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Particulate and Dissolved Forms of N, P and Organic C Transported From Major Land Uses in the Pagsanjan-Lumban Catchment to Laguna de Bay, Philippines

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ABSTRACT

The distribution of the particulate and dissolved forms of N, P and Organic C transported from major land uses in an agricultural watershed was determined. Total Kjeldahl N (TKN), total P (TP) and total organic C (TOC) were determined in both unfiltered (total) and filtered (< 1.2 µm) samples. The particulate fraction (> 1.2 µm, a conservative estimate) tended to dominate offsite transport of TKN, TP and TOC from agricultural land uses, especially in regions with more intense cropping systems, namely Pagsanjan and Lucban. The average proportions of particulate forms of N and P (PN and PP) were higher at Pagsanjan which is a rice growing area (73% of TKN and 68 % of TP) than at Lucban (59 % of TKN and 64 % of TP), which is generally under vegetable production. At Cavinti (a site under coconut production), particulate forms of TKN and TP were dominant while the soluble fraction dominated TOC transport. For the piggery site at Majayjay, particulate forms controlled the movement of TKN and TOC while the soluble form dominated TP transport. A significant, positive relationship was observed between total suspended solids (TSS) and PN and between TSS and POC at all sites. A significant relationship between TSS and TP was only noted at Lucban. Overall, the study showed that despite the conservative estimate (> 1.2 µm colloids only), particulate forms for C, N and P were the dominant fraction from all land uses in these agricultural catchments, except P from the piggeries site. The study suggests that the strategies to minimize or trap the particulate form may help reduce off-site migration of nutrients in the major catchment draining into Laguna de Bay, Philippines.

Key words: *particulates and dissolve forms; Total N,P,C*

INTRODUCTION

Off-site transport of contaminants such as nutrients, sediment and pesticides from agricultural practices is of concern to landholders, regulatory agencies and the general public. The presence of contaminants in waterways can cause eutrophication and ecotoxicological effects on aquatic organisms, which may increase the cost of water treatment for a potable water source (*Sharpely et al. 2000; Cherry et al. 2008*). For example, up to 80 % of European surface waters have been reported to exceed the European Commission's drinking water standard for 50 mg NO_3^- L^{-1} (*Molenat and Gascuel-Odoux 2002*). In England and Wales, 28 % of rivers exceed N concentration of 30 mg NO_3^- L^{-1} (*Environment Agency 2007a*) and 52 % of the total river length exceeds P concentrations of 0.1 mg L^{-1} (*Environment Agency 2007b*).

Both point and non-point (diffuse) sources of nutrient pollution are important contributors to the problems. However, diffuse sources generally dominate and agriculture is often the major contributor (e.g. *Daniel et al. 1998; Cherry et al. 2008*). For example, in England and Wales, it is estimated that agriculture contributes up to 70 % and 28 % of annual N and P loads, respectively, to water (*Defra 2006*). There is a large body of literature about the processes of the transfer of P from soil to surface drainage water (*Haygarth and Jarvis 1999; Heathewaite and Dils 2000*). The processes of P mobilization can be broadly classified into physical (detachment of particles containing P) and chemical (release of phosphate into solution) processes (*Dougherty et al. 2004*). Phosphorus (P) is one of the least mobile plant nutrients in soil but it is transferred from agricultural lands to water bodies dissolved in surface runoff, attached to eroded sediment, and leached through the soil profile (*Lemunyon and Daniel 2002*). A major mechanism for losses of P is off-site transport by sediment as part of erosion processes (*Barrows and Kilmer 1963; Sharpley et al. 1992; Heathwaite 1995*). Particulate P (PP) includes P associated with soil particles and organic matter eroded during flow events and constitutes the major proportion of P transported from most cultivated land in US (60-90 %) (*Sharpley et al. 1992; Douglas et al. 1998*). In the US, PP constitutes between 60 %-90 % proportion of P transported off-site from cultivated land (*Sharpley et al. 1992*). Runoff from grass or forest land or non-erosive soils carries little sediment and is, therefore, dominated by the dissolved form (*Daniel et al. 1998*). Most P in runoff from dairy pastures in southern Australia has predominantly been in a dissolved (< 0.45 µm) form (*Nash and Murdoch 1997; Fleming and Cox 1998; Dougherty et al. 2004*) while in the UK (*Heathwaite 1995*) found up to 60 % of the total P load transported off-site from a grassland catchment, dominated by dairy and beef cattle production, was bound to suspended sediment or organic material (> 0.45 µm).

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Soluble and particulate forms of nutrient transport require different forms of management and mitigation strategies (*Lentz et al. 1998; Oliver and Kookana 2006*). Sources of PP in streams include eroding surface soil, stream banks, and channel beds. Thus, processes that control erosion may also control PP transport (*Daniel et al. 1998*). Various mitigation strategies have been considered including conservation tillage, crop residue management, buffer strips, riparian zones, terracing, contour tillage, cover crops, application of high molecular weight anionic polyacrylamide, and sedimentation ponds (*Daniel et al. 1998*). Buffer strips have been shown to be a highly effective strategy to minimise P transport with up to 97 % removal of total P (PP+DP) in overland flow in certain situations (*Dorioz et al. 2006*). Generally these practices are more efficient at decreasing PP rather than DP load. The transport of dissolved P in runoff is initiated by the release of P from soil and plant material. These processes occur when rainfall interacts with a thin layer of surface soil (1-5 cm) before leaving the field as runoff (*Sharpley 1985*).

The objective of this paper, was to determine the distribution of the particulate and dissolved forms of N, P and C transported from major land uses in an agricultural watershed. In this study, total Kjeldahl N (TKN), total P (TP) and total organic C (TOC) were determined in both unfiltered (total) and filtered (< 1.2 μm) samples. The difference was ascribed to the particulate form. Since the colloids are operationally defined to be <0.45 μm, the use of a coarser filter (1.2 μm) in the present study is likely to represent a conservative estimate of "particulate" form. The findings of this study would help identify appropriate management and mitigation options for the different land uses in the Pagsanjan Lumban catchment that supplies approximately one third of total volume annually of water to the Laguna de Bay, Philippines.

MATERIALS AND METHODS

Pagsanjan-Lumban Catchment

Laguna de Bay is the largest freshwater lake in the Philippines and the second largest in Southeast Asia. The Pagsanjan-Lumban catchment (**Figure 1**) is one of the 24 catchments and is located in the south-eastern part of Laguna de Bay. With an area of approximately 45,445 ha, it is only

Figure 1. Map of the Pagsanjan-Lumban catchment showing the location of the automated water samplers and rainfall gauges (*Cruz et al. 2012*).

the second biggest catchment but it provides the largest flow of water into the lake (*Hernandez 2006*). The catchment has a relatively flat to moderately sloping to rolling topography starting from the lakeshore and moving towards the mountains. About 90 % or 40,900 ha has a slope of ≤18 % while the steeper areas (>18 % slope) constitute only about 10 % (4544 ha) of the total area (*Cruz et al. 2012*).

Site Selection

Four sites were selected for installation of automatic water samplers (*ISCO model 3700*) to collect water draining from the major land uses in the catchment – coconut agroforestry (Cavinti), rice production (Pagsanjan), vegetables (Lucban) and piggeries (Majayjay). To collect water that represents runoff discharging from coconut-based agroforestry, a sampling site near Barangay Tibatib Overflow bridge was selected to sample water from Bombongan River near Cavinti. Salasad River was selected to represent an area dominated by rice. This river receives runoff from Magdalena and Pagsanjan municipalities where rice is the predominant crop although some vegetables are also grown. Another autosampler was installed at the Southern Luzon State University (SLSU) on the Lucban River which receives drainage water from intensive vegetable and ornamental areas. The fourth site was at Majayjay which is a major piggery area. The autosampler was installed at Initian Creek where wastes from the piggeries are disposed of daily. This creek drains into the Balanac river.

Sampling and Laboratory Analysis

Water samples were collected at Cavinti, Pagsanjan and Lucban every 6 h using an autosampler and the daily water samples were composited to provide a weekly sample. The daily water samples were stored at 4 °C until they were transported to the laboratory where they were mixed and composited for analysis. Daily water samples were collected at Majayjay when the majority of piggeries were washed out and then composited to obtain a weekly sample. Collection of daily water samples started in 2007 at Lucban and Cavinti while in Pagsanjan and Majayjay collection started in 2008 and continued until 2009. In addition, grab samples were collected once per week from February to May in 2009 at Balanac and Bombongan Rivers, which meet in a confluence at Pagsanjan River, just befor the river drains into Laguna de Bay.

Total Kjeldahl N (TKN), total P (TP) and total organic C (TOC) were determined in both unfiltered (total) and filtered (< 1.2 µm) samples as described in *Sanchez et al.* (*2012*). The difference between TKN in the unfiltered samples and in the filtered samples (< 1.2 µm) is referred to as "particulate N" (PN, >1.2 µm) which consists of organic N associated with suspended particulate matter and adsorbed ammonium. The TKN in the filtered sample (< 1.2 µm) is referred to in this paper as soluble N (SN) and represents dissolved organic N and NH_4-N. The P concentration in the unfiltered sample represented total P (TP) and that in the filtered sample (<1.2 µm) represented soluble P (SP) thatincludes dissolved inorganic and organic P. Again, particulate P (PP) was determined from the difference between TP and SP. Similarly, the organic carbon concentration of the unfiltered sample represented total organic carbon (TOC) and that of the filtered sample (<1.2 µm) as soluble organic carbon (SOC). Particulate organic carbon (POC) was determined from the difference between TOC and DOC. As the SN, SP and SOC fractions were prepared by filtration, the term "soluble" in this paper refers only to materials that passed through the 1.2-µm filter and does not imply that all materials in the filtrate were necessarily in solution.

RESULTS AND DISCUSSION

Distribution of TKN between Particulate and Soluble Forms

The concentration range of PN (>1.2 µm) transported in the catchment varied considerably among sites over the three-year monitoring period (**Figure 2**). The Majayjay site, where a large number of piggeries discharge effluent, had the highest PN concentration (median values ranged from

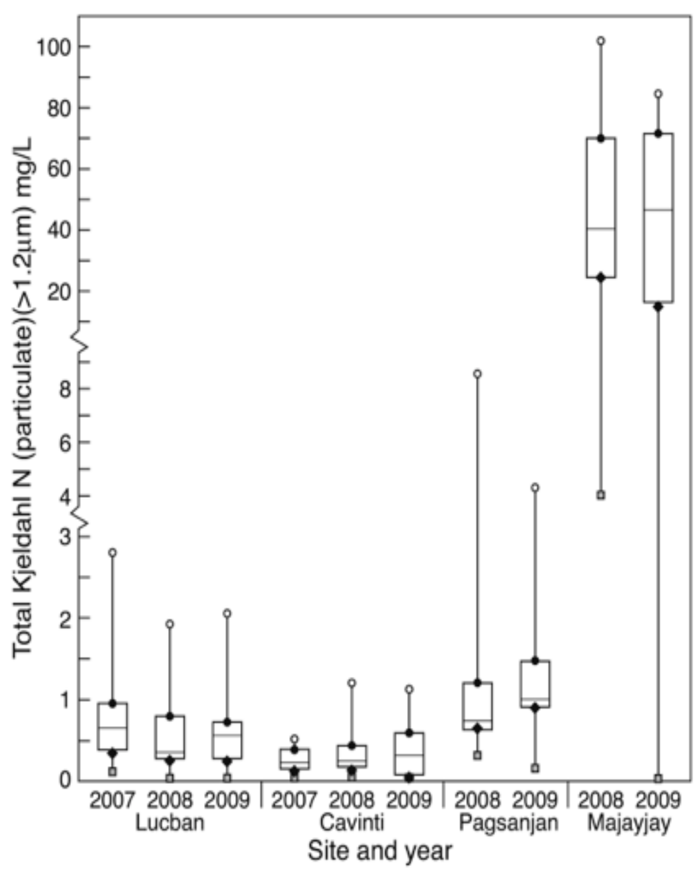

Figure 2. Particulate (> 1.2 µm) N (PN) concentration as influenced by sampling site and year represented as a box and whisker plot.

42.0 to 47.7 mg L^{-1} during 2008-09). The PN (>1.2 µm) concentrations were significantly lower at the monitoring sites in catchments with agricultural activities (i.e. Pagsanjan, Lucban and Cavinti). Pagsanjan had the highest median value of 0.75 mg L^{-1} in 2008 and 0.95 mg L^{-1} in 2009; followed by median values for Lucban of 0.67 mg L^{-1} in 2007, 0.37 mg L^{-1} in 2008 and 0.60 mg L^{-1} in 2009; for Cavinti of 0.22 mg L^{-1} in 2007, 0.25 mg L^{-1} in 2008 and 0.35 mg L^{-1} in 2009 (**Figure 2**).

In Pagsanjan, where there was more intense agricultural activity associated with rice production, the higher concentrations of suspended solids in the runoff coupled with high application rates of N resulted in higher concentrations of PN (**Figure 3**) compared to Lucban and Cavinti (**Figures 4 and 5**). The form of fertilizer (e.g. urea, ammonium sulfate) used by rice farmers in the Pagsanjan area contributed to higher NH_4-N concentration in soluble form and possibly to PN since NH_4+ can also be adsorbed on soil clays and organic matter. Although vegetables were continuously grown in Lucban, farmers used lower N rates and applied chicken manure as an alternative nutrient source.

Variation in SN (<1.2 µm) concentration was also greatest in Majayjay which ranged from 16.4 to 35.8 mg L^{-1} in 2008 and from 0.2 to 41.4 mg L^{-1} in 2009 (**Figure 6**). The SN concentration ranges at the other three monitoring sites did not differ greatly with median values of 0.35, 0.25 and 0.30 mg L^{-1} in 2007, 2008 and 2009, respectively, at Lucban; 0.15, 0.25 and 0.23 mg L^{-1} in 2007, 2008 and 2009, respectively, at Cavinti; and 0.25 and 0.38 mg L^{-1} in 2008 and 2009, respectively, at Pagsanjan. The maximum SN concentrations measured were 1.8 mg L^{-1} at Lucban in 2008 and 1.2 mg L^{-1} at both Cavinti and Pagsanjan in 2009 (**Figure 6**). The relatively higher SN at Lucban reflects the presence of dissolved organic N from the application of chicken manure. A related study of *Bramley and Roth* (*2002*) monitored water quality in the Herbert River, an intensively managed part of the humid tropics in north Queensland, Australia. where the median TKN values in the soluble (<0.7 µm) fraction of 0.62 mg L^{-1} from sugarcane land, 0.30 mg L^{-1} from grazing land and 0.17 mg L^{-1} from forestry, were formed to have similar concentrations to those found in this study. The distribution of PN and SN in each site varied with time but at Pagsanjan,

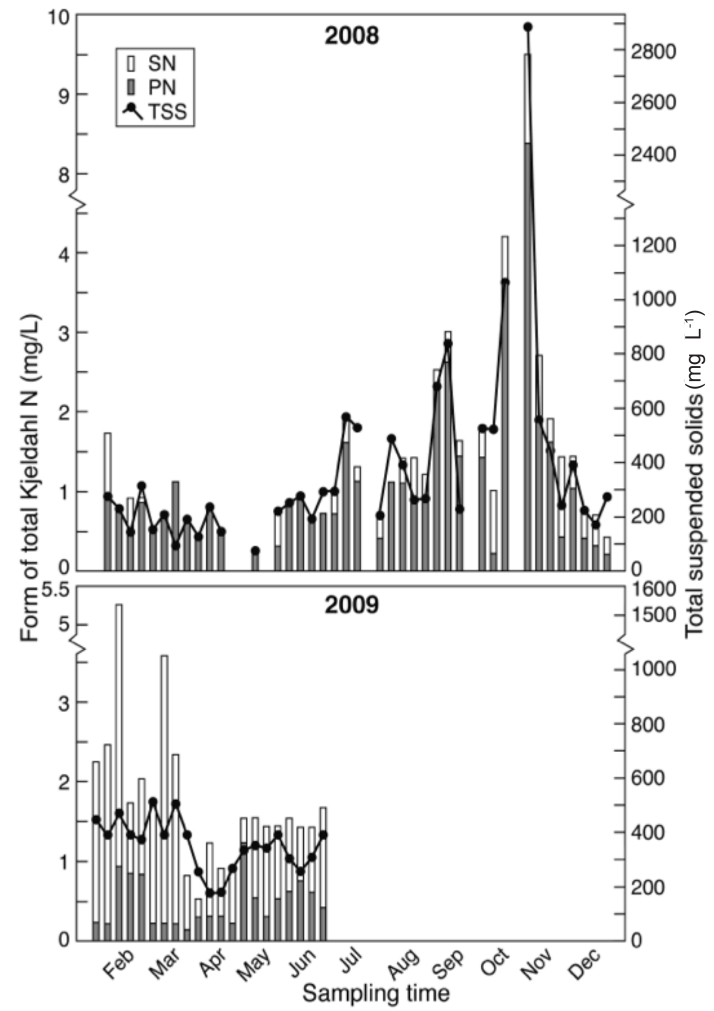

Figure 3. Partitioning of TKN between particulate N (PN) and soluble N (SN) at Pagsanjan in 2008-2009.

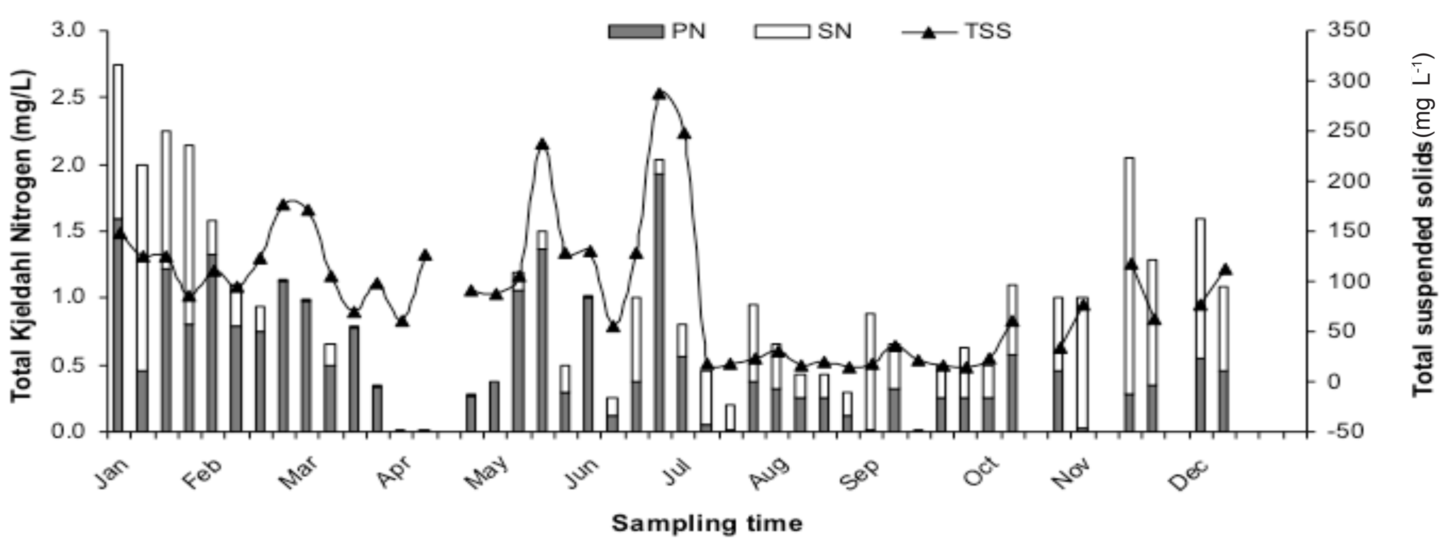

Figure 4. Partitioning of TKN between particulate N (PN) and soluble N (SN) at Lucban in 2008.

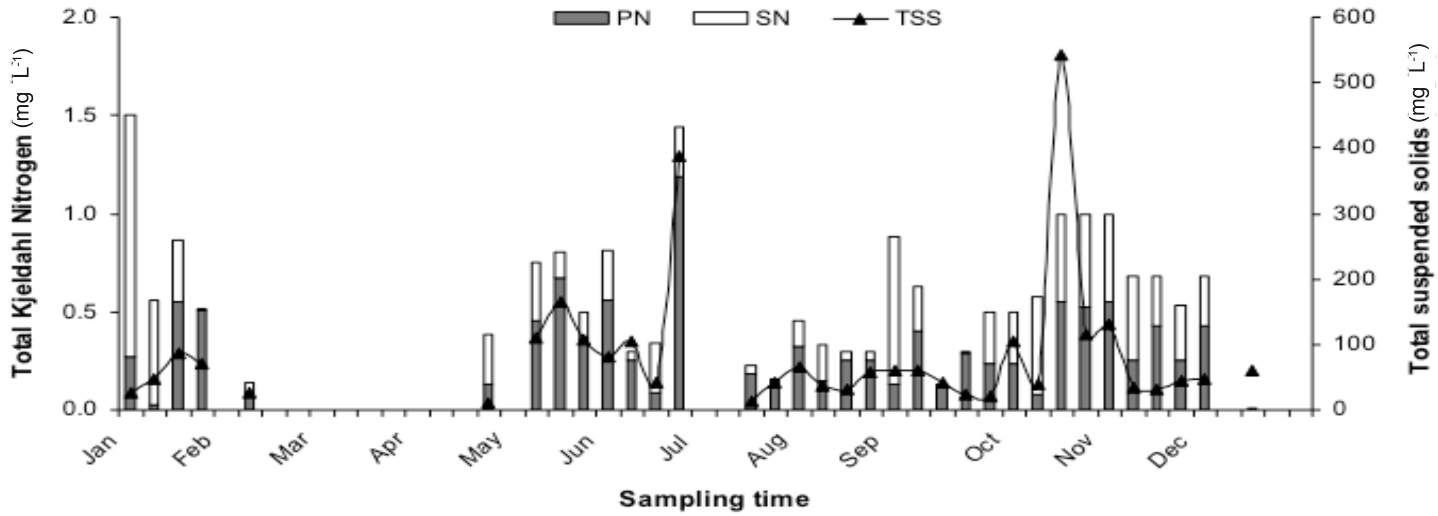

Figure 5. Partitioning of TKN between particulate N (PN) and soluble N (SN) at Cavinti in 2008.

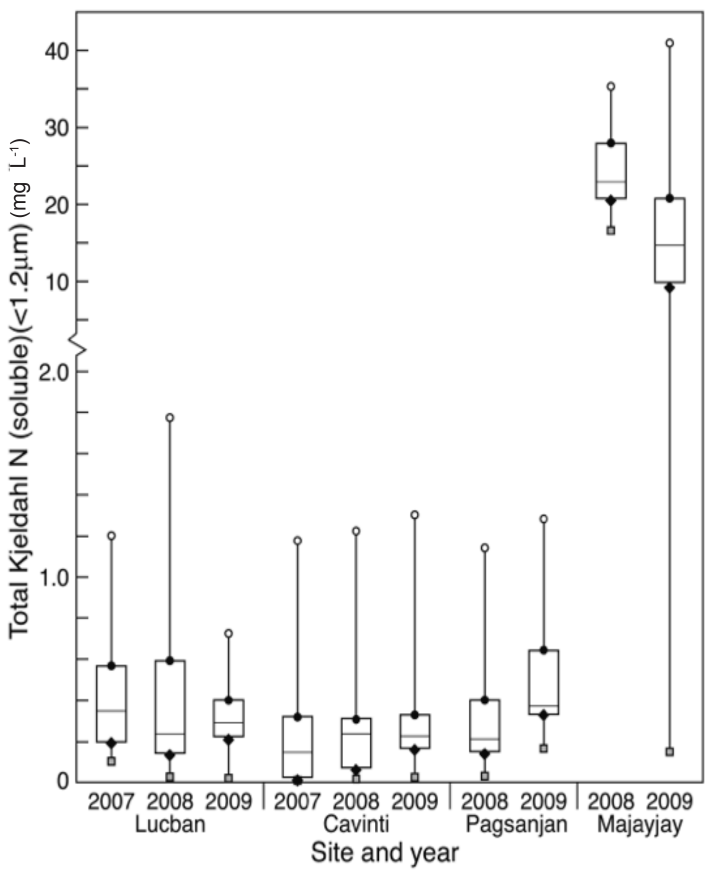

Figure 6. Soluble N (SN) concentration as influenced by sampling site and year.

Lucban and Cavinti PN (>1.2 µm) was the predominant form of N measured in the water samples (**Figures 3**, **4** and **5**). At Pagsanjan, PN ranged from 25 to 99 % in 2008 (mean 76 %) and from 19 to 92 % in 2009 (mean 69 %). About 85 % of all the samples collected in 2008 and 90 % in 2009 were dominated (>75 %) by PN (**Figure 3**).

At Lucban, the average proportion of PN was 62 % (12 to 90 %) in 2007, 57 % (1 to 99 %) in 2008 and 59 % (3 to 98 %) in 2009 (**Figure 4**). A higher percentage of PN was generally observed in March to end May with an average PN (>1.2 µm) of 92 % in 2008 and 57 % in 2009 The proportion of the SN (<1.2 µm) was relatively higher (58 % and 67 %) in July to September 2007 and 2008, respectively (**Figure 4**). The predominant form of TKN at Cavinti was generally PN although there was no consistent trend observed for PN and SN over the 3-year monitoring period (**Figure 5**). The average proportion of PN was 57 %, 59 % and 49 % in 2007, 2008 and 2009, respectively. A high proportion (mean 71 %) of TKN transported from late September to mid November 2007 was in the particulate form but in 2008 the average was only 57 % in the same time period. The soluble fraction dominated the transport process in mid November to December (61 %) in 2007 and in mid March to mid April 2009 (96 %). Unfortunately, there was no data in this time period in 2007 or 2008 for comparison. At Majayjay, the range of PN was 13 to 78 % (mean 60 %) and 25 to 89 % (mean 65 %) in 2008 and 2009, respectively (**Figure 7**). In Pagsanjan, a high percentage of the total samples collected at Majayjay (77 % in 2008 and 82 % in 2009) were dominated by PN. By contrast, the soluble fraction (<1.2 µm) dominated TKN transport at Balanac and Bombongan, which were sites located further downstream. The average proportion of SN was 64 % in Balanac and 73 % at Bombongan for the weekly grab samples collected over four months in 2009. By contrast, *Bramley and Roth* (*2002*) found total N in grab samples taken from surface water in a tropical northern Queensland catchment was dominated by soluble (<0.7 µm) forms of N, that accounted for approximately 80 % of total N.

A very highly significant ($P<0.001$) linear relationship between PN and TSS was observed for the Lucban ($R^2 = 0.55$), Cavinti ($R^2 = 0.28$), and Pagsanjan ($R^2 = 0.78$) data when all the years for each site were considered (**Figure 8**). The removal of 1 high TSS value in the Cavinti data however greatly improved the relationship ($R^2 = 0.41$). At Majayjay, the relationship between PN and TSS was highly significant ($P<0.01$) only

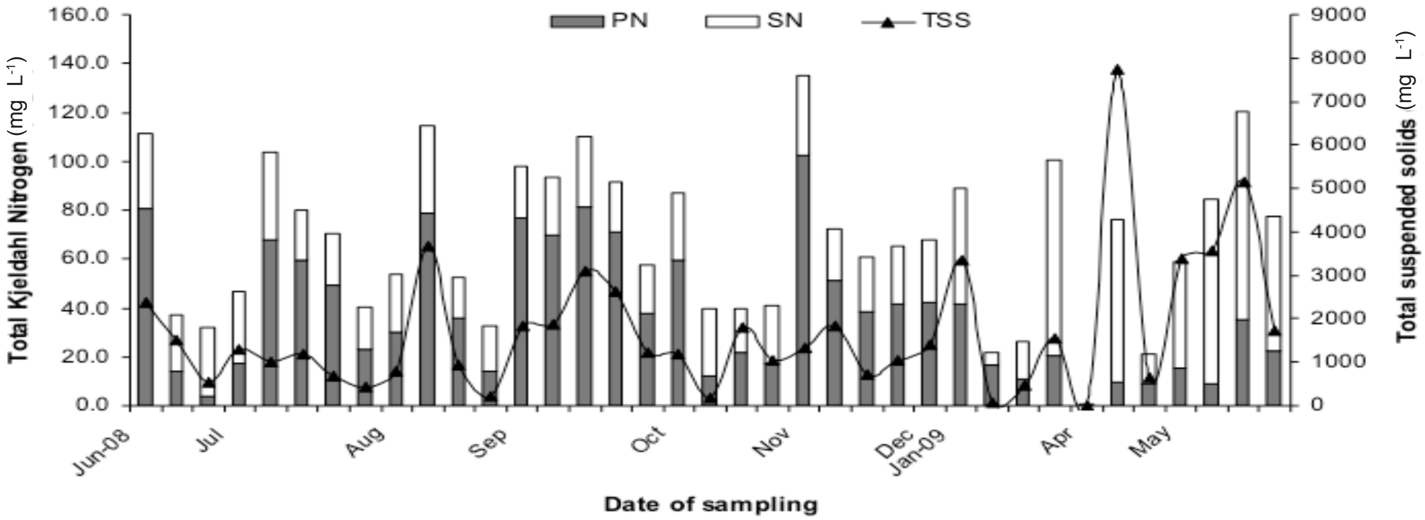

Figure 7. Partitioning of TKN between particulate N (PN) and soluble N (SN) at Majayjay in 2008-2009.

in 2008 (R^2 = 0.41) but not in 2009 (R^2 = 0.08) or when all data was considered (R^2 = 0.02). In tropical and temperate environments, N in runoff has been shown to be closely associated with particulate material. For example, in temperate Oregon, USA, most of the N in surface waters from fields under a wheat-pea rotation was in the particulate (>0.45 μm) fraction (*Douglas et al. 1998*). The N in surface runoff from sugarcane in tropical Mauritius was also tend to be intimately linked to sediment (*Ng Kee Kwong et al. 2002*). Detailed monitoring and modeling in the Johnstone catchment in tropical Queensland, Australia, found the average annual loss of 752 t of N was distributed as 50 % in sediment, 27 % as nitrate-N and 3 % as ammonium-N (*Hunter and Walton 1997*).

Distribution of TP between Particulate and Soluble Forms

As with PN, the highest PP concentrations were found at Majayjay with median values of 7.0 and 3.0 mg L^{-1} in 2008 and 2009, respectively, followed by Pagsanjan, Lucban and Cavinti (**Figure 9**). At Pagsanjan, Lucban and Cavinti, the particulate form dominated TP transport variation in the SP (<1.2 μm) concentrations was also greatest in Majayjay which ranged from 0.20 to 17.76 mg L^{-1} in 2008 and from 0.125 to 5.61 mg L^{-1} in 2009 (**Figure 10**). The SP concentration ranges did not differ greatly in the cropped lands with median values of 0.060, 0.101, 0.045 mg L^{-1} in 2007, 2008 and 2009, respectively, at Lucban; 0.013,0.020 and 0.019 mg L^{-1} in 2007, 2008 and 2009, respectively, at Cavinti; and 0.140 and 0.069 mg L^{-1} in 2008 and 2009, respectively, at Pagsanjan. The maximum SP concentrations were 1.274 mg L^{-1} at Lucban, 0.086 mg L^{-1} at Cavinti, 0.371 mg L^{-1} at Pagsanjan and 96.16 mg L^{-1} at Majayjay, all recorded in 2008.

At Pagsanjan, PP ranged from 5 to 99 % (mean 72 %) in 2008 and 14 to 93 % (mean 62 %) in 2009 (**Figure 11**). In 2008, 98% of the samples collected had higher percentage of PP than SP. The main exception to this occurred in early March to early April 2009 where an average of 27 % PP was obtained. For the same time period in 2008, the average PP was 62 %.

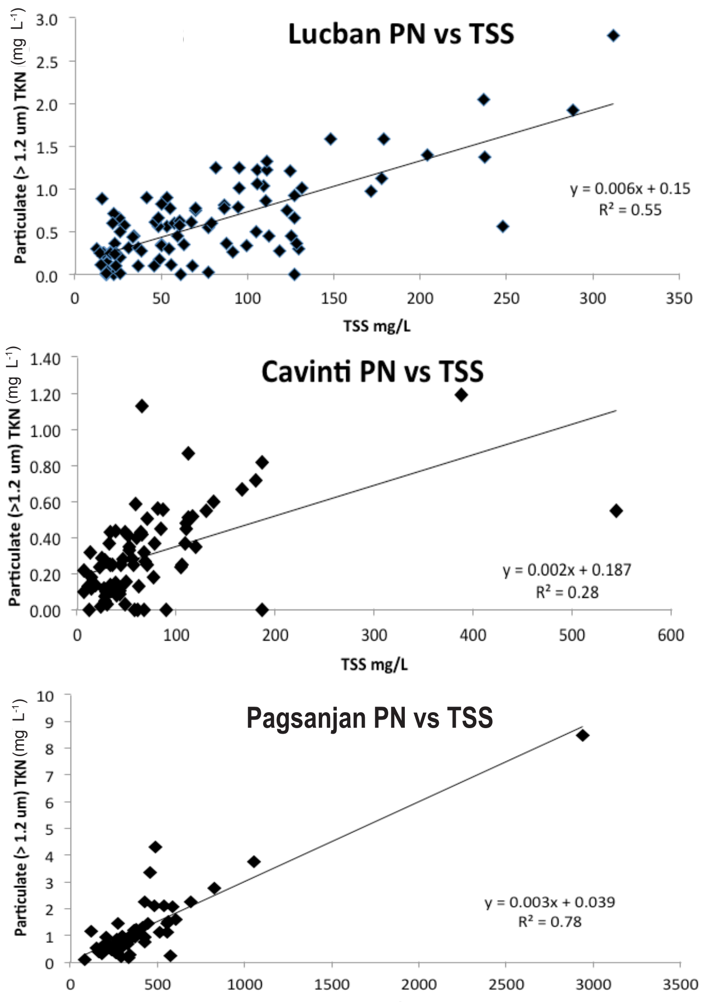

Figure 8. Relationship between PN (>1.2 μm) and TSS concentrations at Lucban (top), Cavinti (middle) and Pagsanjan (lower). (***) = P<0.001

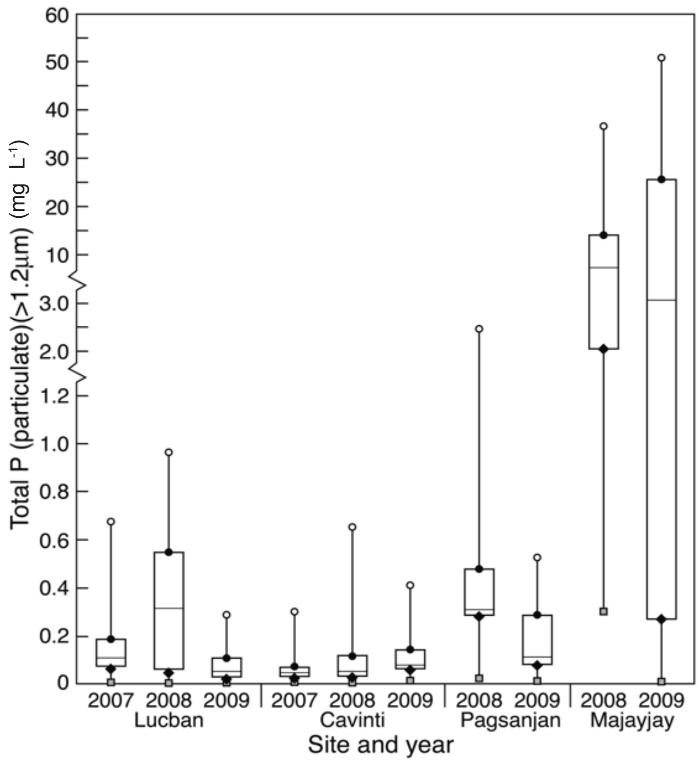

Figure 9. Particulate (>1.2 µm) P (PP) as influenced by sampling site and year.

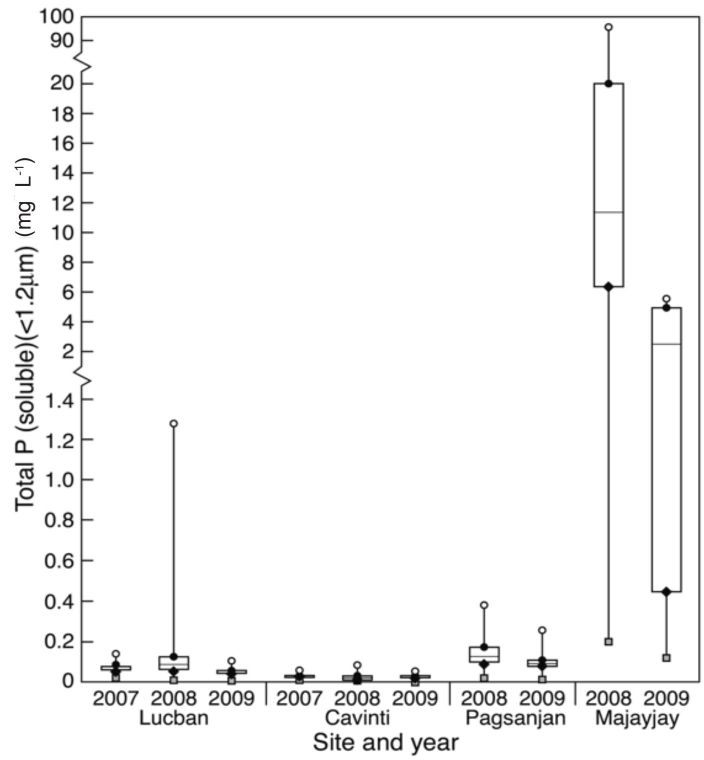

Figure 10. Soluble (<1.2 µm) P (SP) as influenced by sampling site and year.

At Lucban, the proportion of PP ranged from 5 to 88 % (mean 62 %) in 2007, from 41 to 97 % (mean 73 %) in 2008 and from 14 to 84 % (mean 57 %) in 2009 (**Figure 12**). Particulate P generally dominated (>65 %) TP transport, except for the period from August to mid September 2007, where the average PP was 23 %. At Cavinti the proportion of P present as PP ranged from 6 to 99 % (mean 62 %) in 2007, from 27 to 99 % (mean74 %) in 2008 and from 40 to 96 % (mean 79 %) in 2009 (**Figure 13**). PP became less dominant from late July to September 2007 where the average proportion of PP decreased to 32 %. There were no samples for the corresponding time in 2008 so no comparisons between years could be made.

The majority of the studies in the form of P transported off-site have been conducted in temperate environments. There are fewer studies in tropical environments on nutrient transport, let alone the form of nutrients moving off-site from different land uses. The results from Cavinti, Lucban and Pagsanjan in this study agree with some studies in tropical environments that have found that P transport in surface water has been in association with particulate material. For example, *Ng Kee Kwong et al.* (*2002*) found that P was transported predominantly (>70 %) in association with particulate material (> 0.70 µm) in surface water from four different sub-catchments ranging in size from 500 m^2 to 54 ha sown to sugar cane in the tropical environment of Mauritius. Similarly, in tropical north Queensland, Australia, TP measured in drainage water from paddocks planted to bananas and sugar cane compromised mostly particulate P (*Faithful and Finlayson 2005*). Other studies, however, in tropical environments have found the soluble fraction to dominate. In a survey of river water samples collected from 37 sites reflecting the major land uses in the Herbert River catchment, Queensland, soluble (< 0.70 µm) P was the largest fraction of total P (~65 %) (*Bramley and Roth 2002*).

A different distribution pattern of P was observed at Majayjay compared with the other 3 sites (**Figure 14**). At Majayjay, there was generally a more even distribution of TP between the PP and SP forms. In 2008, 75 % of the total annual samples had higher percentage of SP compared with PP while 73 % of the samples had higher percentage of PP compared to SP in 2009. The percentage of SP ranged from 11 to 96 % (mean 41 %) in 2008 and from 5 to 95 % (mean 56 %) in 2009. Of the 35 samples collected between June 2008 and May 2009 at Majayjay 63% had <50 % of TP in the PP (> 1.2 µm) form. Further, only 23 % of the 35 samples had >70 % of TP as PP, which is considerably less compared to other sites. The differences in the forms of P transported off-site at Majayjay compared with the other three Philippines sites most likely reflects the different sources of P between the sites. Majayjay received a large proportion of piggery effluent waste washed from neighboring town into the Initian Creek that drained directly into the river near the sampling location. In this situation, there would be negligible opportunities for any solubilised P or P bound to organic material to sorb to soil. It is also likely that there is a fraction of P bound to suspended organic material from the manure that passed through the

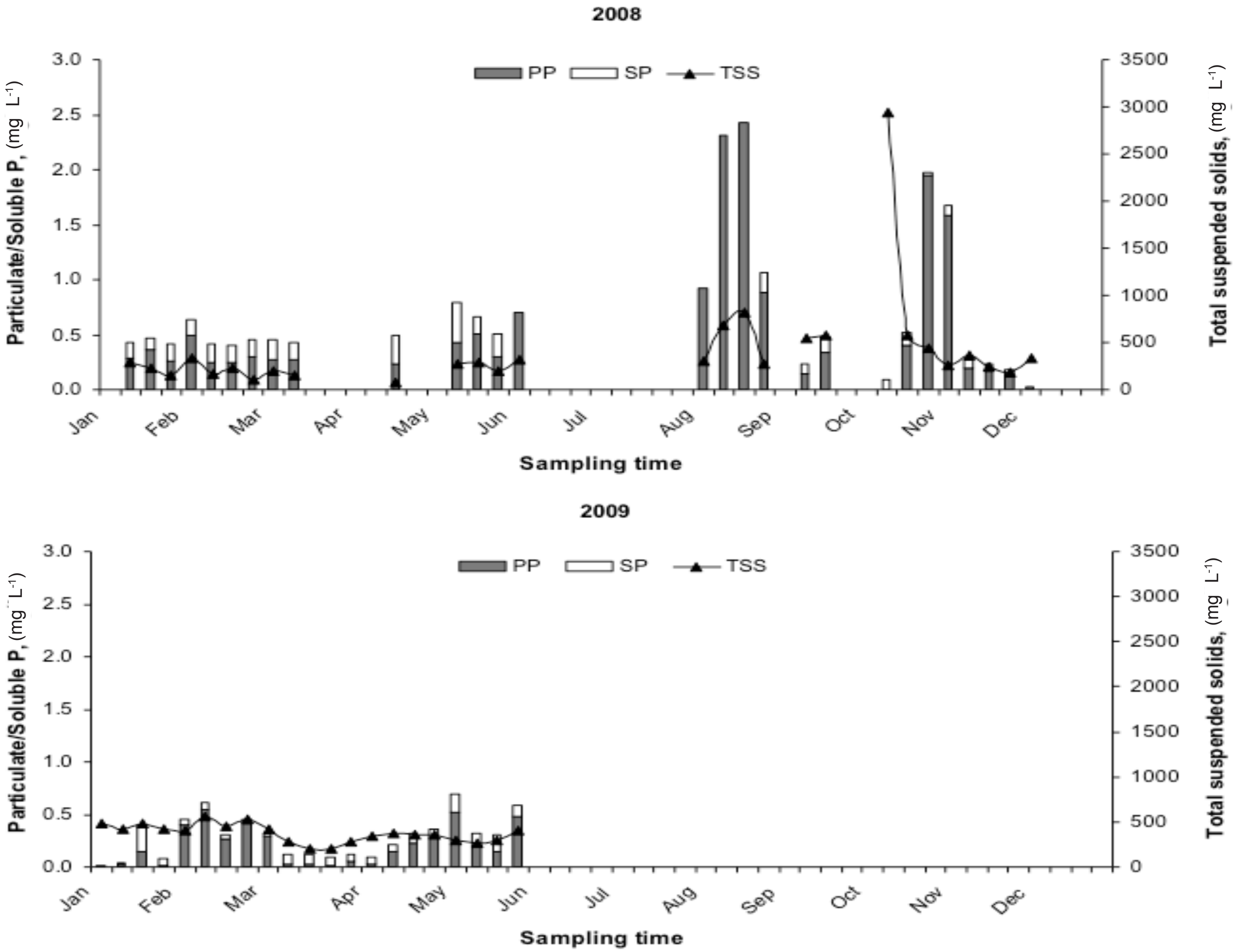

Figure 11. Distribution of TP between particulate (PP) and soluble (SP) forms at Pagsanjan in 2008-2009.

1.2 µm filter that was used as the arbitrary separation of "particulate" and "soluble" in this study. The source of P at the other three sites was agricultural fertilizers and manures applied to fields. In these situations there would be greater opportunities for P sorption to soil as surface water moves through fields. The SP fraction also dominated P transport in Balanac and Bombongan. The average proportion of P in the soluble form was 60 % at Balanac while it was 53 % at Bombongan.

The relationship between TSS and PP concentration was found to vary between sites and between years at the same site. At Lucban, the influence of TSS on PP concentration was highly significant ($P<0.001$) in 2008 ($R^2 = 0.60$) and 2009 ($R^2 = 0.40$) (**Figure 15**) compared to 2007 ($R^2 = 0.28$, $P<0.01$). At Cavinti the influence of TSS on PP was significant ($R^2 = 0.43^*$) only in 2007, but not in 2008 ($R^2 = 0.05$) or 2009 ($R^2 = 0.01$). At Pagsanjan, a significant ($P<0.05$) relationship between TSS and PP was obtained in 2009 ($R^2 = 0.18$) but not in 2008 ($R^2 = 0.003$). In a temperate climate *Heathwaite* (*1995*) studied N and P transport from grassland systems in the UK and found a close link between sediment and P delivery since most of the P was in the particulate and organic form.

Distribution of TOC between Particulate and Soluble Forms

The particulate fraction tended to dominate TOC transport at Lucban Pagsanjan and Majayjay while the soluble form dominated at Cavinti. The proportion of POC at Lucban ranged from 3 to 95 % (mean 57 %), from 16 to 99 % (mean 77 %) at Pagsanjan and from 27 to 94% (mean 74 %) at Majayjay. The proportion of SOC ranged from 3 to 91 % (mean 56 %) at Cavinti. A higher percentage of TOC was associated with the particulate fraction generally from March to June 2008 while the soluble fraction controlled TOC transport from July to October 2008 at Lucban, Cavinti and Pagsanjan. A stronger relationship between TSS and POC was obtained at Pagsanjan ($R^2 = 0.95$, $P<0.001$) and Lucban ($R^2 = 0.59$, $P<0.001$) compared to Majayjay ($R^2 = 0.60$, $P<0.01$), and Cavinti ($R^2 = 0.39^*$).

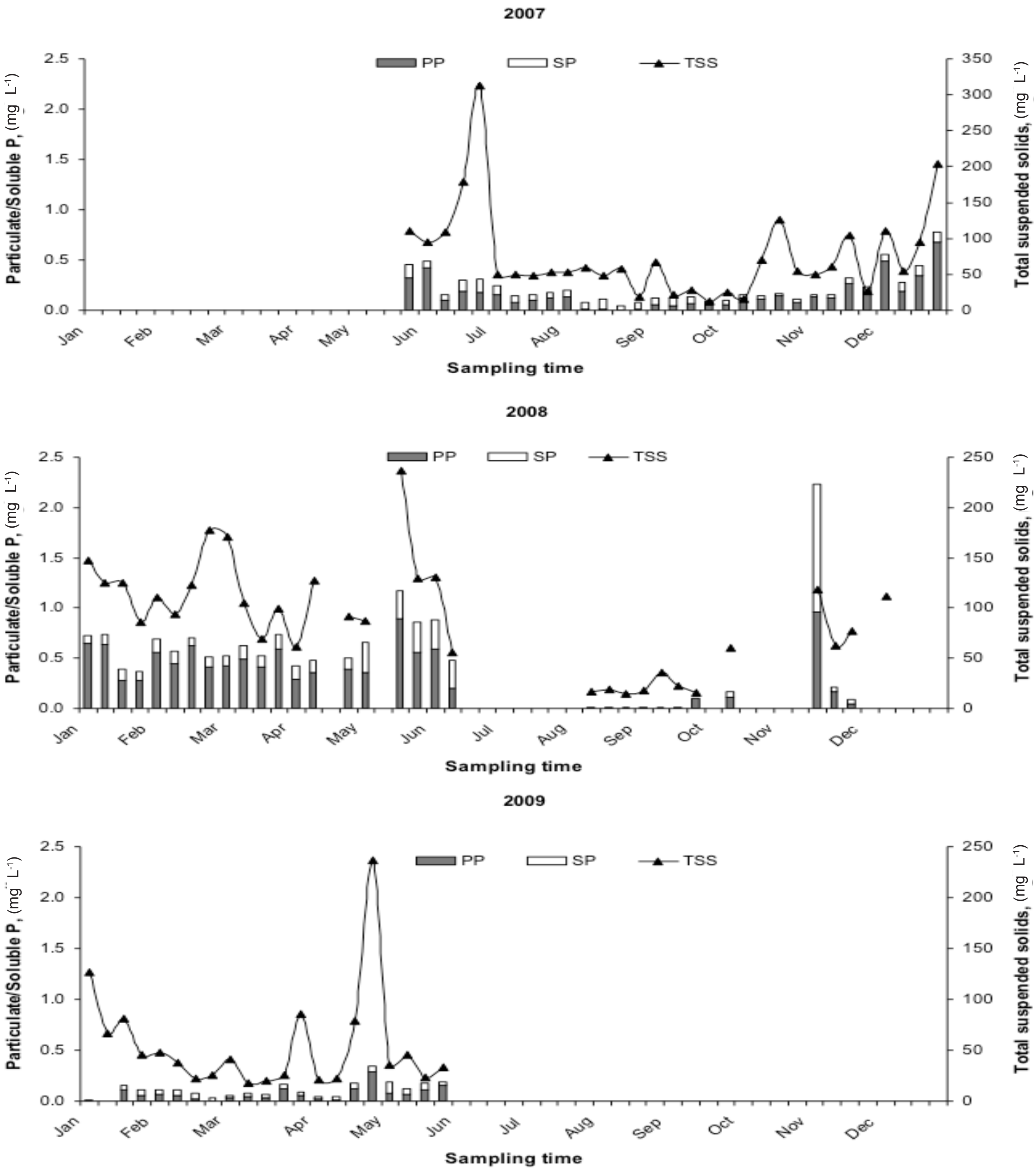

Figure 12. Distribution of TP between particulate (PP) and soluble (SP) forms at Lucban in 2007-2009.

CONCLUSION AND IMPLICATIONS

Particulate N (> 1.2 µm) dominated TKN transport irrespective of land use. The predominantly rice producing area at Pagsanjan had the highest average proportion of TKN in particulate form (73 %) followed by the piggery site at Majayjay (63 %), the vegetable producing area around Lucban (58 %) and the coconut plantation area at Cavinti (55 %). Majority of TP was closely linked to the particulate fraction particularly at Cavinti (72 %), Pagsanjan (68 %) and Lucban (64%) however, the soluble form (<1.2 µm) was the predominant fraction of TP transported off-site at Majayjay

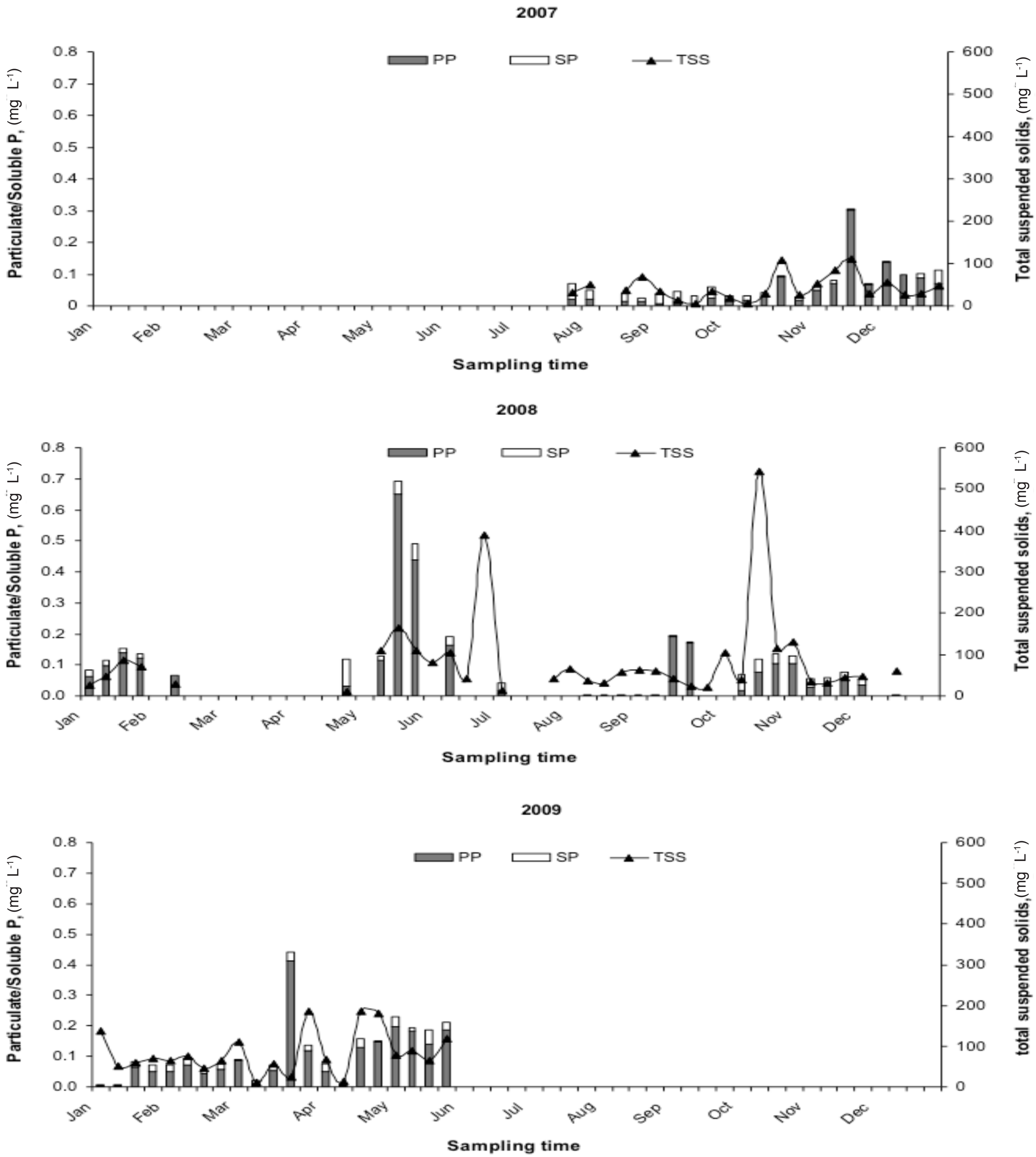

Figure 13. Distribution of TP between particulate (PP) and soluble (SP) forms at Cavinti in 2007-2008 to 2007-2009.

(49 %). Off-site movement of OC was dominated by the particulate fraction at Pagsanjan (77 %), Majayjay (74 %) and Lucban (57 %) while the soluble fraction dominated at Cavinti.

The reduction of particulate forms of nutrients and sediments would have a significant effect on controlling N, P and OC movement into surface drainage water. While various strategies are available for minimizing sediment transport, one of the challenges in tropical environments is the management of off-site transport of sediment under extreme events associated with cyclones and tropical storms.

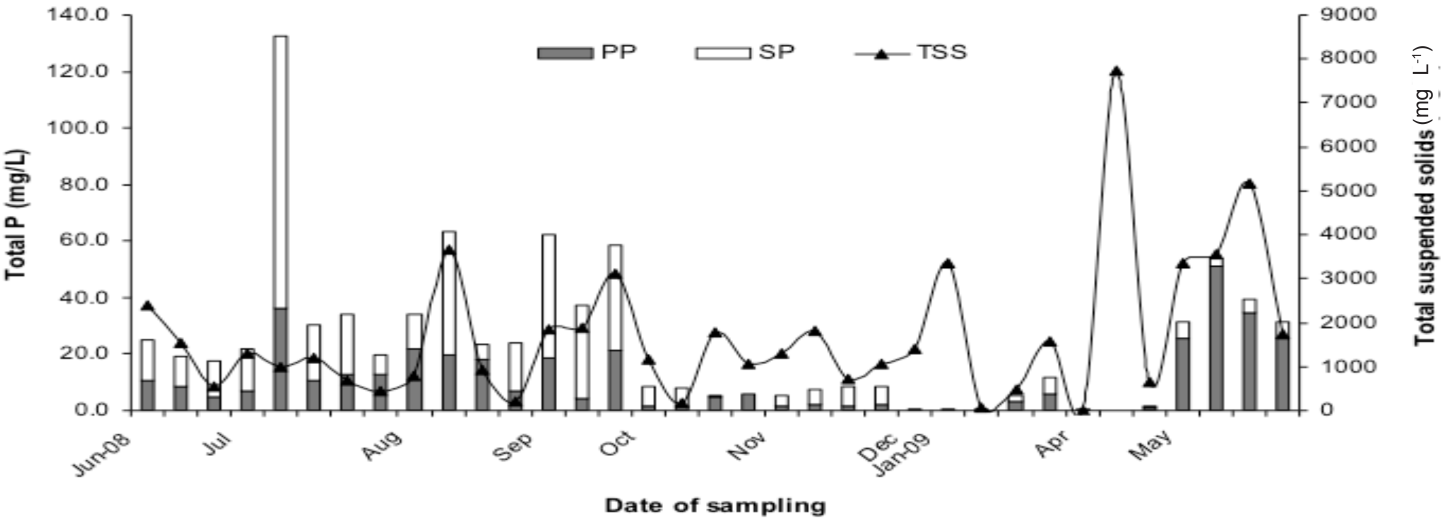

Figure 14. Distribution of TP between particulate (PP) and soluble (SP) forms at Majayjay in 2008-2009.

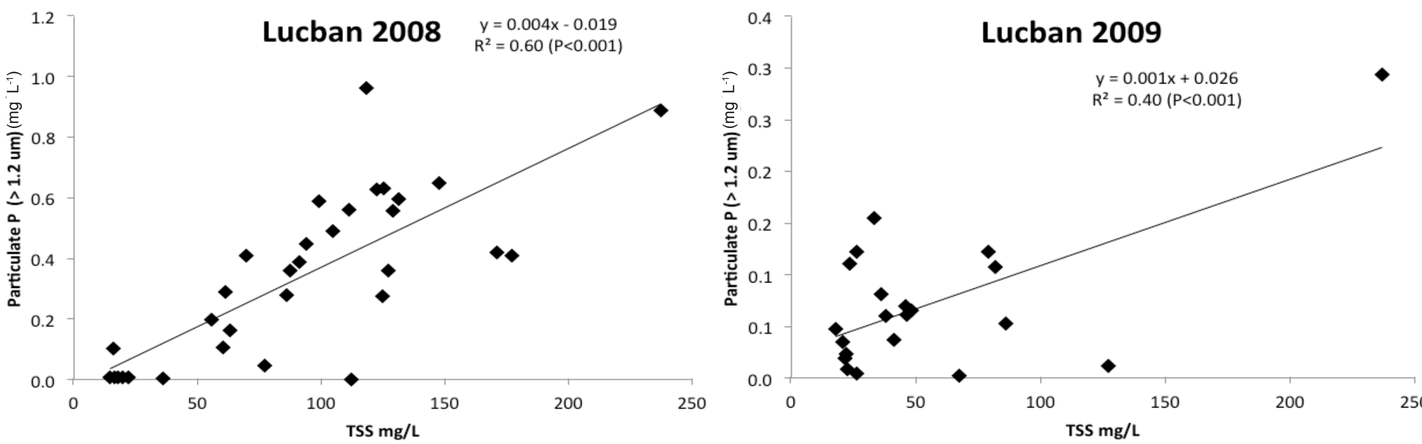

Figure 15. Relationship between PP (> 1.2µm) and TSS in water samples from Lucban in 2008 and 2009.

During such extreme events, the majority of strategies to minimize sediment transport are ineffective. The data from a previous study however shows that even when extreme weather events are not occurring, there is quite a high load of sediment (*Sanchez et al. 2012*) and the implementation of mitigation strategies controlling sediment erosion would be highly beneficial.

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