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Full Length Research Paper

Soil fertility in wetland versus reclaimed land using plant parameters in relation to nitrogen content: The case of Yala Swamp, Western Kenya

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A bioassay experiment was carried out to assess soil fertility of wetland and adjacent reclaimed wetland (agricultural-land) areas in comparison to their nitrogen contents. Though wetland soils had more total N than agricultural-land soils, the greenhouse findings suggest that organic matter in wetlands does not mineralize as readily as in soils drained for longer periods. Also, when total N increased, the roots to shoots (R:S) ratio decreased thus favoring shoot growth, but less so in wetland soil (r = -0.1) than in agricultural soil (r = -0.2). In fact, the C/N ratios indicated that poor nutrient quality in wetland soils as compared to agricultural-land soils. Wetland soils had more acidic pH values which impeded the growing of the maize and shifted the partitioning towards the roots.

Key words: R:S ratio, total N, total biomass, maize, C/N ratio.

INTRODUCTION

The productivity of soil is largely determined by its fertility, which in turn is dependent on the root development zone (topsoil) depth and nutrients stored in its mineral and organic constituents (Vlek et al., 1997). Food security is a pressing concern for the world today especially in sub-Saharan Africa. Increased and sustained production in tropical Africa requires appropriate soil management practices (Nandwa et al., 1994). While developed countries face eutrophication problems due to the excessive application of animal manure and fertilizers, in sub-Saharan Africa soil fertility decline is a major problem affecting crop production (Vlek, 1993; Nziguheba et al., 2000). Maize is sown in areas typified by infertile soils. Farmers produce poor harvests out of holdings which have shrunk and lost productivity; fallows have been abandoned in favor of intensive, multiple cropping year round. Increasing pressure on agricultural-land and the subsequent abandonment of many traditional maintenance strategies for soil fertility have resulted in negative nutrient balances (Kaizzi and Wortmann, 2001). The relegation of maize to ever more marginal and fragile cropping circumstances represents a continual hardship for millions of farmers (Reeves, 1996). In well-drained tropical soils, continuous maize cultivation on recently cleared land depletes nitrogen and may cause erosion (Moser et al., 1996). The result is increasing pressure on virgin lands such as the wetlands.

Wetlands perform a variety of ecological and hydrological functions that benefit humans (Mitsch and Gosselink, 1993). Kenya's wetlands are among the country's most important natural resources for socio-cultural and economic development. The Yala swamp occurs in a densely populated area dominated by small-scale farming, where its ecosystem services and products are highly needed. Local communities depend much on the wetland for their livelihood.

In Western Kenya, wetlands are perceived more as fertile land for production of maize and other agricultural products. The farming system has evolved from shifting cultivation via fallow based farming, to permanent agriculture mainly due to increasing population pressure and market integration (Mango, 1999). Subsistence farming with no fertilizer input is practiced by farmers in this part of Kenya. Farmers use hoes to till the land. In the Yala Swamp, nitrogen content is highly correlated to carbon content. Therefore, reductions in nitrogen content directly impact carbon content in the soil (Mfundisi, 2005).

Maize and other grasses are often used as indicators of nutrient status in organic soils as long as the nutrient under investigation is not a micro-nutrient (FAO, 1988). A maize seed carries a limited amount of nutritive tissue that must suffice to support development of the seedling until such a time that the seedling is established in light, and photosynthesis takes over supply of energy and carbon (Hopkins, 1995). The presence of plant roots has significant effects on the soil microbial population, and hence soil mineralization, because conditions for microbial growth are favorable in the rhizosphere (Sanchez et al., 2002). For example, the soil microflora is heavily influenced by C sources derived from rhizodeposition. Rhizodeposits are easily decomposable substrates translocated from the aboveground parts of the plants to the roots and subsequently transferred into the surrounding soil as root exudates, mucilage, and sloughed cells and tissues (Qian et al., 1997).

The objective of this study was to rapidly assess whether the loss of soil carbon upon drainage impacted the soil fertility status of drained wetland (agricultural-land) as compared to wetland soils using maize growth and root to shoot (R:S) ratio indices in relation to chemical (C, N) analysis.

MATERIALS AND METHODS

Description of the study area

The Yala Swamp is a deltaic wetland along Lake Victoria (LV) in Western Kenya (Figure 1), dominated by *Cyperus papyrus* vegetation. It is located between rivers Yala and Nzoia at 0° 07' N – 0° 01' S/ 33° 58' – 34° 15' E and was formed as a result of backflow of water from LV (Hughes and Hughes, 1992). The swamp is separated from the LV shore by a 5 km sandbar. The swamp covers a total area of 30 000 ha including Lake Kanyaboli, which occupies 1 500 ha, and stretches 25 km west-east direction and 15 km north-south. Several minor lakes are included in this system, e.g., the lakes Sare and Nambeyo (Hughes and Hughes, 1992; Mavuti, 1992).

Soils of the Yala Swamp

Soils in the Yala Swamp consist of eutric Fluvisols, dystric Histosols and humic Gleysols (Sombroek et al., 1982). Fluvisols are soils showing fluvic properties and having no diagnostic horizons other than ochric, mollic, or umbric A-horizons, or histic H-horizon or sulphuric horizon, or sulfidic material within 125 cm of the surface (FAO-UNESCO, 1990).

Soil sampling

Samples were collected during the 2002/2003 short-rain season. Paired plots covering wetland and agricultural land were sampled. In each plot, three samples were collected along a 30 m transect at 5, 15 and 25 m. Soil samples were taken at 0 - 20 cm using a wetland corer and an auger for the wetland and agricultural land, respectively. A 50 mm diameter ring was used to collect soils for bulk density analysis. Bulk density was determined for the agricultural land soil samples. Sampling was limited to the top 20 cm as most arable agricultural practices occur up-to this depth. Location of each sample site was determined by a GPS (Geo-Explore III). Soil Samples were sun-dried and potted.

Chemical analysis and green-house experiment

The soil samples were analysed for total organic carbon and nitrogen using a Carlo Elba CNHS (Vario EL III) analyzer. The pH was determined using (soil to water ratio of 1: 2.5.)

A green house experiment was conducted using all collected top soils (450) samples to evaluate the soil fertility status of wetland soils as compared to surrounding agricultural soils. The average total N for wetland soils was 0.40 ± 0.29%, and that for agricultural soils was 0.22 ± 0.11%. Maize seeds of the same genotype (Zea mays L., HB-1451 variety) were used for the experiment.

The research was established in a completely random design, whereby the pots were placed in a random order after planting the seeds. About 100 g of dry soils were used for potting. First, the soils were watered for 48 h before the seeds were planted. The seeds were then weighed (to select seeds that were alive) and one seed was planted in each pot. No chemicals were used for the soils and plants. The soils were watered every morning with about 50 ml water. The intention was to use the same amount of water for both soils to simulate conditions under natural rainfall events.

The plants were harvested 14 days after sowing. First, the whole plants (roots and shoots) were gently removed from the soil media and washed with tap water followed by distilled water. The shoot and roots were separated and their fresh weight were determined using a 4 digit balance. The roots and shoots were then dried at 65°C for 48 h and their dry weights were determined. A subsample of the maize plants were randomly selected and analysed for total N and biomass carbon using CHNS analyzer.

RESULTS AND DISCUSSION

Observations were made during the fourteen days of the experiment. It was observed that plants grown on wetland soils experienced some burning of leaves during the initial stages of growth. Overall, plants grown on soils from agricultural land appeared healthier than those on wetland soils. Water logging may have stunted growth of plants grown on wetland soils as compared to those on agricultural-land soils.

Descriptive statistics (statistical analysis)

Descriptive statistics for maize-seedling roots and shoots after harvesting and drying are shown in Table 1. The average total biomass for maize grown on wetland and agricultural-land soils were 0.47 ± 0.1 g and 0.55 ± 0.1 g, respectively. The medians for the two categories were 0.47 and 0.54 g. Though differences are small, they are significant due to the large sample size (216) and probably reflect the more hospitable conditions in drained soils with more readily available nutrients.

Root to shoot ratio

The average root to shoot ratios for the maize grown on wetland and agricultural-land soils were 1.67 ± 1 and 1.2 ± 1, respectively, and the medians for the two categories were 1.46 and 1.0. There was a significant difference in the average root to shoot ratio for maize grown on wetland and agricultural-land soils. A study by de Toledo Machado and Furlani (2004) reported that high dry matter

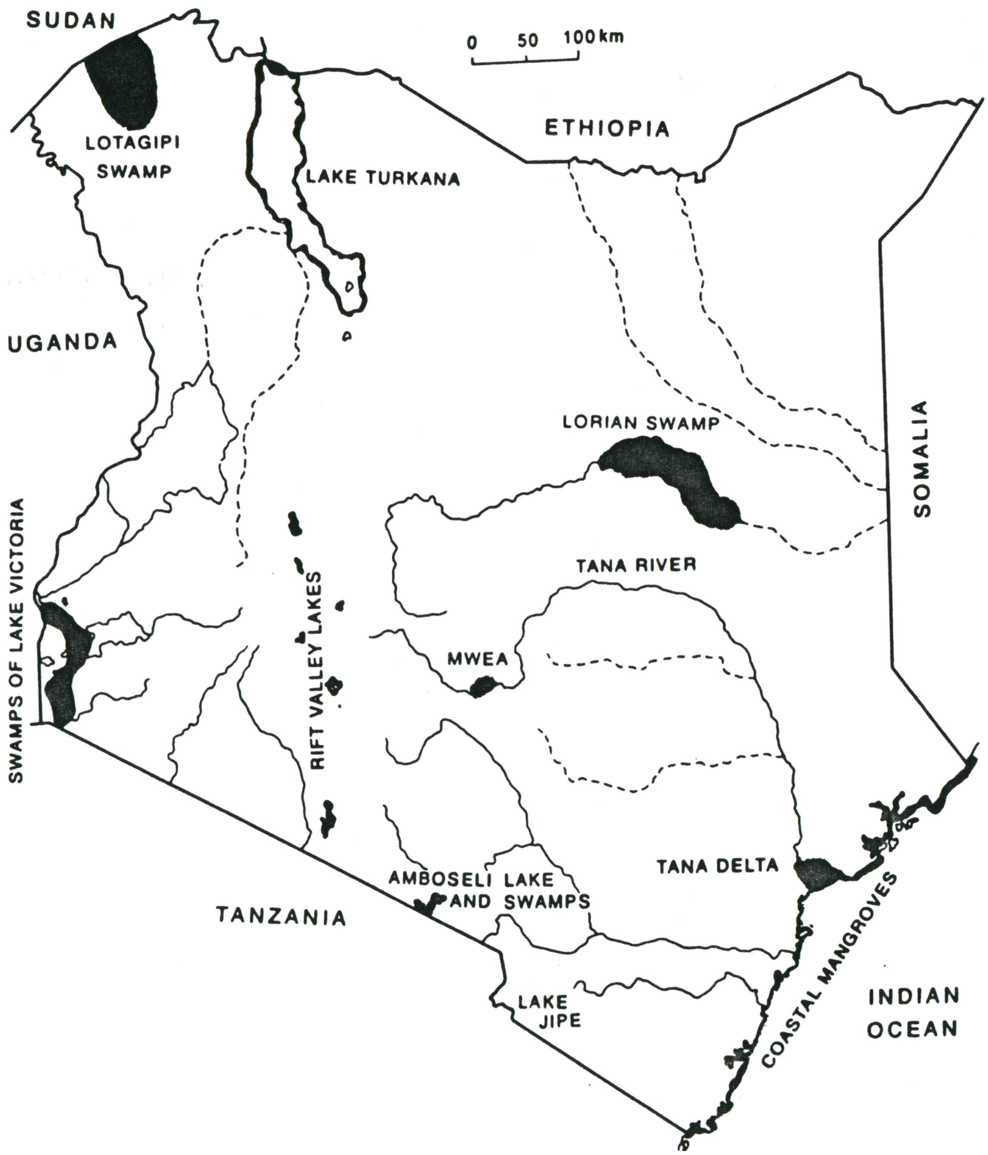

Figure 1. Map of major wetlands of Kenya (Source: Howard, 1992).

Table 1. Total biomass (dry matter) and root to shoot ratios for maize seedlings grown on wetland and reclaimed wetland (agricultural-land) soils.

Descriptive statistics	Maize grown on wetland soils		Maize grown on agric. land soils	
	Total biomass (g)	R:S ratio	Total biomass (g)	R:S ratio
Mean	0.47	1.67	0.55	1.21
Median	0.47	1.46	0.54	1.0
Sample size	216	216	216	216
Std Dev.	0.1	1.4	0.1	1.2

yield in maize plants correlates positively with accumulation of more dry matter on shoots rather than on roots. Annuals generally use small amounts of photosynthate to support root growth, whereas species with perennial roots and rhizomes such as papyrus, often have root: shoot ratios well in excess of 1 (Mitsch and Gosselink,

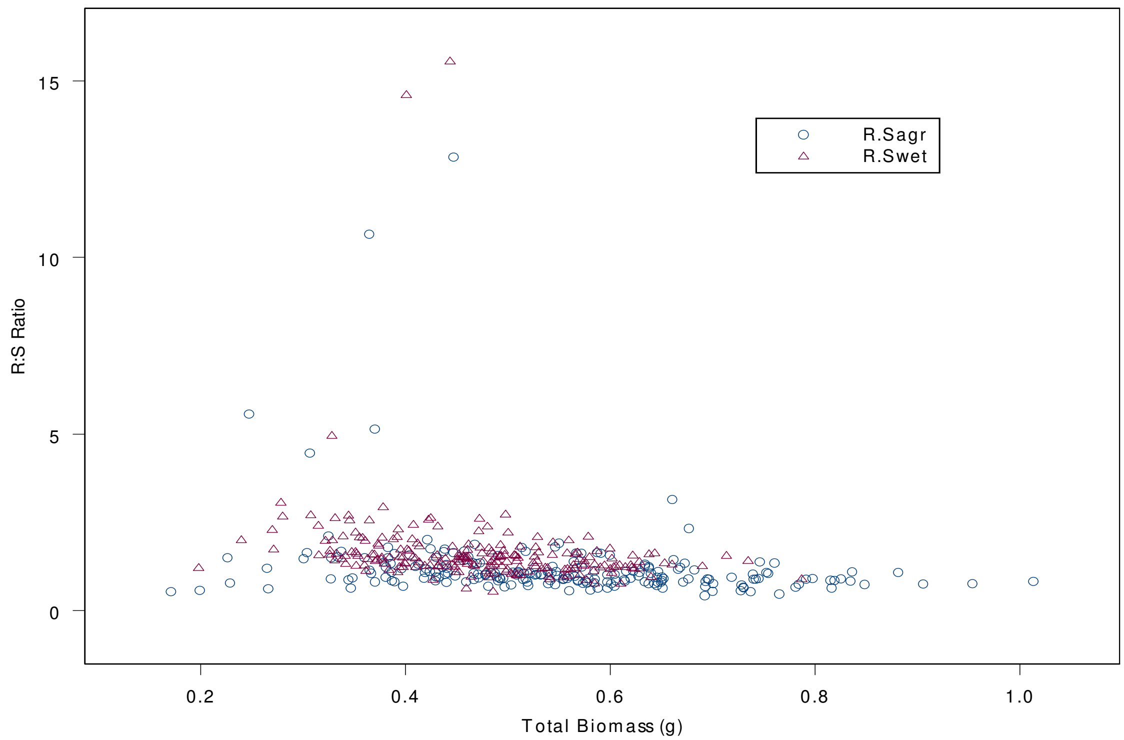

Figure 2a. Total biomass (g) against root to shoot (R:S) ratio for maize grown on wetland and agricultural land soils.

1993). However, early in their development most plants invest heavily in root establishment, and more so if soil conditions are unfavorable. Indeed, it was found that R:S ratio decreased when total biomass increased (Figures 2a and 2b) so that less photosynthate was invested below ground as plants grew bigger (r = -0.2 for both substrates). The maize grown on wetland soils invested more in root development than those on agricultural soils, again suggesting that agricultural soils provided more hospitable grounds for plant growth.

Dry matter partitioning between shoots and roots depends on several external factors in the root and shoot environment (Engels, 1994). The root to shoot ratio is often increased by soil factors which reduce specific root activity (that is, nutrient and water uptake) such as low water potentials and low availability of phosphorus or nitrogen (Chapin et al., 1988), and by environmental factors which increase specific shoot activity (i.e photosynthetic rate) such as high light intensity (Mahall et al., 1981) or CO_2 concentration (Larigauderie et al., 1988). The ambient environmental factors were constant for the experiment as it was carried out under controlled conditions in a greenhouse. However, edaphic factors were different due to differences in the aeration of the soils.

Water logging was imposed in pots filled with wetland soils thus simulating conditions under poorly drained wetland soils. White and Reddy (2001) reported higher rates of N mineralization under aerobic conditions than under anaerobic conditions in the Everglades soils. Since the agricultural-land soils were under aerobic conditions, the mineralization level was supposedly higher than that for wetland soils that were waterlogged. Also the average pH for wetland soils, at 5.4, was outside the suggested pH range for better growth of maize, whereas that for agricultural-land soils, at 6.1, was within the range. In fact, an increase in wetland soils pH resulted in a decrease in the R:S ratio thereby increasing the shoot biomass (r = -0.2), reflecting a more favorable rooting environment. The opposite is true for agricultural soils (r = 0.2), suggesting that the current pH for soils in agricultural land is near-optimal for maize growth.

Total N uptake

For the purpose of this study, nitrogen was considered more important than phosphorus because maize plants largely rely on seed reserves of P during early plant growth (Hopkins, 1995). As the plant matures, available Pi is liberated by an enzyme group, phosphatases, which occur scattered in all tissue cells of plant organs. Root-secreted phosphatase activity is related to plant ability to make soil P available for absorption (de Toledo Machado and Furlani, 2004). Thus, N is the most limiting nutrient for early maize growth. The average total N uptake for maize grown on wetland and agricultural-land soils were 3.5 ± 0.7% and 3.6 ± 0.6%, respectively. Both categories had the same population distribution curves (Figure 3a and 3b). (The medians for the two categories were 3.41

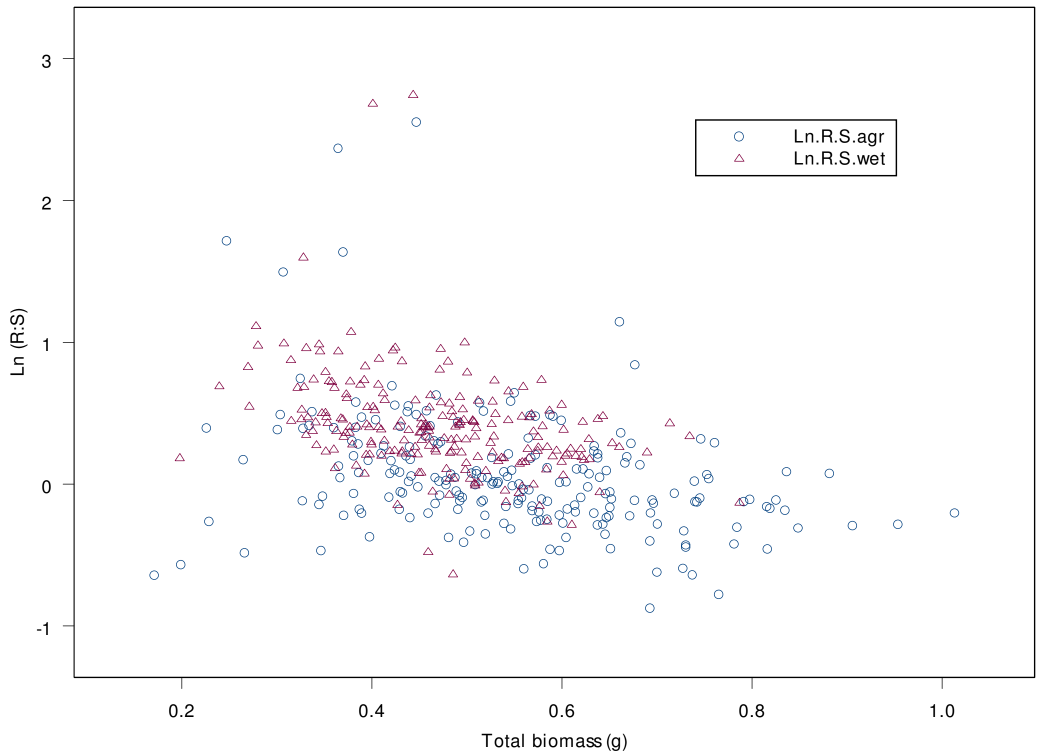

Figure 2b. Total biomass (g) against Ln (R:S) for maize grown on wetland and agricultural land soils.

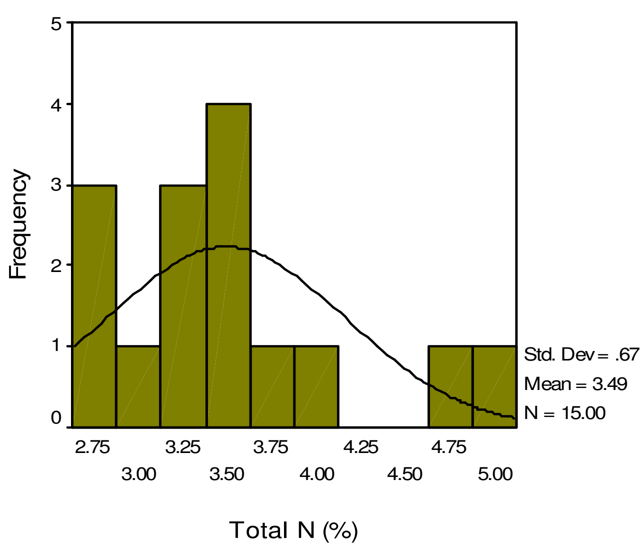

Figure 3a. Frequency distribution for total N (%) in maize grown on wetland top soils.

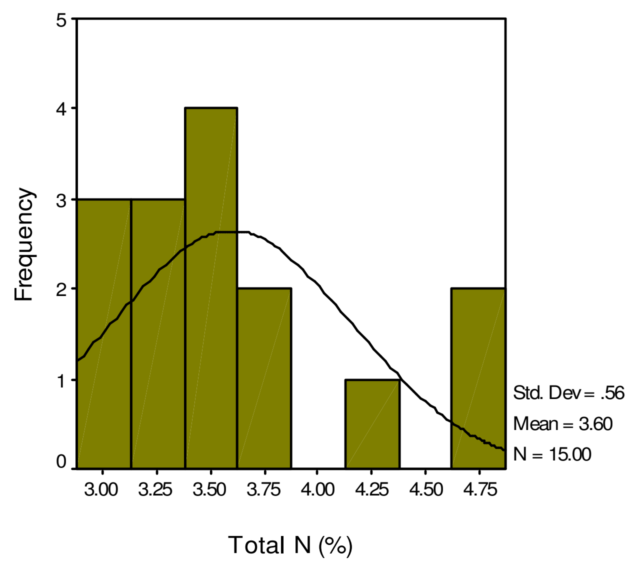

Figure 3b. Frequency distribution for total N (%) in maize grown on agricultural-land top soils.

and 3.45%. There was no significant difference (P = 0.67) in the total N content for maize grown on wetland and agricultural-land soils. The total N amounts were calculated using the total N contents and total biomass for maize plants in each category. The average amount of total N uptake for maize grown on wetland and agricultural-land soils were 16.4 ± 3 and 19.7 ± 3 mg, respectively. The average content of biomass carbon accumulated on the plants over the 14 days were 81 ± 2% (Figure 4a) and 79 ± 2% (Figure 4b) for plants grown on wetland and agricultural-land soils, respectively. The average amounts for the two categories were 376 ± 9 and 440 ± 11 mg, respectively. There was a significant

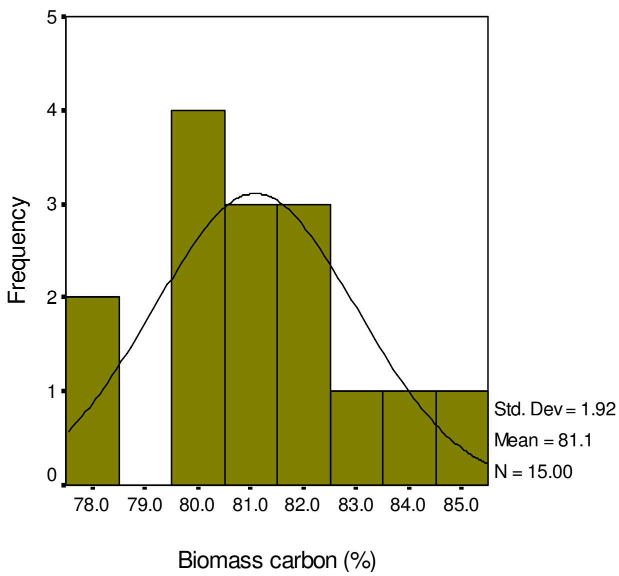

Figure 4a. Frequency distribution for biomass carbon in maize plants grown on wetland top soils.

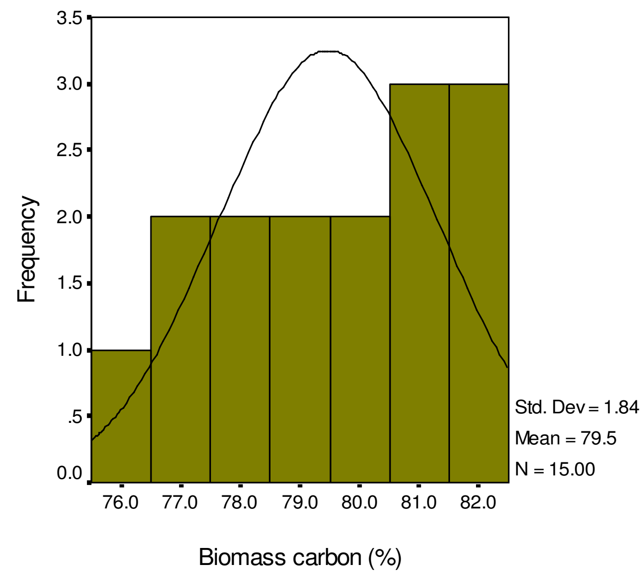

Figure 4b. Frequency distribution for biomass carbon in maize plants grown on agricultural-land top soils.

difference (P = 0.007) in the average amount of biomass carbon accumulated in maize plants grown on wetland and agricultural-land soils.

Though wetland soils had more total N than agricultural-land soils, the greenhouse findings suggest that organic matter in wetlands does not mineralize as readily as in soils drained for longer periods. Also, when total N increased the R:S ratio decreased thus favoring shoot growth, but less so in wetland soil (r = -0.1) than in agricultural soil (r = -0.2). Most of the nitrogen in wetlands is in organic form whereas some quantities of nitrate usually are present in drained wetland soils in which organic materials oxidize rapidly (FAO, 1988). In fact, the C/N ratios indicated poor nutrient quality in wetland soils as compared to agricultural-land soils, which is consistent with the result of the greenhouse experiment. The lower the C/N ratio, the more readily the organic N is released (Alef and Kleiner, 1986).

Conclusion

The result from the experiment clearly showed that nitrogen availability does not correlate with total N in wetland soils. Even though the wetland soils had more total N as compared to agricultural land soils, the latter had higher biomass and lower root to shoot ratios than the former. Also the N uptake was not significantly different for the two categories. Wetland soils had more acidic pH values which impede the development of the maize and shift the partitioning towards the roots. The experiment successfully showed that wetlands following drainage have a significant amount of available N; other factors such as water logging and acidity render wetland soils not hospitable for growth of maize that is not adapted to grow under such conditions. Therefore, it is important to consider these factors before deciding to drain wetlands for plant production, and may as well avoid draining wetlands because they support plants that are adapted to wetland conditions. Also, drainage of wetlands is against the wise use concept of the Ramsar convention. This experiment did not consider other nutrients such as phosphorus and potassium since they are not considered as limiting nutrients at this stage of development of maize plants.

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