 | 11.7 | 13.1 | 3.4 |
| Sub-surface application (SS) | | | | | |
| 0 | 10.9 | 1.9 | 18.7 | 16.8 | 7.8 |
| 2 | 10.5 | 1.8 | 13.5 | 16.5 | 7.3 |
| 4 | 9.9 | 1.4 | 13.3 | 12.1 | 4.9 |
| 6 | 9.3 | 1.1 | 13.0 | 11.9 | 4.6 |
| 8 | 8.9 | 0.9 | 12.7 | 11.7 | 4.2 |
| 10 | 8.4 | 0.9 | 12.4 | 11.5 | 3.6 |
| 12 | 7.7 | 0.5 | 12.1 | 11.3 | 3.4 |
| 14 | 7.2 | 0.4 | 11.8 | 11.1 | 3.1 |
| 16 | 6.6 | 0.2 | 10.9 | 10.7 | 2.7 |

Table 3. Effect of Water hyacinth incorporation on some selected soil properties and dry matter accumulation (g plant^{-1}) of fodder sorghum (average \pm sd)

| Treatment | pH | CEC cmol (+) kg^{-1} | OC | | TN | | HC Cm hr^{-1} | ECe dSm^{-1} | K | Ca | Mg | Na | DM (g plant^{-1}) |
|-------------------------|-------------------|-------------------------------------|--------------------|--------------------|--------------------|--------------------|---------------------------|--------------------------|--------------------|-------------------|-------------------|----|---------------------------------|
| | | | g kg^{-1} | | | | | | | | | | |
| Control | 7.3 \pm 0.01 | 12.93 \pm 0.06 | 0.3 \pm 0.0 | 0.12 \pm 0.01 | 9.73 \pm 0.06 | 1.36 \pm 0.06 | 0.08 \pm 0.01 | 2.26 \pm 0.06 | 0.63 \pm 0.06 | 0.7 \pm 0.03 | 1.2 \pm 0.06 | | |
| Water hyacinth | 5.3 \pm 0.01 | 15.90 \pm 0.23 | 0.6 \pm 0.06 | 0.12 \pm 0.01 | 5.23 \pm 0.06 | 1.33 \pm 0.0 | 0.07 \pm 0.01 | 2.23 \pm 0.12 | 0.56 \pm 0.06 | 0.7 \pm 0.02 | 1.3 \pm 0.10 | | |
| Inorganic fertilizer | 7.3 \pm 0.01 | 12.96 \pm 0.68 | 0.3 \pm 0.01 | 0.15 \pm 0.01 | 8.73 \pm 0.15 | 1.43 \pm 0.06 | 0.08 \pm 0.01 | 2.33 \pm 0.06 | 0.64 \pm 0.06 | 0.7 \pm 0.01 | 1.8 \pm 0.06 | | |
| C.V. | 0.12 | 1 | 8.4 | - | 1.2 | - | - | - | - | - | 5.1 | | |
| P | 0.0001 | 0.0001 | 0.0001 | - | 0.0001 | - | - | - | - | - | 0.0001 | | |
| LSD | 0.0163 | 0.28 | 0.0067 | NS | 0.19 | NS | NS | NS | NS | NS | 0.1489 | | |

CEC: Cation exchange capacity, OC: Organic carbon, TN: Total N, HC: Hydraulic conductivity, ECe: Electrical conductivity of the saturation extract

C.V.: Coefficient of variability, P: Probability at 0.05 level, LSD: Least Significant Difference

holding capacity and thereby reduced downwards movement of water. Application Organic materials were earlier found to improve soil water content through increase of negative charges (Khaleel *et al* 1981; Barzegar *et al* 2002). We speculate that absence of significant effects on soil soluble cations, CEC and dry matter accumulation could be due to sub-optimal amount added. However, most important that during removal of water hyacinth, incorporation of this plant waste to sandy soils away from the Nile will certainly reduce irrigation water needed. This study showed that during field decomposition of water hyacinth residues, N and P (most important nutrients), were not limiting the decomposition process.

REFERENCES

- Ahmed, A.B. (1995). **Impact of Soil Water Management on Salt Leaching and Forage Sorghum Growth in Shambat Soil.** p. 84. M.Sc. Thesis, University of Khartoum, Shambat, Sudan.
- Anderson, J.M. and J.S. Ingram (1993). **Tropical Soil and Fertility: A Handbook of Methods.** CAB International, Walling-ford, UK.
- Barzegar, A.R.; A. Yousefi and A. Daryashenas (2002). The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. **Plant and Soil** 247: 295-301.
- Bekunda, M.A. and P.L. Woomer (1996). Organic resource management in banana-based cropping systems of the Lake Victoria Basin, Uganda. **Agriculture Ecosystems and Environment** 59: 171-180.
- Bolan, N.S.; M.J. Hedley and R.E. White (1991). Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures. **Plant and Soil** 134: 53-63.
- Bremner, J.M. and C.S. Mulvaney (1982). Nitrogen-Total. In: **Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Agronomy Monograph No. 9 (2nd Edition).** pp. 595-622. Eds. Page, A.L.; R.H. Miller and D.R. Keeny. American Society of Agronomy, Madison, WI.
- Buchanan, M. and L.D. King (1993). Carbon and phosphorous losses from decomposing crop residues in no-till and conventional till agroecosystems. **Agronomy Journal.** 85: 631-638.
- Chapman, H.D. and F.P. Pratt (1982). Determination of minerals by titration. **Methods of Analysis for Soils, Plant and Water, 2nd Ed.** pp. 169-170. California University, Agriculture Division, U.S.A.,
- Cochran, V.L. (1990). Decomposition of barley straw in subarctic soil in the field. **Biology and Fertility of Soils** 10: 227-232.
- Cortez, J.; M.J. Demard; P. Bottner and L. Jocteur Monrozier (1996). Decomposition of Mediterranean leaf litters: A microcosim experiment investigating relationships between decomposition rates and litter quality. **Soil Biology and Biochemistry** 28: 443-452.
- Gajalakshmi, S. and S.A. Abbasi (2002). Effect of the application of water hyacinth compost/vermicompost on the growth and flowering of *Crossandra undulaefolia*, and on several vegetable. **Bioresource Technology** 85: 197-199.
- Goering, H.K. and P.J. van Soest (1970). Forage Fiber Analysis. In: **Agriculture Handbook. No. 379, USDA, Washington.**
- Gomez, K.A. and A.A. Gomez (1984). **Statistical Procedures for Agricultural Research.** 2nd Ed., John Wiley and Sons, New York, USA.
- Goyal, S.; S.K. Dhull and K.K. Kapoor (2005). Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. **Bioresource Technology** 96: 1584-1591.
- Hamadi, Z.; Y. Steinberger; P. Kutiel; H. Lavee and G. Barness (2000). Decomposition of *Avena sterilis* litter under arid conditions. **Journal of Arid Environment** 46: 281-293.
- Issac, R.S. and M.A. Nair (2005). Biodegradation of leaf litter in the warm humid tropics of Kerala, India. **Soil Biology and Biochemistry** 37: 1656-1664.
- Jama, B.A. and P.K.R. Nair (1996). Decomposition and nitrogen mineralization patters of *Leucaena leucocephala* and *Cassia siamea* mulch under tropical semiarid conditions in Kenya. **Plant and Soil** 179: 275-285.
- Khaleel, R.K.; R. Reddy and M.R. Overcash (1981). Changes in soil physical properties due to organic waste application: A review. **Journal of Environmental Quality** 110: 133-141.
- Kirkham, D. and W.L. Powers (1972). Darcy's law, Laplace's equation and boundary value problems. **Advanced Soil Physics,** p. 46, Wiley-Interscience, NY.
- Luna-Orea, P.; M.G. Waggar and M.L. Gumpertz (1996). Decomposition and nutrient release dynamics of tropical legume cover crop. **Agronomy Journal** 88: 758-764.
- Macek, T.; M. Mackova and J. Kas (2000). Exploitation of plants for the removal of organics in environmental remediation. **Biotechnology Advanced** 18: 23-34.

- Mafongoya, P.L.; P.K.R. Nair and B.H. Dzowela (1998).** Mineralization of nitrogen from decomposing multipurpose trees as affected by their chemical composition. **Biology and Fertility of Soils 27: 143-148.**
- Maithani, K.; A. Arunachalam; R.S. Tripathi and H.N. Pandey (1998).** Influence of leaf litter quality on N mineralization in soils of subtropical humid forest regrowths. **Biology and Fertility of Soils 27: 44-50.**
- Marschner, B. and A.D. Noble (2000).** Chemical and biological processes leading to the neutralisation of acidity in soil incubated with litter materials. **Soil Biology and Biochemistry 32: 805-813.**
- Murugesan, A.G.; P. Vijayalakshmi; N. Sukumaran and C. Maraippan (1995).** Utilization of water hyacinth for oyster mushroom cultivation. **Bioresource Technology. 51: 97-98.**
- Olson, J.S. (1963).** Energy storage and the balance of products and decomposers in ecological systems. **Ecology 44: 322-331.**
- Richard, L.A. (1954).** **Diagnosis and Improvement of Saline and Alkali Soils. Handbook 60,** USDA, Washington, D.C.
- Rutigliano, F.A.; A. Alfani; L. Bellini and A. Virzo De Santo (1998).** Nutrient dynamics in decaying leaves of *Fagus sylvatica* L. and needles of *Abies slba* Mill. **Biology and Fertility of Soils 27: 119-126.**
- SAS. (1985).** **SAS User's Guide: Statistics, 5th Ed.,** SAS Institute, Cary, NC, U.S.A.
- Soil Survey Staff. (1996).** **Keys to Soil Taxonomy, 7th Edition.** United States Department of Agriculture, Washington, D.C.
- Susarla, S.; V.F. Medina and S.C. McCutcheon (2002).** Phytoremediation: an ecological solution to organic chemical contamination. **Ecological Engineering 18: 647-658.**
- Tang, C. and Q. Yu (1999).** Impact of chemical composition of legume residues and initial on soil pH change of a soil after residue incorporation. **Plant and Soil 215: 29-38.**
- Taylor, B.R.; C.E. Parsons; W.J.F. Parsons and D. Parkinson (1991).** Substrate control of litter decomposition in four Rocky Mountain coniferous forests. **Canadian Journal of Botany 69: 2242-2250.**
- Walkley, A. and I.A. Black (1934).** An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid method. **Soil Science 37: 29-38.**
- Whiteford, W.G.; K. Stinnet and Y. Steinberger (1988).** Effects of rainfall supplementation on microarthropods on decomposing roots in the Chihuahuan Desert. **Pedobiologia 31: 147-155.**
- Woomer, P.L. (1997).** Managing water hyacinth invasion through integrated control and utilization perspectives for lake Victoria. **African Journal of Crop Science 5: 309-324.**
- Woomer, P.L.; R. Muzira; D. Bwamiki; D. Mutetikka; A. Amoding and M.A. Bekunda (2000).** Biological management of water hyacinth waste in Uganda. **Biological Agriculture and Horticulture 17: 181-196.**
- Xia, H. and X. Ma (2006).** Phytoremediation of ethion by water hyacinth (*Eichornia crassipes*) from water. **Bioresource Technology 97: 1050-1054.**
- Xu, J.M.; C. Tang and Z.L. Chen (2006).** The role of plant residues in pH changes of acid soils differing in initial pH. **Soil Biology and Biochemistry 38: 709-719.**