# NITROGEN AND PHOSPHORUS REMOVAL WITH SURFACE RUNOFF FROM DIFFERENT LAND USES- A STUDY IN A SUB CATCHMENT OF UPPER MAHAWELI CATCHMENT AREA IN SRI LANKA

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*Abstract: Catchment of the river Mahaweli is the largest watershed in Sri Lanka. There are four major reservoirs built across river Mahaweli to generate hydropower and to irrigate agricultural lands in dry zone of the country. However, siltation and water quality deterioration of reservoirs are major issues when considering their sustainability. Main agricultural land uses in the Upper Mahaweli Catchment Area (UMCA) are tea plantations and vegetable farming on terraces in hilly slopes. Most of these terraces are not properly managed hence highly vulnerable to soil erosion. Hence, this study was conducted to measure surface runoff and removal of sediments and plant nutrients from vegetable plots in well managed Terraces (WMT) and Poorly Managed Terraces (PMT), Tea Plantations (TP) and Forest Gardens (FG) in a sub catchment of UMCA. Runoff plots were established to measure surface runoff and sediment loads in different land uses. Water soluble and sediment attached nutrient fractions were quantified. Soil chemical parameters of different land uses were also assessed using standard methods. A linear relationship between rainfall and surface runoff were observed in all tested land uses. The sediment transport rate was higher in vegetable plots on poorly managed terraces followed by well managed vegetable plots, tea land and natural forest. Nutrient removal with surface runoff was higher in vegetable plots compared to other land uses. A greater fraction of $NO_3$-N was removed as soluble form from farmlands but in the case of $PO_4$-P and $NH_4$-N removal of particulate fraction was prominent. Particulate losses were approximately 15 times higher than the dissolved losses for $NH_4$-N and approximately 100 times higher than the dissolved losses for $PO_4$-P. In the case of $NO_3$-N, soluble fraction was approximately 1.5 times higher than the particulate losses. Results conclude that, greater amount of nutrients and sediments are transported from vegetable plots on poorly managed terraces. Hence, proper maintenance of vegetable growing terraces coupled with effective nutrient management is very important to reduce downstream siltation and nutrient pollution in surface waters.*
*Keywords: farming on terraces, fractions of transported nutrients, soil erosion, surface runoff.*

## Introduction

In economic point of view, catchment of the river *Mahaweli* is the most important watershed in Sri Lanka because it feeds four major reservoirs viz. *Kothmale, Victoria, Randenigala, Rantambe* and diversion pond at *Polgolla*. These reservoirs generate over 54% of the country's hydropower requirement and irrigate about 300,000 ha of agricultural lands (Gamage, 1997). The Upper *Mahaweli* Catchment Area (UMCA) located 300 m above mean sea level, covers 3124 km$^2$ of the central highlands of the country. Soil erosion has been severe in the UMCA particularly on cropping lands due to a combination of various factors. Farming vegetable crops is the main livelihood of many households living in the UMCA. In general, vegetable gardens are highly vulnerable to soil erosion. Most of these lands have reported annual erosion rates over 75 t/ha thus significantly increasing the sediment yield in runoff and stream water (Bandaratillake, 1997). Continuous growing of crops on steep slopes, without having proper soil conservation, may lead to washing off fine soil particles which help the retention of plant nutrients in the soil, thereby reducing the crop yield. However, most of the farmers do not ready to accept this natural phenomenon, but attempt to enhance soil chemical fertility by applying over dosage of fertilizers and manure (Rajakaruna, *et al*., 2005). Kendaragama (2006) reported that most of the vegetable growers in the entire up country area incorporate inorganic fertilizers at the rates 2-3 times higher than the doses recommended by the Department of Agriculture. Soil erosion is the major process which involved in nutrient export from croplands.  Sediments and plant nutrients removed from vegetable gardens along with surface runoff may significantly contribute to sedimentation in downstream reservoirs and lowering water quality. The loss of nutrients from farmlands is influenced by various factors. The rate of fertilizer application and the maintain of soil conservation measures are the main agronomy related factors whereas time, duration and intensity of rainfall and other soil related factors are considered as natural factors. In agriculture, a terrace is a leveled section of a steep cultivated area, designed as a method of soil conservation by lowering or preventing rapid surface runoff. Nutrient losses from terraced farming systems may highly varied on the degree of terraces management**.** Nearly 70% of vegetables in UMCA

are grown in Poorly Managed Terraces (PMT) which are not constructed and maintained properly. Most of these terraces are slanted steps where no mechanism to reduce the volume and the velocity of surface runoff. Well Managed Terraces (WMT) consists of flat terrace bed (Bench Terraces) which are very effective in terms of runoff control (Stirrat, undated). However, farmers rarely construct WMT due to several limitations. In the above context, this study was conducted to assess existing soil nutrient levels in different land use systems in a sub catchment of UMCA, to quantify sediment and nutrient transport from vegetable plots located in well and poorly managed terraces and compare the results with sediment and nutrient transported from other land uses in the catchment.

## Methodology

### Different land uses selected for the study

The study was conducted in *Kurundu Oya* sub catchment of the UMCA. *Kurundu Oya* is a main tributary of river *Mahaweli* draining into *Randenigala* reservoir. *Kurundu Oya* catchment consists of all the farming systems and other land uses exist in the UMCA. Four land uses include intensive vegetable farming on Well Managed Terraces (WMT), intensive vegetable farming on Poorly Managed Terraces (PMT), Tea Plantation (TP) and a Forest Garden (FG) were selected. The forest garden land use was considered as the control in this field experiment. Well Managed and Poorly Managed Terraces were differentiated based on physical characteristics and management practices (Table 01).

Table 01: Features of WMT, PMT, TP and FG selected for runoff study

|  | Physical Characteristics | Management Practices | Vegetaion/Crop |
|---|---|---|---|
| Well Managed Terraces | Slope – About 60%<br><br>Terrace bed – Horizontal<br><br>Soil great group – Red Yellow Podzolic | Edge of the terrace bed is protected by a grass strip<br><br><br>Surface flow is diverted by interceptor drains | Carrot<br><br>Capsicum |
| Poorly Managed Terraces | Slope – About 60%<br><br>Terrace bed – Slanted<br><br>Soil great group – Red Yellow Podzolic | Edge of the terrace bed is not protected<br><br><br>No interceptor drains | Carrot<br><br>Capsicum |
| Tea Plantation | Slope – About 60%<br><br>Terrace bed - Horizontal<br><br>Soil great group – Red Yellow Podzolic | Edge of the terrace bed is protected by a stone bund<br><br>Surface flow is diverted by interceptor drains | Tea |
| Forest Garden | Slope – About 60%<br><br>No terraces<br><br>Soil great group – Red Yellow Podzolic | No special management | Mixed perennials |

**Soil sampling to determine chemical characteristics**

Soil samples were collected randomly from 0 – 30 cm depth and made into one composite sample. A sub sample from the composite samples was used for laboratory analysis. Samples from vegetable farming systems in both WMT and PMT were taken prior to land preparation. Sampling of tea growing soils was done before applications of any fertilizers. Soil samples were also collected from natural forest in the same catchment for the purpose of comparison. Same agronomic practices (ie: land preparation, fertilization and weeding) were adopted for both WMT and PMT as practiced by the farmers. General management practices of tea plantations were adopted for runoff plot established in the tea land. All collected samples were air dried and passed through a 2 mm sieve prior to analysis. All the soil analysis were conducted in Soil Science Laboratory at *Rajarata* University of Sri Lanka.

**Runoff measurement for sediment and nutrient**

Runoff study was conducted in Kurundu Oya sub catchment of UMCA during 12 months period. Surface runoff coming from three land uses was measured and analyzed for sediment and nutrients such as $NO_3$-N, $NH_4$-N and $PO_4$-P. Four experimental plots (25x10m) were established on WMT, PMT, TP and FG which were located in same slope category (about 60% slope). Calibrated rectangular weirs were installed with sediment traps at the outlet of each plots and discharge was measured. Precipitation was recorded with the help of a Tipping Bucket rain gauge installed at the same location. Measurements were taken in 16 independent rainfall events occurred during study period. Water samples from surface runoff were collected to estimate particulate and soluble nutrients (i.e. ammonium N, nitrate N and P) removal from each plot. At the same time soil sampling was carried out prior to the particular rainfall event to estimate the available nutrient levels (i.e. ammonium and nitrate N and available P) in the soil. Samples taken from runoff study were transported to the Soil and Water Engineering Laboratory of the Department of Agricultural Engineering, University of Peradeniya, and stored in a deep freezer for analysis.

**Analysis of nutrients in the soil, sediments and runoff water**

Soil samples were analyzed to determine soil properties. Dry sieving technique was used to determine gravel percentage of soil samples. Soil pH, EC, $NO_3$-N, $NH_4$-N, available P, exchangeable K and organic matter content were measured using following analytical methods (Table 02).

Table 02: Analytical methods of chemical parameters

| Chemical parameter | Method of analysis |
|---|---|
| Soil pH (1: 2.5 soil: water) | Potentiometric 1:2.5 soil water suspension (Jackson, 1973) |
| Soil EC (1:5 soil: water) | Soil water suspension 1:2.5 (Bruah and Barthakur, 1997) |
| Soil organic matter | Walkely and Black (Walkely and Black, 1934) |
| Available P | Olsen's method (Olsen and Sommers, 1982) |
| $NO_3$ -N | Sodium salicylate method (Dharmakeerthi et al, 2007) |
| $NH_4$-N | Sodium salicylate method (Dharmakeerthi et al, 2007) |
| Soil Exchangeable K | Ammonium acetate (Jackson, 1973) |

In the analysis of suspended sediments, samples were filtered through Whatman No.01 filter papers. The sediments retained after filtration was dried at $40^oC$ for 24 h weighed and compared

with the weight of another filter paper after filtration of an equal volume of pure water as the control. The dried sediment samples were then used for nutrient analysis. The particulate fraction of P, ammonium and nitrate N of sediment and filtrate samples were determined using same analytical procedure given in table 02.

### *Procedure of statistical analysis*

The objective of the statistical analysis was to identify the significance of land use on existing soil parameters in the catchment. In addition, it was attempted to elaborate the significance of terracing and available soil nutrient concentration on nutrient export with runoff from farm plots. The mean comparison was done using single factor Analysis of Variance (ANOVA) F test. Multiple means comparison was carried out with Duncan Multiple Range Test (DMRT) using SAS statistical software. The correlation between different parameters of the runoff study was evaluated using $R^2$ values obtained from regression models.

## RESULTS AND DISCUSSION

### *Gravel content in the top soil*

There are a number of indicators which have been developed to measure the severity of soil erosion. The gravel content (particles > 2mm in diameter) of the top soil (0-30 cm depth) is one of the indicators widely used in present erosion studies (Botschek *et al*., 1998).

The average gravel percentage of the top soil in four land uses in the catchment ranged from 14 to 35% (Table 03).  PMT showed significantly higher gravel percentage of 35% compared to other three land uses. In general, land availability of the catchment for farming is highly limited. Therefore, vegetables are grown on very steep slopes, which are not suitable for any purpose other than planting of tree species. Most of these lands belong to high erosion hazard category in which soil loss is around 75 t/ha/year (Stirrat, 1997). During land preparation, soil is directly exposed to intensive rainfall which is resulted severe erosion hazard.  As a result, soil is very shallow and depths are reduced to few centimeters. There are many vegetable growing locations

where soils are eroded down to decomposing parent material. Nayakakorale (1998) reported that annual vegetable farming on poorly managed terraced lands cause severe soil erosion in *Nuwara Eliya* district. Well managed terraces exhibited gravel percentages of 28% which was comparatively low with respect to PMT. However, this gravel percentage is moderately higher compared to top soil gravel content of FG. Soils in WMT were protected by stone bunds and vetiver grass strips. Apart from that terraces were properly maintained. However, high cropping intensity combined with improper cultural practices may be the possible reason for washing off of finer soil particles. The top soil gravel percentage of tea plantations was 22%. It was less than the gravel content of PMT and WMT. Even though, tea provides a good ground cover, surface soil is subjected to severe erosion during land preparation, young stage of the plantation and the period after pruning. The damage occurred during these critical periods is very difficult to recover even after ground cover is well established. Soils sampled from FG reported lowest gravel percentage of 14% showing potentially low vulnerability for soil erosion. Forest gardens in the area consist of different tree species with different canopy heights. The dense vegetative cover and thick layer of litter on the ground surface protect soil from direct impact of raindrops and rapid movement of surface runoff.

Table 03:  Basic soil characteristics of different land uses

| Land use | Gravel % | Soil pH | Soil EC $dSm^{-1}$ | Soil OM % | Av. P ppm | Ex. K ppm | Av. N ppm |
|---|---|---|---|---|---|---|---|
| WMT | $22^{bc}$ | $5.5^{b}$ | $0.24^{a}$ | $2.8^{b}$ | $103.5^{a}$ | $615.5^{a}$ | $32.5^{a}$ |
| PMT | $35^{a}$ | $5.7^{ab}$ | $0.22^{ab}$ | $2.2^{b}$ | $55^{b}$ | $423^{b}$ | $16.2^{b}$ |
| TP | $28^{b}$ | $5.8^{ab}$ | $0.21^{ab}$ | $2.1^{b}$ | $24^{c}$ | $128^{c}$ | $9.8^{c}$ |
| FG | $14^{c}$ | $6.2^{a}$ | $0.18^{b}$ | $3.8^{a}$ | $16.4^{c}$ | 118c | $9.2^{c}$ |

*Means in the columns with same superscript are not significantly different at P ≤ 0.05

### *Soil pH and EC*

Most of the soils found in intermediate and wet zone in up country of Sri Lanka are strongly acidic in reaction (Mapa *et al*., 2005). Similar to that, pH of the all four land uses ranged from 5.5 to 6.2 indicating acidic to moderately acidic in nature. (Table 03). No significant difference in soil pH was observed in agricultural land uses. High leaching and adding of acid forming inputs may be the most significant factor for acidity development in agricultural land uses. Soil pH of FG showed significantly higher value probably due to high amount of basic cations in exchangeable sites. Electrical Conductivity of soil sampled from four land uses ranged from 0.18 to 0.24 dSm$^{-1}$ indicating less potential to salinity development (Table 03). However, WMT, PMT and TP showed significantly higher EC levels compared to FG soils. Most possible reason could be application of chemical fertilizers for vegetable crops and tea plantations. In general salt accumulation is not that problematic in all farming systems possibly due to removal of soluble salts through surface runoff.

### *Soil organic matter*

Soil Organic Matter (SOM) content provides better indication about the degree of soil fertility in terms of crop production. Weil (1982) found that SOM content in the least eroded soil is significantly higher than that in the highly eroded soils. However, a proper assessment of fertility loss by soil erosion in Sri Lanka has not been conducted so far. Organic matter content of different land uses varied from 2.1 to 3.8% (Table 03). A significantly higher (P< 0.05) SOM content (3.8%) was observed in FG soil compared to other three land uses. This can be attributed to the continuous accumulation of plant debris and less erodibility of the forest soil. Soil sampled from WMT and PMT reported SOM contents of 2.8 and 2.2 respectively. Excessive use of organic manure such as poultry and cattle manure is a common practice among vegetable growers in the UMCA. Therefore, soil contains fairly high organic matter content despite its high vulnerability to soil erosion. Wijewardane and Yapa (1999) reported that application of poultry manure for vegetable farming is more popular among farmers in the up country because it

increases the production significantly when compared to other organic manure such as cattle manure and compost. Tea plantation soil showed least SOM contents of 2.1%. Since organic matter application is not commonly practiced, tea soils are generally low in organic carbon. Gamage (1997) reported that 165 kg of organic matter was removed from one hectare of young tea (without mulch) during 3 months period due to soil erosion.

**Soil available N**

A significant difference ($P < 0.05$) was observed in available N contents among different land uses (Table 03). Most of the agricultural land uses have shown significantly higher nitrogen concentration compared to that of non-agricultural land uses. Highest available N concentration of 32.5 ppm was reported in WMT followed by 16.2 ppm in PMT. The reason could be the application of very high doses of inorganic fertilizers and poultry manure into vegetable plots. In general, hybrid vegetable varieties grow fast and produce remarkably higher yield. Hence, response to nitrogenous fertilizers is very high. Therefore, farmers tend to apply fertilizer mixtures with high nitrogen levels which are promoted by fertilizer selling companies.

*Available P*

Available P content of different land uses vary significantly (Table 03). Both WMT and PMT showed significantly higher available P content compared TP and FG. The highest available P content of 103.5 ppm was reported in WMT. It was significantly higher compared to 55 ppm of available P content reported in PMT. Since P fixation is high in tropical soils, vegetable growers tend to apply over doses of chemical fertilizers to obtain better yield. Hence, vegetable growing soils contain excessive amount of accumulated P in intensive farming areas. The available P content of tea growing soil was 24ppm indicating slightly higher level. The possible reason could be application of rock phosphate in regular intervals.

*Exchangeable K*

Potassium is another important element for plant growth which exists in the soil in different forms. The mean exchangeable K levels showed significant difference (P<0.05) between different land uses (Table 03). Very high K contents were reported in vegetable plots in WMT (615.5 ppm) and PMT (423 ppm). Most of the vegetable growers apply fertilizer mixtures recommended for potato for all the vegetables because it is available in any agro-chemical shop in the area. These mixtures contain high amount of K because it is an essential element for tuber formation. Therefore, a gradual increase of K content especially in vegetable growing soils is being observed. Potassium buildup in vegetable growing soils was reported in 1998 in several locations in Nuwara-Eliya district (Nayakekorala, 1998). The critical level of K for most of the annual crops is about 200 ppm.

**Rainfall and runoff relationship**

The relationship between rainfall and surface runoff associated with FG, TP intensive vegetable farming in WMT, PMT which were measured using runoff plots are shown in Figure 01. A positive linear correlation was observed between rainfall and surface runoff in all the plots. Runoff volumes were grater in PMT followed by WMT, TP and FG. The maximum interception of rainwater occurred in the FG because of well established canopy cover and the litter. Tea plantation also showed high amount of rainwater interception possibly due to well managed vegetative cover. Highest runoff coefficient of 0.2 was observed in PMT which was 13 times higher than the runoff coefficient (0.015) of FG and 2 times higher than the runoff coefficient (0.1) of WMT (Table 04). The results indicate that more sediment can be lost from vegetable plots on PMT when compared to the WMT in the same slope category. The possible reason could be interception of surface runoff is not very effective in PMT because of low infiltration, slanted beds and unprotected edges of the bunds.
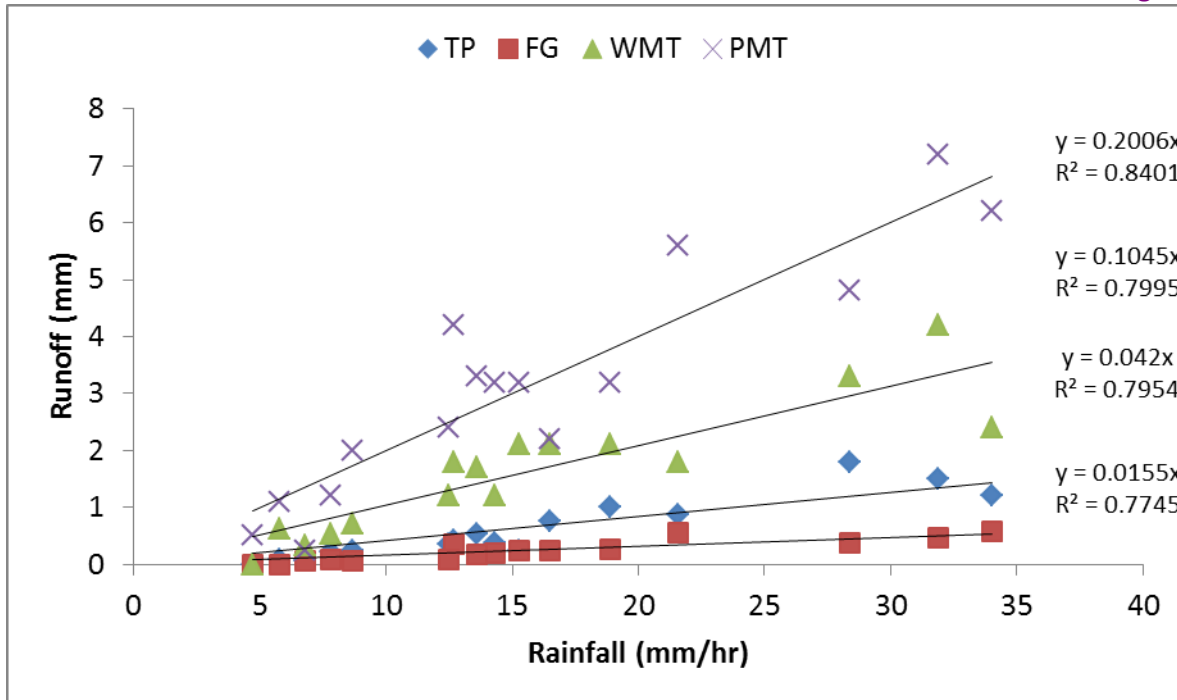
Figure 01: Rainfall runoff relationship in the FG, TP, PMT and WMT

Correlation analysis showed a linear relationship between rainfall and runoff in all four plots indicating fairly high $R^2$ values. The highest $R^2$ value of 0.84 and the highest gradient of 0.02 were noted in PMT. It shows that response to rainfall is grater in terms of runoff generation of PMT compared to the WMT, TP and FG under similar physiographic conditions. Soil analysis revealed that gravel content of vegetable growing plots were fairly high indicating grater vulnerability to soil erosion. This scenario can be more severe in PMT compared to WMT. In general, highly eroded soils exhibit low infiltration because of deteriorated soil structure. This may be the possible reason to explain increased surface runoff reported in PMT.

**Rainfall and soil loss relationship**

The amount of sediment transported was higher in PMT followed by the WMT, TP and FG (Figure 02). Grater $R^2$ values were reported in WMT and PMT indicating a strong relationship between rainfall and sediment transport compared to FG. The highest sediment export coefficient of 1.29 was observed in PMT which is about 1.5 times higher than the sediment export coefficient (0.84) of WMT and 129 times higher than the sediment export coefficient (0.1) of FG (Table 04). Since soil surface is covered by plant debris, the rate of soil erosion is very low in FG. Apart from that, the lowest runoff volume was also reported in FG. On the other hand incapability to reduce surface runoff may be the reason for the elevated soil loss associated with PMT. The plot on WMT was also noted in producing small amount of soil erosion which is ascribed the fact that WMT encourage sediment deposition which results in decreased sediment and sediment bound nutrient loss. Although, plots established on WMT and PMT had annual crops the vegetation of TP and FG were entirely different. Then it is clear that, the crop factor (C) was mainly responsible to low sediment yield generated from TP and KFG. Despite the same crop, slope and plot size in WMT and PMT, the sediment yield was significantly higher in PMT indicating the effect of erosion control factor (P). The strip of vetiver grass established at the edge of PMT serve as filter to reduce sediment load transported with runoff. In addition, interceptor drains in WMT reduces runoff velocity and increases the time of opportunity for infiltration.
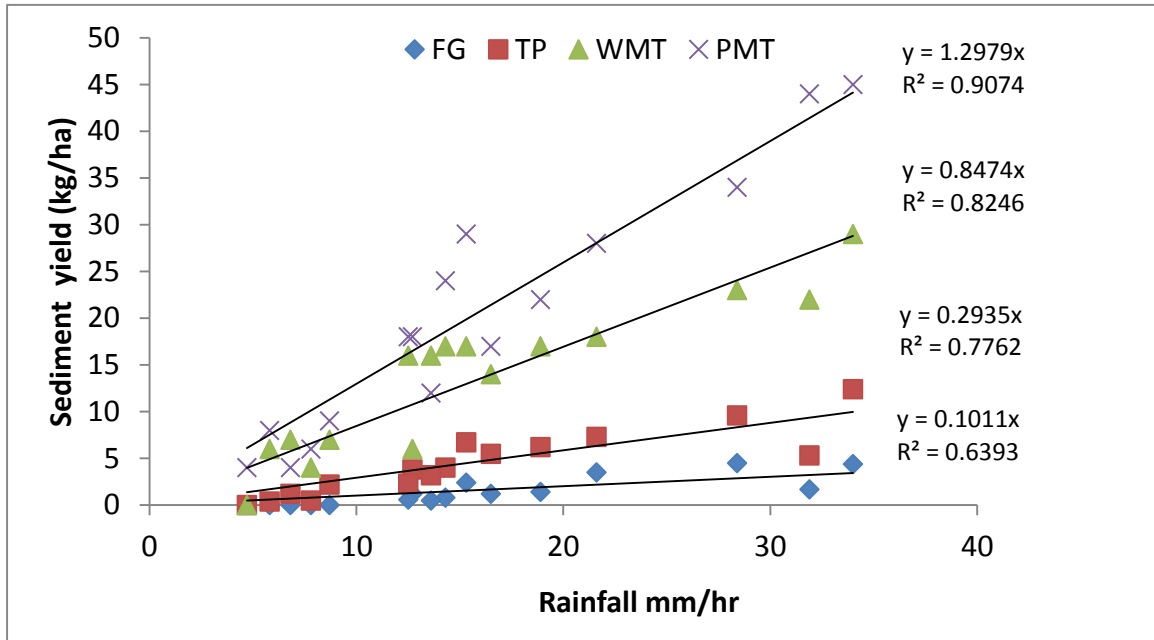
Figure 02: Rainfall soil loss relationship in FG, TP, WMT and PMT

Table 04: Runoff and sediment export coefficients of WMT, PMT, TP and FG

| | Runoff coefficient of the equation | Sediment export coefficient of the equation |
|---|---|---|
| Well Managed Terraces (WMT) | 0.1 | 0.84 |
| Poorly Managed Terraces (PMT) | 0.2 | 1.29 |
| Tea Plantation (TP) | 0.04 | 0.29 |
| Forest Garden (FG) | 0.02 | 0.1 |

**Soil available nitrogen and nitrogen export relationship**

*NO$_3$- N and NH$_4$-N removal from four land uses*

Particulate or soluble fractions of NO$_3$-N and NH$_4$-N were not detected in the runoff generated from FG with respect to all measured rainfall events. However, fair amount of suspended sediment was observed in the surface runoff generated from FG plot. The available nutrient level reported in the FG soil is significantly low compared to other tested land uses. This suggests that nutrient export is independent from sediment transport under low nutrient concentration in the soil. Though very low amount NO$_3$-N were detected in surface runoff, no relationship was observed between NO$_3$-N and soil available N in tea growing soil. In addition sediment contained NO$_3$-N and NH$_4$-N were also remained in very low level indicating no contribution of tea plantations to nitrate pollution in surface waters.

NO$_3$-N export from WMT and PMT showed positive correlation with high $R^2$ value (Figure 03 & 04). The soil available N level in both type of terraces varied from 100 to 325 kg/ha over the measured period because frequent application of fertilizers and organic manure into the crop. The export coefficient of soluble nitrate reported in PMT and WMT was approximately 1.5 times higher than that of particulate nitrate indicating soluble nitrate loss is more significant when compared to the particulate nitrate loss (Table 05).
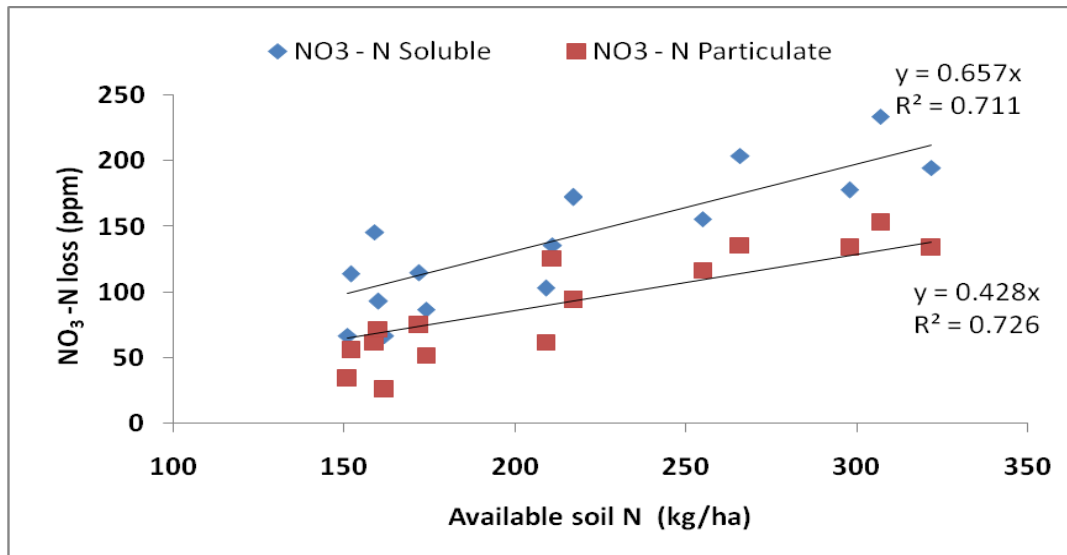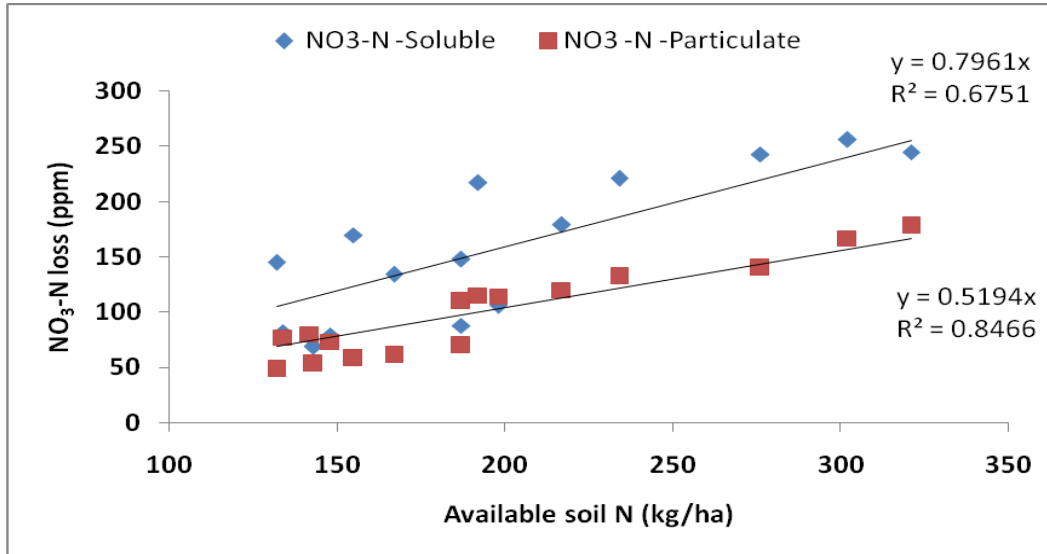
Figure 03: Relationship between soluble and particulate $NO_3$-N loss with runoff and soil available N concentration in the WMT

The results revealed that $NO_3$-N transport in soluble form is dominant compared to the particulate fraction exist in the surface runoff in both WMT and PMT. Moreover, both fraction of nitrate transfer has increased with increase in the concentration of available soil N irrespective of the type of terrace. Since nitrate is an anion, its adsorption to negatively charged soil particles is extremely low. Therefore, more $NO_3$ is in soluble form in nature hence highly susceptible to leaching and removal with surface runoff.

Figure 04: Relationship between soluble and particulate $NO_3$- N loss with runoff and soil available N concentration in the PMT

The similar trend was observed by Kato *et al.* (2009). They reported that dissolved fraction of $NO_3$ is dominant in the runoff measured during one year period in an agricultural watershed adjacent to Lake Kasumigaura, Japan. Dayawansa (2002) also confirmed this pattern of higher concentration of $NO_3$ in surface runoff through analyzing data generated from 1 ha of land cultivated with alfalfa and corn.

Table 05: $NO_3^-$, $NH_4$-N and $PO_4$-P export coefficients of WMT and PMT

| | $NO_3$-N | | $NH_4$-N | | $PO_4$-P | |
|---|---|---|---|---|---|---|
| | Particulate | Soluble | Particulate | Soluble | Particulate | Soluble |
| WMT | 0.42 | 0.65 | .029 | .002 | .099 | .001 |
| PMT | 0.51 | 0.79 | .073 | .005 | .108 | .001 |

The $NH_4$-N transported with surface runoff has a positive and linear correlation with available N concentration of the soil in WMT and PMT (Figures 05 and 06). Loading of $NH_4$-N also observed in the soil because over application of chemical fertilizers and poultry manure is a common practice in vegetable farming. In contrast to $NO_3$-N, sediment attached particulate fraction of $NH_4$-N was greater in runoff compared to the soluble fraction.
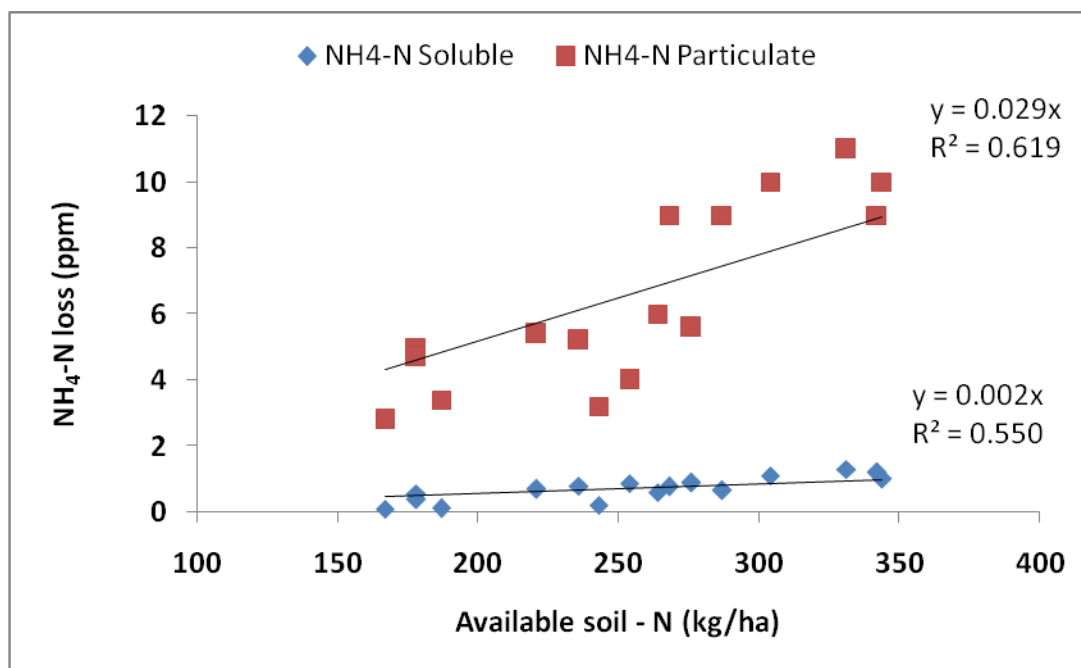


Figure 05. Relationship between particulate and soluble $NH_4$- N loss with runoff and soil available N concentration in the WMT.

According to export coefficients, the particulate fraction of $NH_4$-N loss reported in WMT and PMT were nearly 15 times higher than that of soluble fraction (Table 6). However, particulate loss reported from PMT was well above (ie. more than 2 times) higher than particulate loss from WMT. This may possibly due to higher amount of sediment transport from PMT. However, the correlation of both fractions with soil $NH_4$-N concentration was not much strong compared to the same correlation of $NO_3$ -N.

It is a well known fact that retention of $NH_4$-N ion in the soil cation exchange complex is extremely high. Therefore, only a little would be reached to the soil solution. Perhaps this may be the reason for low amount of dissolved fraction of $NH_4$-N detected in the runoff.
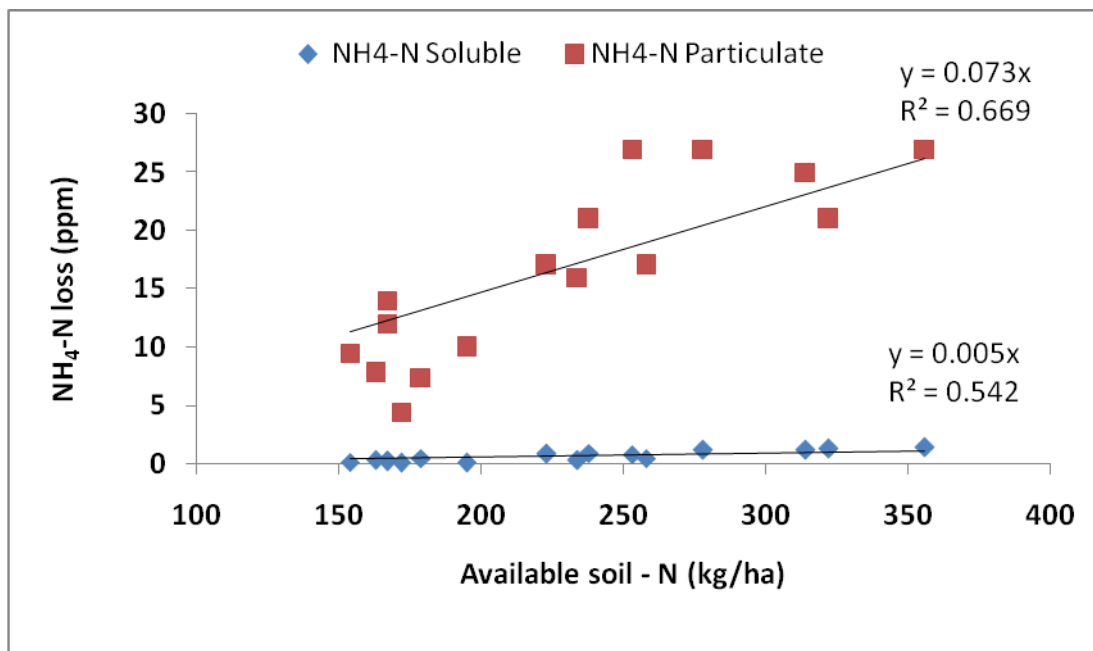


Figure 06: Relationship between particulate and soluble $NH_4$ -N loss with runoff and soil available N concentration in the PMT

**Soil available P and $PO_4$-P export relationship**

Particulate or soluble fractions of $PO_4$-P were not detected in the runoff generated from TP and FG with respect to all measured rainfall events. The most possible reason could be available P level reported in the TP and FG soil was significantly low compared to other tested land uses.

However, inorganic P transported with runoff from vegetable plot in WMT and PMT increases with the increasing rate of inorganic P available in the soil (Figure 07 and 08). The possible reason is increased amount of P available in vegetable growing soil and more sediment transport

with particulate P (P attached to sediments) with increasing volume of surface runoff. Miyoshi, (1978) also observed a positive correlation between surface runoff and P transport. Mihara *et al* (2005) reported that coefficients of nitrogen and phosphorus transfer increased with increasing average concentration of nitrogen and phosphorus in the soil. Therefore, surface runoff and erosion can be considered as main P transport mechanisms in the soil system (Sharpley *et al*., 1993). However, findings of some other studies indicate that this relationship does not always exist. A reduction of particulate P content has been reported with the increasing sediment concentration in the surface runoff in an agricultural watershed located in Southern Plains, USA (Pieterse, *et al.*, 2003).
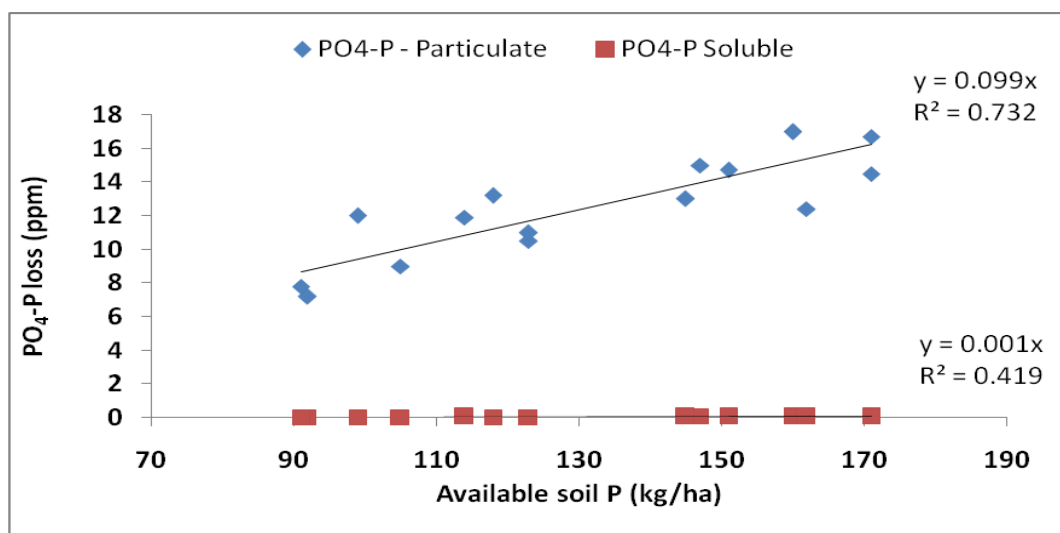


Figure 07: Relationship between particulate and soluble inorganic P loss with runoff and soil available P concentration in the WMT

Phosphate export coefficients indicated that, ratio between particulate and soluble forms of P loss from WMT and PMT were approximately 100 (Table 05). Mihara *et al.* (2005) also confirmed this pattern of particulate and soluble P losses with surface runoff generated from agricultural land uses. Their experimental results showed that particulate P losses were approximately 100

times higher than the dissolved losses of P hence suspended sediments carry most of the P lost
from agricultural fields. This shows the nature of P sorption in the soil matrix. Researchers have
emphasized that P sorption increased significantly at the level of added P in the soil. Many
factors such as presence of humus and availability of Fe and Al affect P sorption in the soil. The
great soil group dominant in the study area is Red Yellow Podzolic with prominent B horizon
which contain fairly high amount of Fe, Al and decomposing organic matter indicating high P
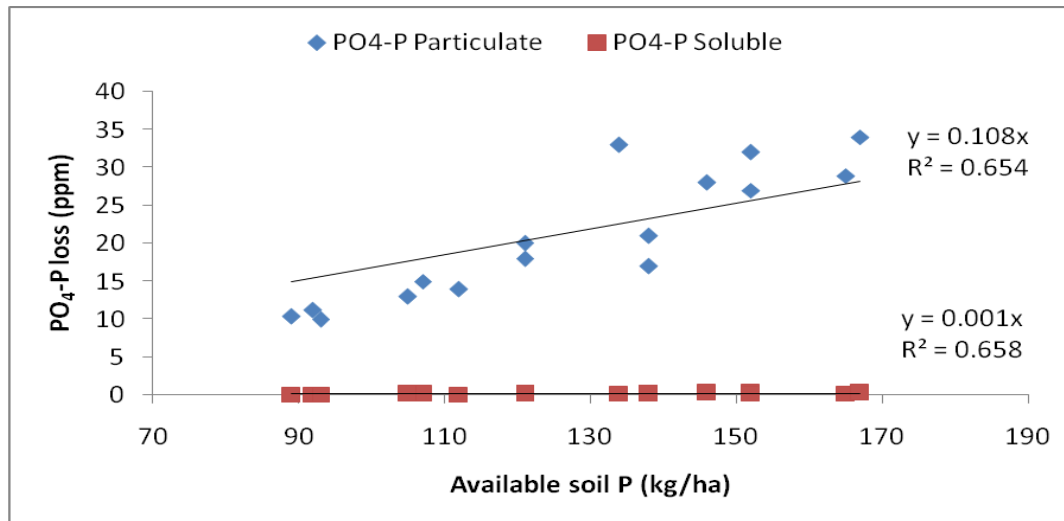sorption capacity (Mapa *et al*., 1999).



Figure 08: Relationship between soluble and particulate inorganic P loss with runoff and soil
available P concentration in the PMT

When compared to WMT, PMT showed approximately two times higher P export with surface
runoff. This may probably due to increased volume of runoff and sediment yield reported in
PMT. This indicate not only the land use but also appropriate management of terraces also an
important factor which determine nutrient export. Similar to N, the concentration of inorganic P
of the soil in both types of terraces was extremely high and it ranged from 90- 170 kg/ha. Since
soil nutrient level is strongly and positively correlated with nutrient transport with runoff, this
scenario indicates extremely high risk of nutrient pollution in water bodies. Heathwaite *et al.*

(1996) reported that soluble and particulate P increase in surface runoff with application of chemical fertilizers. Similar observation also made by Kothyari *et al.* (2004) by reporting a strong positive relationship between soil loss and nutrient loss in the Bhetagad watershed in Central Himalaya in India.

## Conclusions

Most of the soil parameters of tested land uses were significantly varied. Well managed terraces have remarkably high soil nutrient level compared to other land uses exist in the catchment. Hence, the influence of agricultural intensification on nutrient accumulation in the soil is clearly evident. Poorly managed terraces generate greater volume of surface runoff and sediment load compared to TP, FG and WMT. When compared to FG, WMT and PMT exhibited 10 and 20 times higher volume of surface runoff and 8 and 12 times higher sediment load respectively. This indicates adopting appropriate management practices can significantly reduce soil loss from terrace beds. A positive correlation exists between soil nutrient concentration and nutrient transport with surface runoff in both WMT and PMT. However, nutrient export from PMT is much greater compared to WMT. The content of nutrients in surface runoff generated from TP and FG are negligible comparing to WMT and PMT. A greater fraction of $NO_3$-N is removed as soluble form from farmlands but in the case of $PO_4$-P and $NH_4$-N removal of particulate fraction is prominent. Particulate losses are approximately 15 times higher than the dissolved losses for $NH_4$-N and approximately 100 times higher than the dissolved losses for $PO_4$-P. In the case of $NO_3$-N soluble fraction is approximately 1.5 times higher than the particulate losses. Less nutrient content exported from TP and FG indicates that the main reason for increasing N and P in surface water is intensive agriculture. Moreover, greater amount of nutrients and sediments are transported from vegetable plots on PMT. Hence, proper maintenance of vegetable growing terraces is very significant in order to reduce nutrient pollution in surface waters.

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