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Full Length Research Paper

Effect of straw mulch application on nutrient concentration in runoff and sediment in a humid region in Kenya

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Straw mulch use has been studied extensively especially for soil erosion and runoff control in arid and semi-arid regions but few studies have been done with regard to nutrient loss and accumulation in humid climate regions in Africa. The objective of the present study was to investigate the effects of straw mulch application using different methods on nutrient loss and accumulation in a humid region in Kenya. Straw mulch was applied to runoff plots at 0, 3 and 5 Mg ha^{-1}, either incorporated into the 0 to 0.2 m soil layer or placed on the soil surface. The concentration of NH_4–N, NO_3–N, and PO_4–P in the runoff decreased exponentially and significantly with advancing time. The K concentration in the runoff followed a hyperbolic pattern with a minimum value between 33 and 55 days after planting. In all the treatments, the concentrations of the NH_4–N associated with the sediments decreased, in general, with advancing time. However, no corresponding progressive increases of the NO_3–N concentration in the sediments were observed. The concentrations of the sediments-associated NH_4–N, NO_3–N, PO_4–P and K in the mulch treatments were higher than those in the control, although these differences were not significant in all the rainstorms. Under this humid climate, either surface placement or incorporation of straw mulch at 3 or 5 Mg ha^{-1} enriched the soil with NO_3–N, PO_4–P and K. The soil was enriched with NH_4–N after incorporating straw mulch at 3 Mg ha^{-1} and or surface application at 3 and 5 Mg ha^{-1}.

Key words: Erosion, nutrient accumulation, nutrient loss, sediment enrichment, water quality.

INTRODUCTION

Soil erosion caused by water is a serious problem in cultivated lands in many parts of the world, and is a major cause of land degradation in Kenya (Tiffen et al., 1994). There is overwhelming evidence that runoff from agricultural land is a major diffuse source of nutrients and eroded sediment entering surface water reservoirs (Owino et al., 2006; Ntow et al., 2008; Poudel and Jeong, 2009). Moreover, in recent decades, deterioration in the quality of water in these water bodies has become an increasing environmental problem (Withers and Sharpley, 2008). Interventions like mulching with straw have been used in many situations to mitigate soil erosion and related agro-chemical transport from cultivated fields during rain or irrigation (Ahuja et al., 2006). For this purpose, straw mulch is commonly applied as a soil cover or incorpo-rated into the topsoil (Blanco-Canqui and Lal, 2007). The benefits of using straw mulch for reducing soil erosion and runoff are widely acknowledged. Gachene et al. (1997) observed that surface placement of maize straw in Kabete, Central Kenya increased infiltration rates and decreased soil erosivity while Danga and Wakindiki (2009) observed that surface application of 5 Mg ha^{-1} straw mulch decreased annual soil loss to 1.82 from 14 Mg ha^{-1} in the control. Nevertheless, research data on this topic is often conflicting and therefore inconclusive. For example, while Lentz and Bjorneberg (2003) reported that wheat straw application reduced soil erosion by increasing water infiltration, Blanco-Canqui and Lal (2007)

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Table 1. Some soil physical and chemical properties at the experimental site in Kenya.

Depth (m)	Sand	Silt	Clay	OC	N	P	pH	K	Ca	Mg	Na	CEC
	(g kg^{-1})							(cmol(+) kg^{-1})				
0-0.2	700	90	210	14.20	2.15	22.16	5.16	1.34	1.60	1.52	0.26	14.56
0.2-0.8	580	130	290	8.60	0.15	5.25	5.59	0.80	0.86	1.36	0.22	9.58
>0.8	760	80	160	7.40	0.05	5.60	5.63	0.75	0.80	1.20	0.20	8.56

CEC= Cation exchange capacity. OC= Organic carbon.

did not observe any increases in the infiltration rates in a ten-year study. Furthermore, nutrients are reported to have different modes of transport. For example, N is mostly transported in soluble form in percolating water while P is often transported in association with soil particles (Pionke et al., 2000). This scenario reflects the considerable influence that application of straw mulch may have on nutrient loss and accumulation in cultivated fields. While use of straw mulch for soil and water conservation has been extensively studied in the arid and semi-arid conditions of the tropics (Tian et al., 1995; Danga et al., 2009), few studies have assessed its effects on nutrients in the humid areas. These regions are generally characterized by high annual rainfall and relatively low evaporation rates. We hypothesized that the quantity and method of straw mulch application affects nutrient loss and accumulation in a cultivated field during the growing season in humid climate. Therefore, our objective was to investigate the effects of straw mulch application using different methods and quantities on nutrient loss and accumulation during a growing season in a humid region in Kenya.

MATERIALS AND METHODS

A field experiment was conducted at the Moi University farm in Kenya (35°18'E and 0°35'N, at an elevation of 2154 m above sea level). The experimental site with 7% slope had been under wheat crop for 5 years. Long term precipitation ranges from 900 to 1300 mm, with an annual average of 1124 mm. Rainfall is evenly distributed from March to September, with three distinct peaks in April, June, and August (Figure 1). Mean monthly maximum and minimum temperatures were 23 and 10°C, respectively, and temperature variability within a year was small. Soils of the experiment site are acidic, dark red, friable Rhodic Ferralsols underlain by tertiary phonolites and murram (FAO, 1990).

Pre-treatment soil characterization was done by taking profile pits and collecting soil samples, horizon-wise. These samples were taken to the laboratory, air-dried, crushed, and sieved to pass a 2 mm mesh. Physical and chemical properties of the soil (Table 1) were determined following standard procedures (Rowell, 1994). The experimental field was cultivated to a depth of 0.2 m with hand tools, and raked to produce a uniform tilth on 28 March. 2003. Fifteen erosion plots (2 m wide and 10 m long, separated by a 1 m wide buffer) were constructed across the slope, a month later. On 6 May, 2003, 39.3 kg ha^{-1} of P, as single-superphosphate, and 12.6 kg ha^{-1} of N, as calcium ammonium nitrate, was incorporated into the topmost 0.15 m soil layer by raking. Straw mulch treatments, which included three levels of wheat straw application (control with no mulch and 3 and 5 Mg ha^{-1} mulch) and two placement methods (deep placement into the top 0 to 0.2 m soil and surface placement) were administered simultaneously and wheat seeds (cv. 'Kenya Fahari C1') drilled across the slope at the rate of 125 kg ha^{-1}. Deep placement, however, was done before seeding using hand tools but surface mulch was applied soon after seeding. The trial was laid out in a completely randomized factorial design with three replicates. Agronomic practices like tillage, planting, plant population, and fertilizer application were in accordance with the local farmers' practices. Selection of the straw mulch treatments also was consistent with the local practices of using wheat straw for erosion control. Small- scale wheat farmers in Kenya generally use an ox- drawn mould board plough, which can incorporate up to 5 Mg ha^{-1} straw approximately 0 to 0.2 m deep.

Runoff and sediment was collected after each erosive rainstorm event (Figure 1). The contents of the tanks were thoroughly stirred after recording the total volume of the runoff (using a measuring cylinder) and 0.25 L samples of the suspension were drawn. These samples were transported to the laboratory, centrifuged at 5500 rpm and the supernatant liquid and the sediment separated for measurement of NH_4–N, NO_3–N, PO_4–P, and K. NH_4 and NO_3 were extracted using 2 M KCl solution, PO_4 by the Bray I, and the K by the Mehlich-1 method. The nutrients in the extracts and runoff water were determined by steam distillation for NH_4 and NO_3, by spectro-photometry at 660 nm for PO_4, and by ICP-AES for K (Rowell, 1994).

Soil samples were also taken from three positions in all erosion plots for chemical analyses both before (prior to the fertilizer application and seeding) and after the growing season. At each position, 0 to 0.2, 0.2 to 0.4, and 0.4 to 0.6 m depths were sampled. Available nutrient concentrations (NH_4 –N, NO_3–N, PO_4–P, and K) were determined (Rowell, 1994) after the soil samples were air-dried, crushed, and passed through a 2 mm sieve. The data were subjected to analysis of variance using the general linear model for completely randomized factorial design and regression. Treatment differences were examined using Duncan's new multiple range tests ($p < 0.05$; Buysse et al., 2004).

RESULTS AND DISCUSSION

The concentrations of the nutrients, NH_4–N, NO_3–N, PO_4–P, and K in the runoff water from the eight erosive rainstorms are presented in Figure 2, as functions of the days after planting, in the various treatments. One regression line was calculated for each nutrient (Figure 2) since no significant differences were found between the nutrient concentrations in the runoff water in the various treatments, except for NH_4–N, and K in the 1st erosive rainstorm. The concentrations of the nutrients in runoff are controlled mainly by their contents in the uppermost soil layer and the runoff properties. The concentration of NH_4–N, NO_3–N, and PO_4–P in the runoff decreased exponentially and significantly with advancing time (Figure 2). Inorganic fertilizer application and cultivation of the

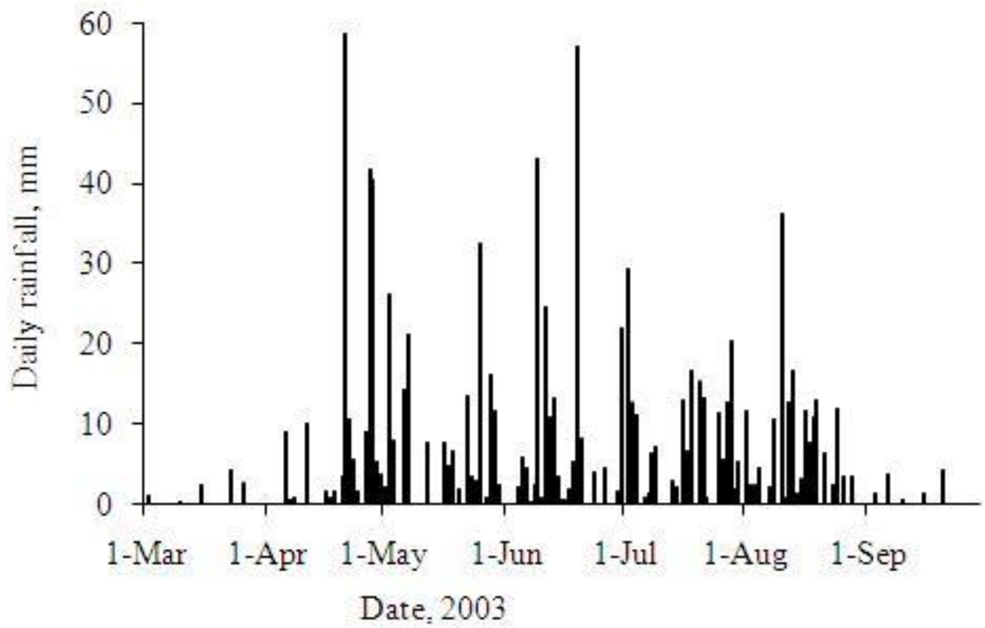

Figure 1. Daily rainfall distribution during the growing season at the experimental site in Kenya.

0 to 0.15-m upper soil layer before seeding increased the NH_4–N, NO_3–N, and PO_4–P contents. Therefore, their concentrations in the runoff water during the 1st erosive rainstorm were high (Figure 2) . In contrast, the sharp decreases in the concentrations of these nutrients in the runoff during the successive rainstorms could have resulted from their removal from the soil surface layer, mainly in the uptake by plants and microorganism, and by downward leaching, surface removal by the previous runoff events, nitrification of NH_4–N and denitrification of NO_3–N, and fixation of PO_4–P by sesquioxides in the soil. Potassium fertilizer was not applied to the experimental field; therefore, the K in the runoff water mainly resulted from the release of K from soil components. The K concentration in the runoff water followed a hyperbolic pattern with a minimum value of between 33 and 55 days after planting (Figure 2), which probably was caused by the high runoff and consequent K dilution during this period (Figure 2).

The concentrations of the nutrients, NH_4–N, NO_3–N, PO_4–P, and K that were associated with the sediments in the runoff water from the eight erosive rainstorms, in the various treatments, are presented in Figure 3, as functions of the number of days after planting. The interaction of the nutrients with the sediments was mostly by adsorption of the cationic NH_4 and K on the planar surfaces of the clay particles, adsorption of the anionic NO_3 and PO_4 at the broken edges of the clay particles, and fixation of PO_4 on Al and Fe oxides in the soil. Kaolinite, which is the dominant clay mineral of the soil in the experimental field (Obura et al., 2006), has relatively large edge surface with positive charge at pH <7 (van Olphen, 1991), therefore, the contribution of this edge surface to the adsorption of the anionic nutrients in the sediment could be high (Figure 3). In all the treatments, the concentrations of the NH_4–N associated with the sediments decreased, in general, with advancing time (Figure 3), most probably because of nitrification of the NH_4–N to NO_3–N. However, no corresponding progressive increases of the NO_3–N concentration in the sediments was observed (Figure 3), probably because of the denitrification process and downward leaching of this anion during the rainstorms. Moreover NO_3–N has been reported to be transported mainly in percolated water (Pionke et al., 2000).

The concentrations of the sediments- associated NH_4–N, NO_3–N, PO_4–P, and K in the mulch treatments were higher than those in the control, although these differences were not significant in all the rainstorms (Figure 3). These higher concentrations of the nutrients in the sediments in the mulch treatments could have been caused by two main factors: (1) Mineralization of the wheat straw, which would enhance the nutrients contents in the topmost soil layer; and (2) Higher clay percentages in the sediments in the mulch treatments than in the control (Danga and Wakindiki, 2009). The clay fraction was the component of the sediments that was most strongly associated with or enriched with the nutrients. It can be concluded that the 2nd factor was the dominant reason for the higher concentrations of nutrients associated with the sediments in the mulch treatments than with those in the control (Figure 3) since no significant differences were found between the nutrients concentrations associated with one weight unit of clay in the sediments, in the various treatments.

Available NH_4–N, NO_3–N, PO_4–P, and K, in the soil in

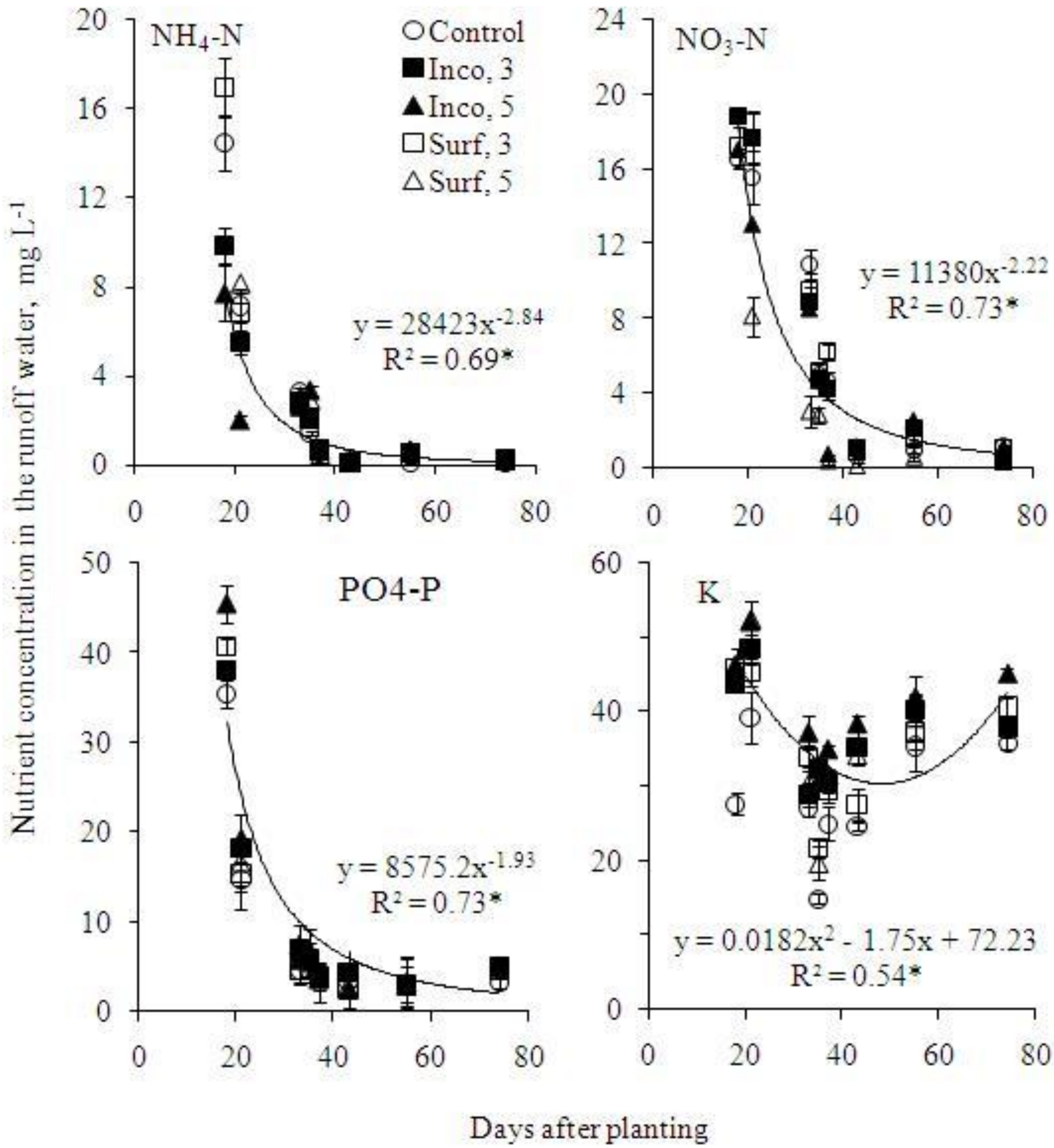

Figure 2. Concentrations of the various nutrients in runoff water from eight erosive rainstorms as functions of the number of days after planting in the control, 3 Mg ha^{-1} mulch incorporation (Inco. 3), 5 Mg ha^{-1} mulch incorporation (Inco. 5), 3 Mg ha^{-1} mulch surface placement (Surf. 3), and 5 Mg ha^{-1} mulch surface placement (Surf. 5). Bars represent standard deviations and * is significant R^2 value.

the various treatments before and after the growing season, are presented in Figure 4, as functions of soil depth. No significant differences were observed among the nutrients contents in the soil in the various treatments at the sampling before the growing season so one line (the dotted line) was plotted in Figure 4 for each nutrient; it represents the average values of that nutrient over all the treatments. In the control treatment, the contents of all the studied nutrients in the 0 to 0.2 and 0.2 to 0.4 m soil layers at the end of the growing season were, in general, significantly lower than those before the growing season (Figure 4) . These results indicate that in the control treatment, the uptake of nutrients by plants and their losses during the growing season were greater than the amounts

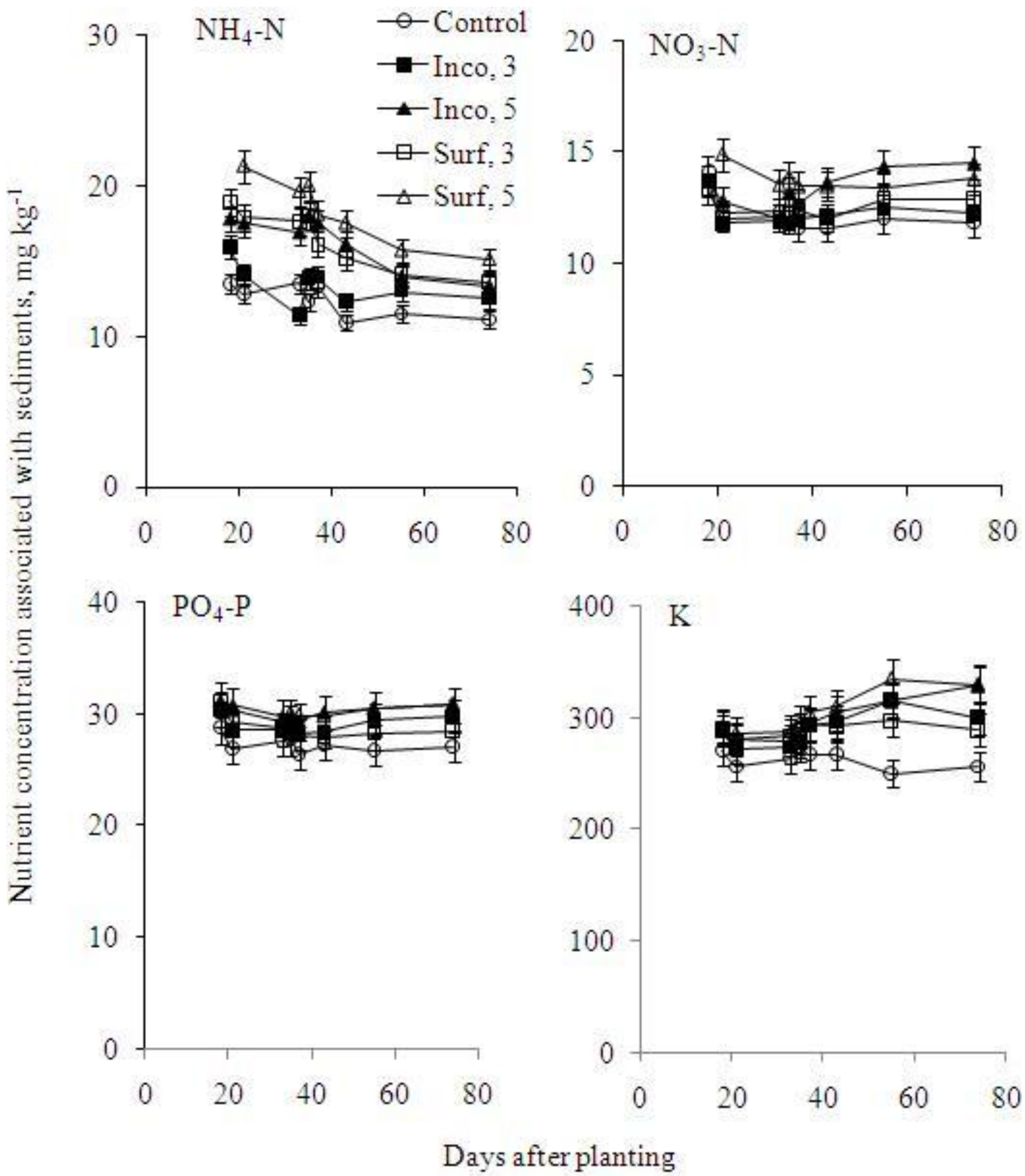

Figure 3. Nutrient loss in sediment from eight erosive rainstorms as functions of the number of days after planting in 3 Mg ha^{-1} mulch incorporation (Inco. 3), 5 Mg ha^{-1} mulch incorporation (Inco. 5), 3 Mg ha^{-1} mulch surface placement (Surf. 3), and 5 Mg ha^{-1} mulch surface placement (Surf. 5). The vertical bars represent standard deviations.

added to the field in the applied fertilizers.

In contrast, in the mulch treatments, the contents of the nutrients in the 0 to 0.2 and 0.2 to 0.4 m soil layers at the end of the growing season were significantly higher than those before the growing season, except for that of NH_4–N in the 5 Mg ha^{-1} surface treatments.

The NO_3–N content in the soil down to the 0.4 to 0.6 m layer increased significantly in the 3 and 5 Mg ha^{-1} surface treatments and in the 5 Mg ha^{-1} incorporation treatment, probably because of its high mobility in the soil (Pionke et al., 2000). It can be concluded from these results (Figure 4) that under this humid climate, either surface placement or incorporation of straw mulch at 3 or 5 Mg ha^{-1} enriched the soil with NO_3–N, PO_4–P and K. Secondly straw mulch incorporation at the lesser quantity of 3 Mg ha^{-1} or surface application at 3 and 5 Mg enriched the soil with NH_4–N.

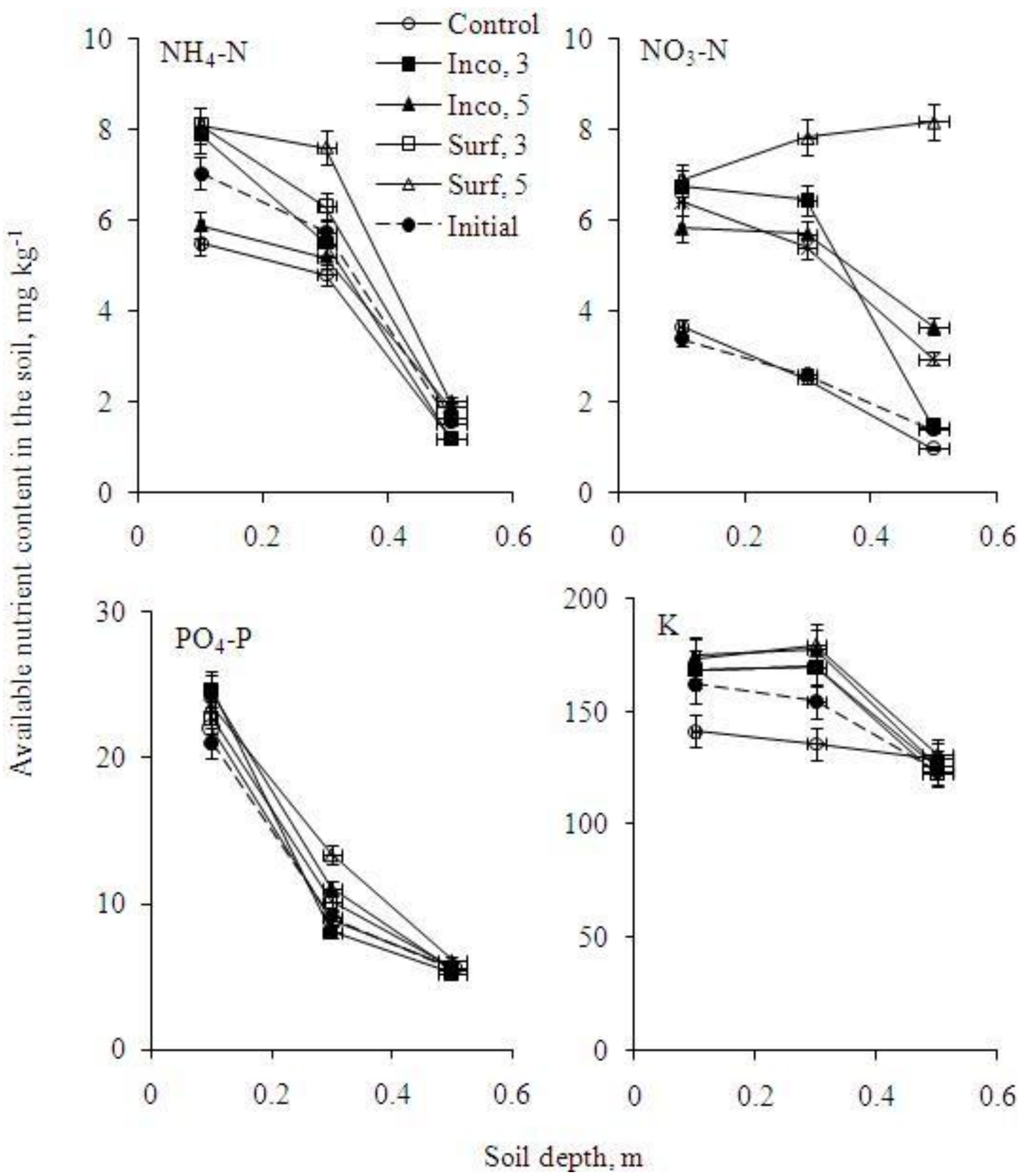

Figure 4. Nutrient contents at different soil depths before (initial) and after the growing season in the control, 3 Mg ha^{-1} mulch incorporation (Inco. 3), 5 Mg ha^{-1} mulch incorporation (Inco. 5), 3 Mg ha^{-1} mulch surface placement (Surf. 3), and 5 Mg ha^{-1} mulch surface placement (Surf. 5). Bars represent standard deviations.

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