Nutrient and Sediment Transport from Two Different Agriculture Land Uses

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Abstract

For the past decades, the number of research on Non Point Source (NPS) pollution has increased due to its nature being the major source of pollution to water degradation around the world. The study of NPS in Malaysia is scarce especially in agricultural areas. This research aims to provide quality and quantity of runoff pollutant loadings from an agricultural farm at a plot scale. Two plots were constructed at different land use (fruit orchard and vegetable farm). Tipping bucket flow gauges were installed at the end of each slope to measure runoff volume and collect water sample. The water samples were collected over a period of three months, immediately following rainfall events. Nine water parameter (Nitrite, Nitrate, Ammonia, Total Nitrogen, Phosphate, Total Phosphorus, Chemical Oxygen Demand, Total Suspended Solid, pH) analyses were conducted by using the DR5000 UV-Spectrometer. Result indicated that Total Suspended Solid (TSS) from fruit orchard is much higher while the nutrient and Chemical Oxygen Demand (COD) in vegetable farm is higher in comparison. COD is higher in vegetable farm runoff than fruit orchard since organic fertilizers such as chicken manure are applied. Runoff collected is much higher in the fruit orchard since no effective cover crop there. Overall, the results confirmed that runoff waters from agricultural areas are heavily polluted and could affect the nearby receiving water in long term if it is not monitored and controlled.

Keywords: NPS, Nutrients, Sediment, Runoff, Fertilizer

Abstrak

Sejak 10 tahun yang lalu, bilangan penyelidikan mengenai pencemaran tanpa titik (NPS) telah meningkat kerana ia merupakan sumber utama pencemaran air permukaan di seluruh dunia. Kajian ini bertujuan untuk menyediakan kualiti dan kuantiti bahan pencemaran air larian dari sebuah ladang pertanian pada skala plot. Dua plot telah dibina pada aktiviti pertanian yang berbeza (kebun buah-buahan dan ladang sayur-sayuran). Tolok air aliran larian permukaantelah dipasang pada akhir setiap cerun untuk mengukur jumlah air larian permukaan dan pengumpulan sampel air. Sampel air dikutip selama 3 bulan.
Analisis untuk 9 parameter air (Nitrit, Nitrat, Ammonia, Jumlah Nitrogen, Fosfat, Jumlah Phosphorus, Keperluan Oksigen Kimia, Pepejal Terampai, pH) telah dijalankan menggunakan UV-Spektrometer. Keputusan daripada analisis makmal menunjukkan bahawa pelepasan pepejal terampai (TSS) dari kebun buah-buahan adalah lebih tinggi manakala nutrient dan Kepr luan Oksigen Kimia (COD) di ladang sayur-sayuran adalah lebih tinggi dalam perbandingan. COD adalah lebih tinggi dalam sayur-sayuran ladang larian kerana baja organik seperti tahi ayam digunakan. Ketiadaan tanaman penutup yang sesuai menyebabkan air larian permukaan yang terkumpul adalah lebih tinggi di dalam kebun buah-buahan. Secara keseluruhannya, keputusan mengesahkan bahawa air larian dari kawasan pertanian adalah sangat tercemar dan boleh menjejaskan air permukaan berdekatan dalam jangka masa panjang jika ia tidak dipantau dan dikawal.

Kata kunci: NPS, Nutrien, Sedimen, air larian permukaan, Baja

1.0 INTRODUCTION

Non point source (NPS) pollution refers to the pollution where the pollutants are from an unknown point of entry into receiving water bodies. Due to its diffuse source and complicated generation, neither the task of monitoring nor controlling of the NPS is difficult.[1] In the past decade, we can see that the number of research on NPS have increased due to its nature being the major source of pollution to water degradation around the world.[2-5]

Based on a keyword analysis, it is found that water quality, non point pollutions, and watershed were the trending issues on NPS research while "agriculture", "land use" and "runoff" were the major causes of NPS pollution.[6] Even though there are many research conducted on crop management practices in agricultural land, this sector have remain as the largest diffuse source of water pollution around the globe and at a critical stage in developing countries like the United States, Japan, China, Spain and many more.[7-11]

Examples of pollutants from agricultural operations include nutrients (Nitrogen and Phosphorus), pesticides, pathogens (livestock excreta), oil spills and sediments.[12] This pollutants are transported by surface runoff, leaching or by subsurface flow.[13,14] This pollutants can degrade surface water via runoff and groundwater via leaching which will later leads to eutrophication and hypoxia.[15-17].

Among all the pollutant transport agents, the surface runoff is the main pathway. It occurs due to excess rainfall or irrigation water that is not infiltrated into the soil structure due to low infiltration rate. There are two types of infiltration mechanism where the Hortonian mechanism or the infiltration excess is the more prominent than the Dunne mechanism (saturation excess). This statement is true during storm events but the runoff generation can be altered due to lateral distribution of water movement as the areal size increases. The surface runoff depends on various factors like rain depth, rainfall intensity, antecedent soil condition, soil cover and the soil texture mainly.[18,19]

Besides surface water degradation, NPS can also cause land degradation by soil erosion. Soil erosion is threat to the terrestrial ecosystems and prominent environmental problem where it can reduce the fertility of an arable land.[20,21] In tropical areas, the agricultural soil usually have either low nutrient content or missing an essential nutrient for plant growth due to limited nutrient cycling. Therefore, farmers tend to increase the use of fertilizers to soil to increase cop production.[22] Although it may help to increase the soil fertility, nutrient loss could also occur due to poor fertilizer application and timing by surface runoff and leaching.[23] Later, this nutrients will cause to pollution to receiving water bodies and affect human health when this water is consumed.[24]

Main nutrients or crop macronutrients that cause water pollution are Nitrogen (N) and Phosphorus (P).[25,26] This nutrients are needed by plants in large amount since soil worldwide are deficient in this elements which causes a huge gap between what is required and provided by the soil.

Nitrogen can occur in many forms like Nitrate (NO_3^-), Nitrite (NO_2^-) and Ammonia (NH_3). Nitrate is considered the most dangerous form due to its mobility properties. Not only can it move into streams by runoff, it can also contaminate groundwater. There are researches that shows leached nitrates in soil can take decades to enter groundwater due to long traveling time between the vadose zone and saturated zone.[27] Ammonia is more mobile than usually thought in previous literatures.[28]

On the other hand, Phosphorus (P) is nutrient essential to plant growth but can cause water eutrophication.[29,30] Sediment transport or soil erosion plays an important role P movement by surface runoff since P tends to attached to soil particles.[31-34] Phosphorus are less transported via subsurface flow due to subsoil fixation.[19] Transport of phosphorus originating from chemical fertilizer or animal manure are affected by the crop practice (fertilization time application, soil tillage system and irrigation) and weather condition (rainfall amount, wind speed and temperature).[23]

Large amount input of fertilizers causes malpractices such as low use efficiency and recovery which leads to low economic return. In addition, processes like volatilization, leaching, pollutants accumulation in water causes great pollution to the environmental, deteriorate the ecosystem and affect human health. It does not only affect the agriculture outcome at the moment but will cause heavy impact on the development of agricultural industry in the long term.[35-37]

Suspended solids refer to small solid particles, which remain in suspension in water as a colloid or due to the motion of the water. Generally the amount of particles that suspend in a sample of water is called total suspended solids (TSS). It is used as one indicator of water quality. The greater the TSS in the water, the higher its turbidity and the lower its clarity.[38] Seal formation at the soil surface during rainstorms reduces rain infiltration and leads to runoff and erosion.[39] Large losses of soil usually occur under continuous cropping systems in the tropics owing to high rainfall erosivity coupled with predominately weak soil structure..[40]

In this paper, a field experiment was conducted to provide quality and quantity of runoff pollutant loadings from an agricultural farm at a plot scale.

■2.0 EXPERIMENTAL METHOD

The experimental site is located in a small agricultural catchment, situated at the Pusat Pertanian Moden, Kluang about 13 km from the Kluang Town, Johor (1◦95'N, 103◦15'E). The elevation at the catchment is from 15 to 55m above sea level. It has an average annual temperature of 26.7 ◦C, a max daily temperature of around 34 ◦C, annual rainfall of 1778 mm and humidity around 65 to 100%.

Two different land uses were compared. These were a vegetable farm with bittergourd planting (Momordica charantia) and jackfruit orchard (Artocarpus heterophyllus). The physical properties of both sites were showed in Table 1.

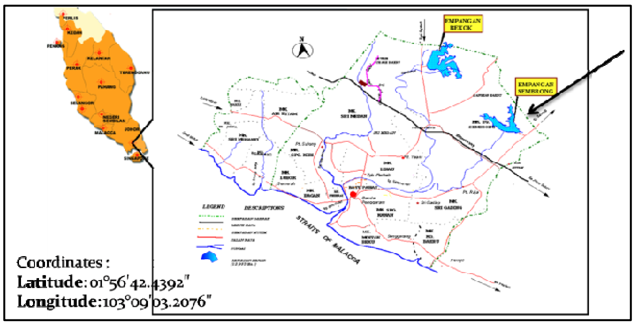


Figure 1 Site Location

Table 1 Plot Charateristics

Characteristics	Site 1	Site 2
Land use	Vegetable Farm	Fruit Orchard
Vegetation	Bitter gourd	Jackfruit
Slope	5⁰	3-5⁰
Plot Size	96 m²	220 m²
Crop Cover	Mulching	Grass
Top Soil Texture	Sandy clay	Sandy clay Loam
Altitude (msl)	20m	34m
Soil pH value (surface)	5.92	4.66

Two runoff plots were constructed at both sites. An experimental plot approach was applied in this research due to the fact that the results obtained at the plot scale can be extrapolated for larger area for changes.[41-,43] At the plot scale, agricultural operations tend to homogenize soil surface and vegetation characteristics.[44] In addition, small plots had greater runoff volumes per unit area compared to the watersheds. Because of longer flow paths (transport distances) in the watershed, there are more opportunities for infiltration and deposition, resulting in lower per unit area runoff volumes.[45]

The ONSET RG2-M Model automatic recording rain gauges will be calibrated and used in this study. It consists of three major components; a tipping bucket, an aluminum housing and HBO event data logger. One rain gauge will be installed at each study site in order to get reliable estimate of areal rainfall on evenly basis.

Equipments are installed at both sites to oversee the rainfall and overland flow during the period from 2013 to 2014 (Fig. 1). Precipitation was measured using a rain gauge (Model ONSET RG2-M). The rain gauge was connected to a data logger and the data were recorded automatically at 30 minute intervals.

Overland flow was monitored and collected using experimental plots along the slope. The plots were constructed using steel plates where 0.20m was projected above the ground while 0.25m was inserted into the soil. At the lower end of both plots, Tipping Bucket Flow Gauge (Model TB1L) was fixed. This equipment usually used for measuring water flow coming out of a pipe or a drain. However for this research, it will used to measure runoff from the plot area. This unit comes with a dual reed switch where when connected to a data logger, the tips which represents the runoff period and quantity can be stored and collected when required. The flow gauge operation is similar to a tipping bucket rain gauge where the bucket will tip when one side of it reaches 1 liter set capacity of water on it. Once the bucket tip, the runoff water will flow into a collection bucket where water samples can be collected later for chemical analysis. The overland flow was sampled after a rainfall event to determine the pollutant concentrations at laboratory.

The collected samples of sediment and water were transported back immediately to the Environmental Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia for analysis. The sediments suspended in the water samples were filtered through a 0.45 μm glass fiber filter paper and then used to measure the nutrient concentration (N & P) for the following parameters:

Nitrate (NO_3)	Nitrite (NO_2)
Ammonia(NH_3)	Total-Nitrogen (TN)
Phosphate (PO_3)	Total Phosphorous (TN)
Chemical Oxygen Demand (COD)	

The nutrient analysis will be conducted using the HACH DR5000 ultraviolet spectrometer.

■3.0 RESULT AND DISCUSSION

Till date, there were 60 storm events were monitored at both sites since day of equipment installation. Water samples were collected from 22 runoff event. Runoff loading analysis was conducted for 14 events only due to equipment malfunction. Nutrient loading was calculated by multiplying the analytes concentration by the measured water volume for that respective sample which is depicted in Figure 2.

Overall the runoff amount generated from both sites is very low. This may due to the high infiltration rate at both sites since the surface soil at both sites have high percentage of sand. Clay typically has a higher runoff water yield than sandy soils because of their low infiltration capabilities. Since the site is located at a tropical country, the infiltration rate can be affected due to due to cracks or by swelling of the soil from the hot weather. Infiltration is highest at the end of dry season while minimum infiltration is during rainy season after sequence of rain events. The denser the cover crop, the greater is the hydraulic resistance and the lower the runoff volume compared to cropped soil. Concentration and loads can also decrease when the nutrient is intercepted by the vegetation foliage as the crop grows. Runoff increased greatly when soil surface water regimes changed from infiltration to exfiltration condition. This indicated soil detachment was limited under saturation and seepage condition. Saturation and seepage conditions promoted N and P transport to runoff.[46] The wetter the soil, the lower the infiltration rate. The initial infiltration rate of a moist soil is lower than the initial infiltration rate of an identical dry soil. As time progresses, the infiltration rate of these two conditions will converge to the same steady-state value.

Good structure soil has high porosity and is well permeated. In this way, soil water can infiltrate soil and reduces the surface runoff. The soil density also affects the infiltration velocity and stabilization time of seepage, which will influence transport of nutrients in surface soils. Influence of water content or porosity of soil on transfer of nutrients is mainly due to the balance between aeration, which diminishes with water content and favorable humid conditions for microbial biomass.[47]

In addition, the root systems of plants facilitate infiltration and may reduce nutrient loss by adhering soil particles and blocking surface runoff on slope. Branches and leaves decrease the influence of raindrops on the initiator of the erosion process. Therefore, the subsurface flux in slope soil covered with vegetation is more than uncovered.

From the statistical analysis in Table 2 and 3, it can be seen that the pollutants released from Site 1 is higher in average when compared to Site 2. In comparison, maximum value of each nutrient is higher in Site 2 except for nitrite. Manure is used as fertilizer at Site 1 as it contains nutrients that can serve as a substitute for inorganic fertilizer and organic matter that can improve soil characteristics including infiltration, porosity, and water holding capacity. Water pH comparison shows that runoff from site 2 is more acidic where it reaches as low as 4.49. The acidic nature of the topsoil at site 2 (pH=4.66) may have contributed to this situation.

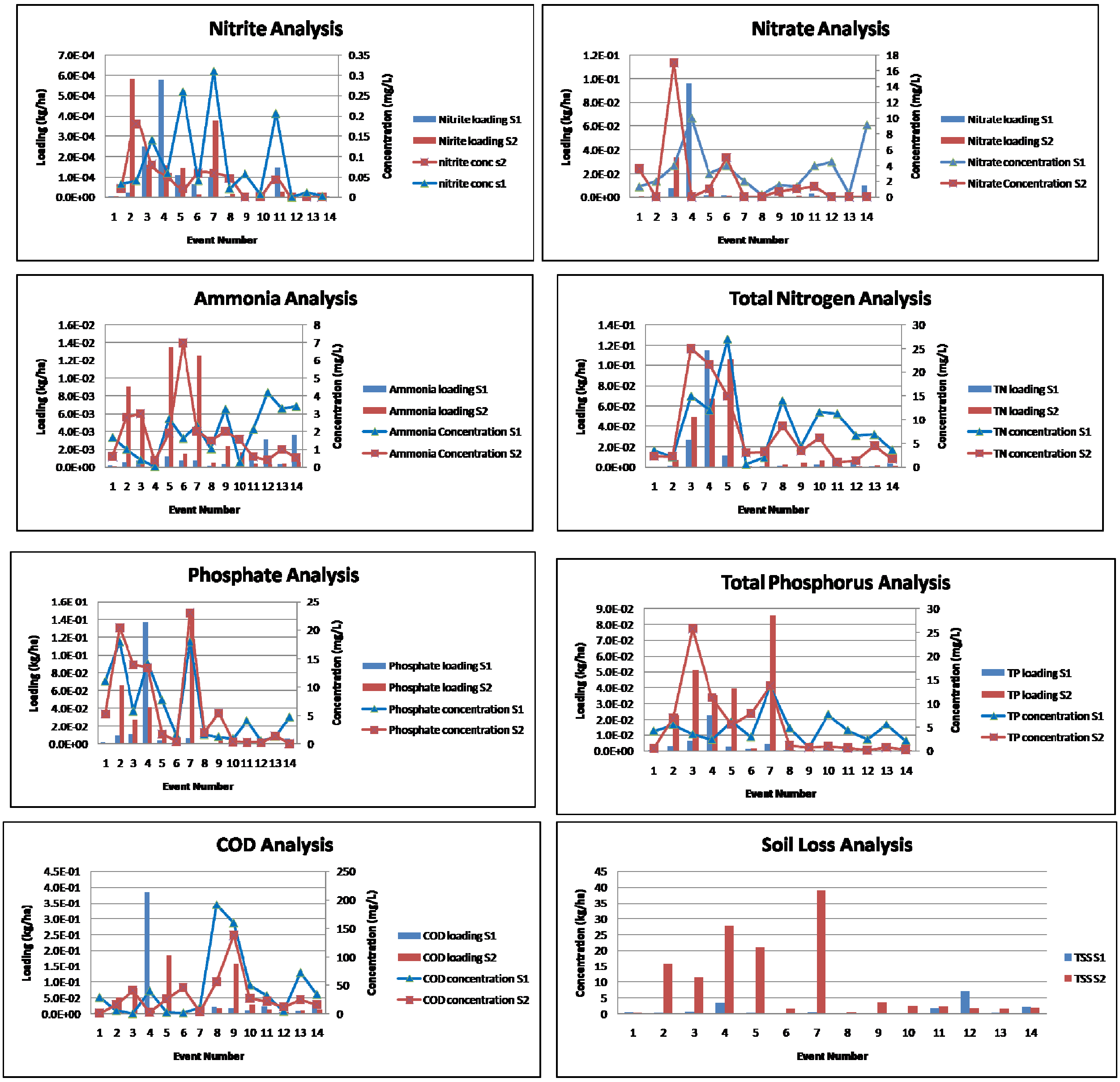
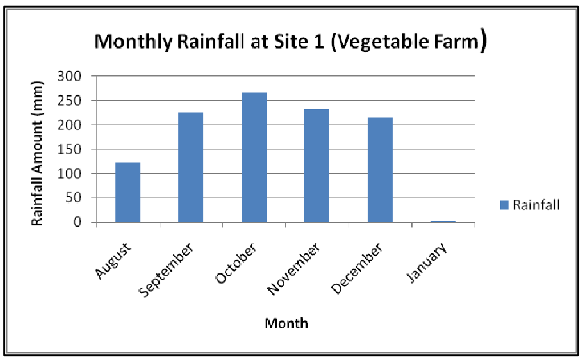


Figure 2 Pollutants Loading and Concentration

Figure 3 Monthly Rainfall at both Sites



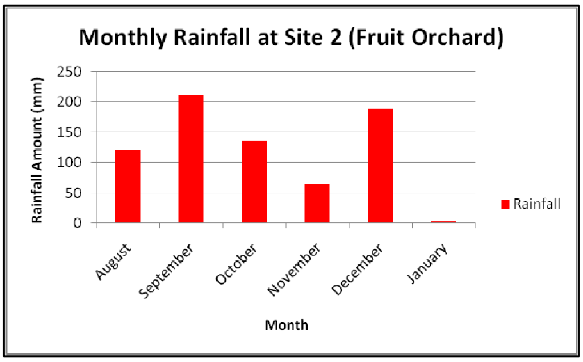


Table 2 Site 1(Vegetable Farm) runoff pollutants concentration

Statistics (n=22)	Nitrite	Nitrate	Ammonia	TP	TN	COD	Phosphate	TSS	pH
Average	0.079	3.29	1.51	4.61	8.36	40.94	3.76	1964	6.01
Min	0.002	0.3	0	0	0	0.7	0	48	4.73
Max	0.385	10	4.18	18	27	191	13.73	15160	7.42
S.D	0.11	2.96	1.29	3.03	6.18	48.16	5.83	3555	0.65

Table 3 Site 2 (Fruit Orchard) runoff pollutants concentration

Statistics (n=22)	Nitrite	Nitrate	Ammonia -Nitrogen	TP	TN	COD	Phosphate	TSS	pH
Average	0.050	2.592	1.286	4.112	4.986	29.591	3.608	3379	5.40
Min	0.001	0	0	0	0	1	0	62	4.49
Max	0.18	17	7	25.8	25	138	23	8907	6.50
S.D	0.05	4.78	1.54	6.34	6.78	28.70	6.94	2248	0.55

Concentrations of nutrients significantly decreased with increasing rainfall intensity because of more runoff and the associated rapid dilution.[50]The presence of most nutrients was greater in the runoff (liquid phase) than in the sediments (solid phase).[51-53]

Among the main components of N, Nitrate (NO_3^-) shows higher concentration in runoff water than Ammonia (NH_3) and Nitrite (NO_2^-). This may occur due to high water solubility of nitrate while ammonia is prone to volatilization. The maximum value of Nitrate and Ammonia at both sites have exceeded the acceptable standard of the Malaysian National Standard for Drinking Water Quality where Nitrate should be less than 10mg/L while Ammonia should be less than 1.5mg/L. Phosphorus concentration is higher during high rain intensities since phosphorus tends to adsorbed to soil surface. High rainfall intensity accelerates soil erosion thus increasing the phosphorus transported during runoff event. COD in Site 2 is quite high (more than 10mg/L which is the permissible limit in Malaysian Standard) due to high amount of dead leaves from the trees or littering of wild animal which intrudes into the study site.

The amount of Total Suspended Solid (TSS) is much higher at Site 2 (3379mg/L) than Site 1 (1964mg/L) in average. Site 2 cover crop is consist of grass planting at the slope proves not to be effective since the surface soil contains more fine material (clay). Figure 2 shows that the amount of runoff from site 2 is higher. The kinetic energy of runoff flowing over the field increases as the slope of a field increases. Logically, the larger the watershed size, the higher the annual runoff. However, higher runoff does not always indicate higher rates of erosion. Rainfall with higher kinetic energy contributes to greater sediment loss.[48] Average TSS concentrations in the range of 25-80 mg/L represent moderate water quality. An average concentration of 25 mg/L has been suggested as an indicator of unimpaired stream water quality. Some countries use 50 mg/L as a screening level for potential impairment to waterbodies. TSS from both sites is high and therefore able to affect the receiving water.

Sediment bound nutrient loss are affected by the interaction of rainfall intensity and vegetation cover.[5] Low vegetation cover and high rainfall intensity leads to higher loss of sediment and nutrient. A positive linear relationship can be seen from the soil nutrient loss.[20] Runoff amount generated depends on the vegetation cover and slope angle. The greater the slope angle, the higher the potential for runoff and soil loss. Erosion rate also depends on the crop cover.[49] Crop cover is positively related to soil macropores which results on surface runoff generation and infiltration under high intensity rain events. In grassland, less infiltration of rainwater can be observed where the macropores are blocked with fine particles of soil. Rainfall characteristics control the runoff generation under extreme storm as intake capacity of macropores is exceeded.

■4.0 CONCLUSION

The characteristics of 22 runoff event at 2 different agricultural land uses were collected at site and tested at laboratory. The concentrations of nutrients (except nitrite) in runoff water from fruit orchard are found to be much higher than runoff from vegetable farm especially after the application of fertilizers. The amount of TSS was also found to be high in the runoff from fruit orchard due to less cover crop planting.

Runoff, TP and TN can be reduced by conservation tillage and contour farming.[54] In comparison, conservation tillage is more effective in controlling soil, water and nutrient loss. Reduced tillage has been shown to be effective in decreasing the quantities of surface run-off and often also the concentrations, although the reduced water volume as a result of increased infiltration can lead to higher concentrations if surface run-off does arise.

Latest researches have proven that application of commercial fertilizers may be more detrimental to nutrient loading and water quality than animal manures. Addition of gypsum to critical areas in fields treated with soluble AT_z or poultry litter appears to be a viable management strategy to reduce off-site water quality concerns.[55] A new management based on sloping lands needs to be further studied, including changing fertilization quantity, improving fertilization technology, adjusting vegetation coverage, and studying cultivation systems on different sloping lands within an agricultural land.[56]

However, more research is required, as the nature of the study was only preliminary where other pollutants like pesticides and organic carbon should be analyzed too.

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