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Effectiveness of grass filter strips for runoff nutrient and sediment reduction in dairy sludge-amended pastures[1,2]

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ABSTRACT

An experiment was conducted to test the hypothesis that grass filter strips are effective in reducing nutrient and sediment concentrations in runoff from grazed pasture amended with dairy manure sludge. The experiment was carried out under recommended practices in two fields of a dairy farm in San Sebastián municipality, Puerto Rico. Runoff generated following a precipitation event was diverted into runoff-collection devices placed at 0, 10, and 20 m within a grass filter barrier. Samples were analyzed for suspended solids (SS), total Kjeldahl nitrogen (TKN), dissolved phosphorus

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(DP), and total phosphorus (TP). Suspended solid concentrations in runoff entering the filter strips were minimal, which is indicative that SS losses are not numerically significant from pasture fields exhibiting high vegetative coverage. Elevated TP and TKN concentrations were observed in runoff events occurring within 10 days after manure application. This finding indicates that farmers must avoid scheduling manure applications at times when significant rains are expected, because direct runoff will result in excessive off-field nutrient losses if no filter strip is present. In both fields, DP concentrations in runoff were significantly reduced with a filter strip 20 m wide, whereas TP concentrations were significantly reduced only from the field exhibiting the highest concentration in runoff, i.e., Toronjo field. A 27% decrease in TKN concentration was observed in the Toronjo field as a result of the 20-m filter strip (relative to the entrance), but such reduction was nonsignificant. Although the 20-m grass filter strip was effective in reducing nutrient concentrations in runoff from manure-amended fields, the implementation of other best management practices is needed to reduce the impact of nutrient losses to levels that do not pose a threat to the integrity of the receiving waters.

Key words: grass filter strips, dairy manure sludge, nutrient runoff concentrations, water quality

RESUMEN

Eficacia de franjas filtrantes para la reducción de nutrientes en escorrentía de pasturas enmendadas con efluentes de vaquerías

Se realizó un experimento para probar la hipótesis de que las franjas vegetativas filtrantes son efectivas en reducir las concentraciones de nutrientes y sedimentos en la escorrentía que se genera de pasturas enmendadas con cieno de estiércol vacuno. El experimento se realizó siguiendo prácticas recomendadas en dos predios de una finca dedicada a la ganadería de leche en San Sebastián, Puerto Rico. La escorrentía que se generaba luego de cada evento de precipitación se canalizaba a un aparato para recoger escorrentía localizado a 0, 10, y 20 m dentro de una franja vegetativa filtrante. Las muestras se analizaron para sedimentos suspendidos (SS), nitrógeno total Kjeldahl (TKN), fósforo disuelto (DP) y fósforo total (TP). Las concentraciones de SS en escorrentía entrando a la franja filtrante fueron muy bajas, lo cual es indicativo de que las pérdidas de SS de suelos bajo pasturas con buena cobertura vegetativa no afectan significativamente la calidad del agua. En eventos de escorrentía que ocurrieron 10 días luego de la aplicación del cieno de estiércol se observaron concentraciones elevadas de TP y TKN. Estos resultados indican que el agricultor debe evitar aplicar el estiércol cuando se esperan eventos de precipitación significativa ya que la escorrentía que se genera causaría pérdidas excesivas de nutrientes si no hubiese una franja filtrante. En ambos predios evaluados, las concentraciones de DP en la escorrentía se redujeron con la franja filtrante de 20 m, mientras que las concentraciones de TP se redujeron solamente del predio con mayores concentraciones en escorrentía (Toronjo). Se registró una reducción de 27% en las concentraciones de TKN del predio con la franja de 20 m, pero la reducción no fue estadísticamente significativa. Aunque la implementación de franjas filtrantes de 20 m son efectivas para reducir las concentraciones de nutrientes en la escorrentía de predios enmendados con cieno de estiércol vacuno, la implementación de otras prácticas de manejo son necesarias para reducir las pérdidas de nutrientes a unos niveles que no amenacen la integridad de las aguas receptoras.

Palabras clave: franjas filtrantes, efluentes de vaquerías, concentración de nutrientes en escorrentía, calidad de aguas

INTRODUCTION

Losses of soil, nutrients, pesticides, pathogens and other biological and chemical materials from agricultural lands can be reduced through implementation of conservation plans (Mausbach and Dedrick, 2004). These plans include the application and implementation of conservation practices otherwise known as Best Management Practices (BMPs) (USDA-NRCS, 1999). The latter are a specific group of individual practices utilized to maintain or enhance the sustainability of farms by conserving the natural resource base from which the agricultural industry is derived, to improve the efficient use of nutrients, to reduce pesticide losses, and to maintain water quality. Those BMPs specifically used on dairy farms help ameliorate the potential negative impact that dairy production-related activities may have on the environment (Meals and Braun, 2006; Soupir et al., 2006).

Grass filter strips (NRCS code 393) have been promoted as an adequate practice for reducing nutrient and sediment loads in runoff (Doskey et al., 1997; USDA-NRCS, 2001b). Their implementation has been encouraged via state and federal programs, and the USDA Natural Resource Conservation Service has guidelines for installation and maintenance. Unfortunately, there is scant quantitative information on their effectiveness for nutrient and sediment removal under conventional farming practices in Puerto Rico. For example on Puerto Rico dairy farms, dairy manure sludge from waste storage facility (NRCS code 313) is applied to fields used for haylage or pasture following Nutrient Management Plan specifications (NRCS code 590) (USDA-NRCS, 2001a). The implementation of grass filter strips placed at edge of fields on footslopes where runoff occurs is probably effective in nutrient and sediment removal. Researchers have not determined the ideal grass strip width (between the field and drainage channel) for effective nutrient and sediment reduction under specific scenarios (e.g., slope, soil type, hydrologic conditions) in Puerto Rico. Although longer strip widths are probably more effective, they may not be economically feasible as this practice reduces the available manure application and grazing area because said portion of the fields needs to be excluded from other activities. The objective of this experiment was to test the effectiveness of two grass strip widths in removing nutrients and sediment in runoff from two fields amended with dairy manure.

MATERIALS AND METHODS

The experiment was performed on the Pura Brisa dairy farm located in the municipality of San Sebastián. The farm's owner is a participant in USDA-NRCS conservation programs and manages manure accord-

ing to recommended Conservation Practice Standard 590 (USDA-NRCS, 2001a). During the time the experiment was being conducted, the farm had approximately 120 milking cows and about 80 heifers, bulls, and dry cows for an equivalent of 144 animal units, which produced approximately 300 ton/yr of manure (dry wt) (Torres, 2005). The farm has approximately 58 ha under pasture production, primarily used for grazing. An area of about 16 ha receives 20.95×10^6 L effluent for an estimated annual dairy manure sludge P load of 56 kg P/ha. Up to an additional 45 kg P/ha could be added from direct excretion of grazing animals and about 24 kg P/ha as fertilizer P supplemented by the farmer on an annual basis. Further details of the farm management and P-mass balance can be found in Torres (2005). The soil predominating on the farm belongs to the Soller series (Clayey, mixed, active, isohyperthermic, shallow Typic Haprendolls) (Beinroth et al., 2003) with minor inclusions of Vertisols (USDA-SCS, 1975) with slopes ranging from 5% up to 40%. The waste treatment lagoon has a capacity of 2,340 m^3 and receives part of the dairy manure generated on-farm which is eventually spread to selected fields through underground tubing and spraying systems (NRCS Code 633) (USDA-NRCS, 1999).

Two fields (Toronjo and Cementerio) in Finca Pura Brisa were selected. Over 90% of the field areas had soils that belong to Soller series (USDA-SCS, 1975). The predominant forage grass in both fields, as well as in the filter strip was Stargrass (*Cynodon nlemfuensis*) with minor inclusions of grama colorada (*Axonopus compressus*). Both fields had received dairy manure sludge (from the temporary waste storage lagoon) for about five years prior to this trial. The lowest 25 m from the edge of fields closest to the drainage channels/streams where the filter strips were eventually placed were excluded from the dairy manure sludge application during the experiment. Ortega-Achury et al. (2007) documented that 60% of the field areas were in the "Low" and "Medium" soil test P categories (Olsen-P), and 33, 5, and 1% were in the "High", "Very high" and "Extremely high" soil test P categories, respectively, suggested by Sotomayor-Ramírez et al. (2004). The highest soil test P values were in field areas farthest away from water bodies and drainage channels. The lower portions of the field under pasture production served as natural and previously established vegetative filter strip.

Field pastures were grazed at approximately five-week intervals. Field topographic maps were generated with a global positioning system device, and after reconstructing the in-field topography, two strips of 10 and 20 m (33 and 66 ft) widths, respectively, were constructed in the lower footslope portions of each field. The size of the strip width was controlled by fencing an area 20 m downslope (i.e., the strip width) × 21 m long (60 × 70 ft) (i.e., perpendicular to the slope) to exclude ani-

mals. The fenced area was not grazed, thus permitting luxurious grass growth throughout the experiment. Within each fenced area, three groups of runoff collectors were established. Each group consisted of three runoff collectors equidistantly placed to characterize the spatial variability within each field at selected strip widths. The first group of collectors (group 1) was placed at the transition point between the portion of the field receiving manure and the edge of the filter strip (i.e., 0 m). The second group of collectors (group 2) was placed at a distance of 10 m (33 ft) from the edge of the group 1 field collectors. The third group of collectors (group 3) was placed at a distance of 20 m (66 ft) from collectors in group 1. A total of nine collectors were placed within each field. The exact placement and orientation of the runoff collectors was performed while considering topography, field area, water movement, rock formations, and slope. The fenced areas were established from 1 to 13 August 2004, and final installation of the collectors was performed on 23 August 2004. Because of the possible soil-area disturbance during establishment, it was decided to permit a two-week period for the disturbed area to return to its original state prior to initiation of runoff water collection about 18 September 2004.

The runoff collectors were constructed as described by Daniels and Gilliam (1996). Runoff water samples were collected after each runoff event during two rainfall periods. Period 1 lasted from 19 September through 6 December 2004, whereas period 2 occurred from 6 March 2005 to 1 June 2005 (Figure 1). Runoff water was diverted through the

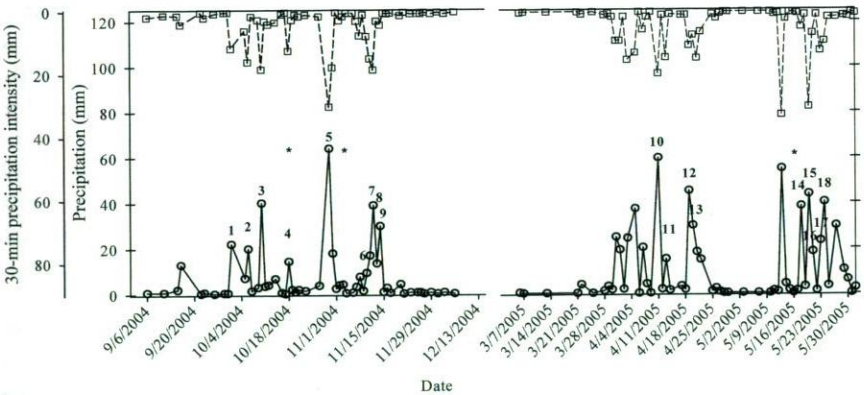

FIGURE 1. Daily precipitation (open circles) and 30-min precipitation intensity (open squares) at Finca Pura Brisa from September to December 2004, and from May to June 2005. The numbers in the graph correspond to complete runoff events that occurred and were collected as a result of the precipitation events. Asterisk denotes the date when manure was applied to the Toronjo field.

collectors to acid-washed 1-L Nalgene® collection bottles equipped with an automatic shut-off valve that was activated once each bottle was filled. Runoff samples were collected for nearly 90% of the runoff events. After each runoff event, the bottles were removed from the collector system, capped and transported to the laboratory. After removal, a new set of clean 1-L bottles were placed onto the runoff collector system. The collectors gathered up to 1 L of runoff, and the bottles received the first fraction of runoff, which is the most nutrient and sediment concentrated portion of the runoff event.

Total suspended solids [hereafter referred to as suspended sediments (SS)] were quantified by filtering a runoff aliquot through glass fiber filter (Whatman GF/F) (EPA method 160.1) (USEPA, 1999). The unfiltered subsample was digested by using the acidic persulfate oxidation method (Pote et al., 2000). Orthophosphate-P in digest, described as total P (TP) was quantified by using the ascorbic acid method (Murphy and Riley, 1962), followed by quantification using a Bran+Luebbe Autoanalyzer. Total Kjeldahl N (TKN) was quantified following a Kjeldahl digestion of the unfiltered sample followed by NH_4+ analysis using the Bran+Luebbe Autoanalyzer. Samples were filtered through 0.45 μm size filter and the filtrate was analyzed for DP by using the ascorbic acid method as described previously.

Grass height was measured weekly within the grazed field and the grass inside the filter strip was measured at 15-day intervals by using the Disk Meter method (Tucker, 1980). Disk readings were calibrated against herbage mass measured by using data collected by Torres (2005). During the study period, herbage biomass estimates within the filter strip varied from 1,500 to 3,200 kg dry matter/ha. The Cementerio field was grazed from 17 to 22 September 2004, 31 October to 3 November 2004, 1 to 5 December 2004, and from 12 to 23 April 2005. Toronjo field was grazed from 17 to 22 September 2004, 1 to 5 December 2004, and 26 April to 12 May 2005. Dairy manure sludge was applied to Cementerio field on 18 October 2004 and to Toronjo on 18 October and 1 November 2004 and on 18 May 2005. During period 2, sludge was not added to Cementerio field. The farmer fertilized Cementerio field on 1 December 2004 with 224 kg/ha 15-5-10 (N-P_2O5-K_2O).

Precipitation was gathered from a point between the two experimental fields. Records were gathered for both sampling periods (Figure 1). The twenty-nine precipitation events which resulted in runoff had a total precipitation of 655 mm (25.8 in), and the 30-min precipitation intensity (I-30) minimum, maximum, and mean values were 0.25, 33, and 10.3 mm, respectively. Out of the twenty-nine runoff events, fifteen occurred during period 1 and fourteen were sampled during period 2. Nine events in each period (18 total) were considered complete. A com-

plete event is referred to as one in which at least 80% of the collection bottles from both fields had a water sample. Lack of runoff water collected may be due to low runoff depths or water movement diverted away from the collector areas.

A statistical analysis was performed to evaluate the effects of the width of the filter strip (0, 10 and 20 m) on SS, TP, DP and TKN concentrations separately for each field with three replications within each filter strip width, using Proc Mixed of SAS (Statistical Analysis System, Cary, NC). Each of the runoff events was considered a repeated measure, and an event*width statement in the random term was included, thus assuming that each runoff event could affect one width and not another in a random manner. The effects of recent applications on the extent of nutrient concentration losses in runoff were evaluated by contrast comparisons among four events occurring immediately after application (<10 days) and four events prior to application. Nutrient data were natural log transformed prior to statistical analysis, and values reported are the inverse natural log values.

RESULTS

In the Toronjo field, the 10-m filter strip width reduced incoming runoff TP and DP concentrations by 29 and 32%, respectively (Figure 2A, B). Similarly, the 20-m grass filter strip reduced TP and DP concentrations by 47 and 49%, respectively, relative to that entering the filter strip. Concentrations of TP were 2.27, 1.61, and 0.967 mg P/L at 0-, 10-, and 20-m grass filter strip widths, respectively, and concentrations of DP were 1.61, 1.09, and 0.82 mg P/L at 0-, 10-, and 20-m grass filter strip widths, respectively. In the Cementerio field, DP concentrations were effectively reduced by 23% in the 20-m grass filter strip width only, whereas the 16% TP concentration decrease at the 20-m grass filter strip width was not significant ($P > 0.05$). The greater TP concentration observed in runoff from Toronjo relative to that of Cementerio field concurred with the greater amounts of dairy manure sludge applied. At Toronjo, there was a trend for the DP/TP ratio to increase with an increase in filter strip width, which suggests that the filter strips were more effective in reducing the particulate P fraction relative to the dissolved fraction (Figure 2C).

Previous work in Puerto Rico (Sotomayor-Ramírez et al., 2006; Ortega-Achury et al., 2007) and in the USA (Kleinman and Sharpley, 2003; Schroder et al., 2004) have shown that TP concentrations in runoff are influenced by high precipitation occurring shortly after manure application. Nutrient concentrations at the entrance of the filter strip were significantly higher when runoff occurred within ten days after

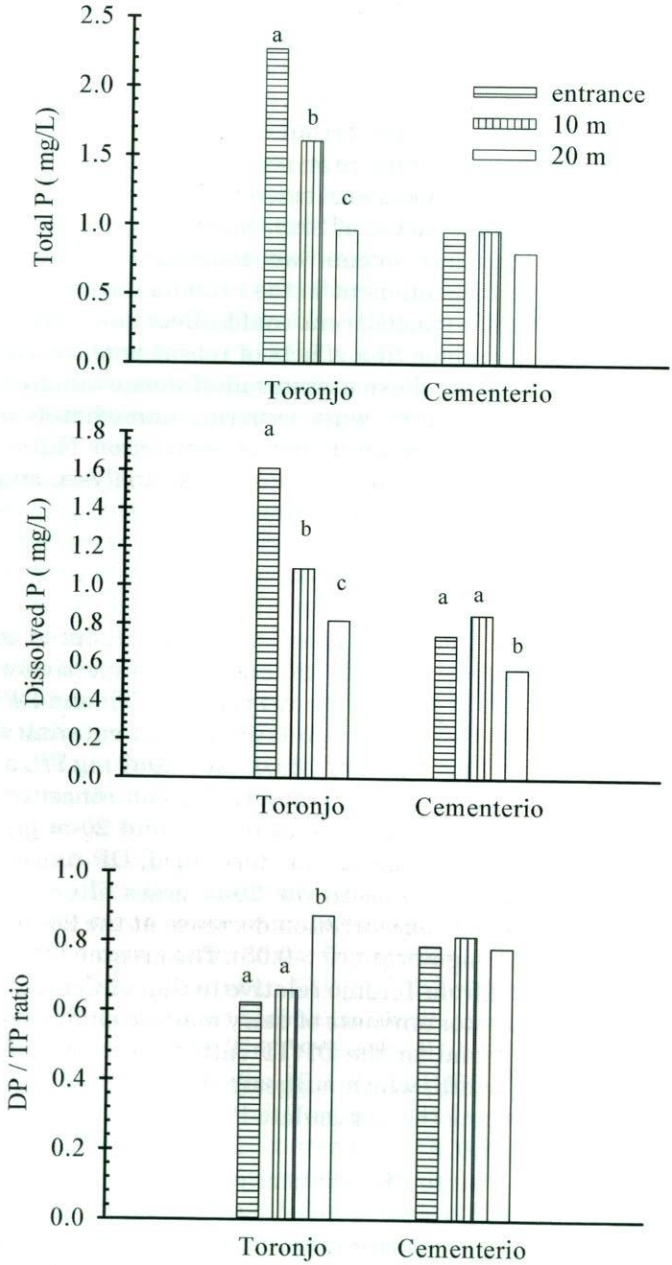

Figure 2. Mean total phosphorus concentrations (TP) (A); dissolved phosphorus (DP) concentrations (B); and DP/TP ratios (C) in runoff in grass filter strip widths of 10 and 20 m in the experiment.

application than on all other days, with TP concentrations at the entrance of the filter strip of 3.13 and 2.03 mg/L ($P < 0.05$), respectively, and with DP concentrations of 1.71 and 1.48 mg/L ($P < 0.1$), respectively (Table 1). For example, dairy manure sludge was applied in the morning of 18 October 2004 in the Toronjo field. Elevated TP concentrations of 3.74 mg/L were observed in runoff event number 4, which occurred the afternoon of 18 October, and runoff TP concentrations for event 5 (12 days later) had lower TP concentrations (Figure 3). In another instance, dairy manure sludge was applied in the morning of 18 May 2005 on Toronjo field, and runoff event number 14 occurring that afternoon had elevated TP concentrations of 9.79 mg/L. In the next runoff event following the application, and those thereafter, TP concentrations were clearly reduced. These findings indicate that manure application should be coordinated with climatic information to avoid applications at times of high rainfall probability.

It is encouraging that following the application of dairy manure sludge to the fields, such as during events number 4, 6 and 14, runoff TP concentrations were significantly reduced in grass filter strips of 20-m width in Toronjo. Maximum threshold TP concentration of 1 mg P/L in runoff from agricultural fields has been suggested (USEPA, 1986; Parry, 1998), yet this suggested limit is far from being implemented in Puerto Rico. Table 2 demonstrates that the proportion of events with concentrations of less than 1 mg P/L increased with increasing filter strip width in both fields. Furthermore, TP and DP concentrations at 20 m were similar 10 days following application and on the remaining

TABLE 1.—*Mean nutrient (TP, DP and TKN) and suspended sediment (SS) concentrations at the entrance and at 20-m grass filter strip on runoff occurring 10 days after application (recent application) and on runoff occurring on all other days (without recent application) in Toronjo field.*

Parameter	Entrance (0 m)		20 m	
	Recent application[1]	Without recent application	Recent application	Without recent application
	mg/L			
TP	3.13	2.03[2]*	1.16	0.879
DP	1.71	1.48**	0.872	0.752
TKN	3.08	2.73	2.28	2.14
SS	66	44	51	33

[1] Recent refers to runoff events occurring ≤10 days following manure application; without recent application refers to events occurring after a manure stabilization period greater than 10 days.

[2] Comparison within buffer strip width indicates significant differences between recent application and without recent application at *$P < 0.05$, and **$P < 0.1$.

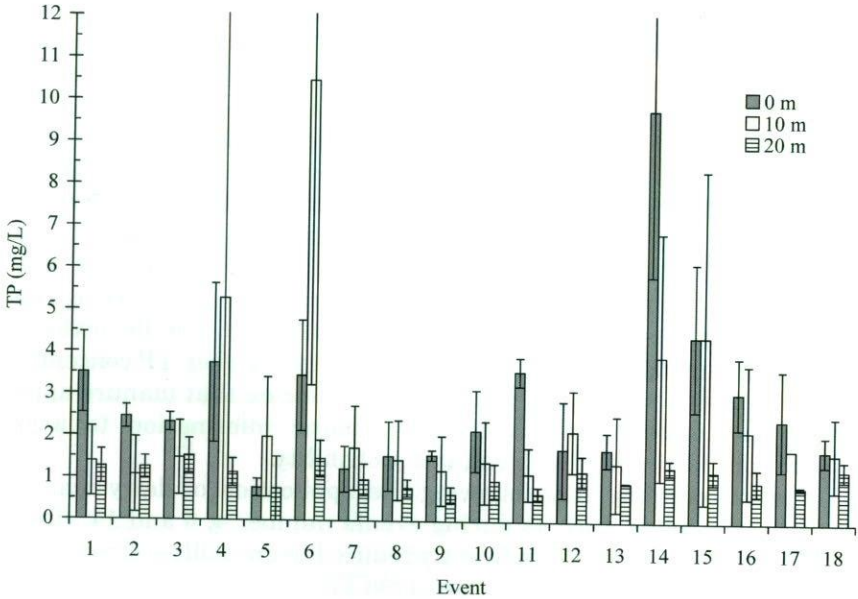

Figure 3. Temporal variation of total phosphorus concentrations (TP) in runoff in two grass filter strip widths of 10 and 20 m in the Toronjo field.

days, all of which suggests that the filter strips were equally effective with and without recent dairy manure application (Table 1). Although nutrient concentrations were significantly reduced because of the presence of a grass filter strip of 20-m width, concentrations may still be of concern from a water-quality perspective. These observations demonstrate that a combination of BMPs (e.g., reducing dietary P intake, scheduling P application during the dry season) is needed to achieve an environmentally sound manure management program in Puerto Rico.

In the Cementerio field, mean TKN concentrations were 1.81, 2.01, and 1.92 mg N/L for grass filter strip widths of 0, 10, and 20 m, respectively (Figure 4). At Toronjo, mean TKN concentrations were 2.73, 2.19, and 2.0 mg N/L for grass filter strip widths of 0, 10, and 20 m, respectively. Concentrations were reduced on average 19 and 73% with filter strip widths of 10 and 20 m, yet there were no statistical differences as a result of filter strip width. As it occurred with P concentrations, higher TKN concentrations were observed at Toronjo as a result of increased dairy manure application. The TKN concentrations at the entrance (0 m) were somewhat lower than mean values reported by Ortega-Achury et al. (2007) of 2.99 and 5.97 mg/L for Cementerio and Toronjo, respectively, which may be a reason why statistical differences in nutrient re-

TABLE 2.—*Proportion of events with runoff concentrations less than 1 mg P/L at the entrance (0 m) and two filter strip widths (10 and 20 m) in Toronjo and Cementerio fields.*

Filter strip width (m)	Field	
	Cementerio	Toronjo
	%	
0	50	5
10	55	17
20	72	44

duction with the two filter strip widths were not found. As it occurred for TP, the TKN concentrations were clearly reduced following application (notice events 6 through 9 and events 14 through 18) with the 20-m filter strip. Large precipitation events such as those observed for events 1, 5 and 7 did not cause increased TKN concentrations.

DISCUSSION AND CONCLUSIONS

The suspended sediment values are well below the current total dissolved solid (TDS) water quality standard for class A waters in Puerto Rico, 500 mg/L (PREQB, 2003). This finding indicates that suspended sediment losses from well covered (>90%) pasture fields are minimal

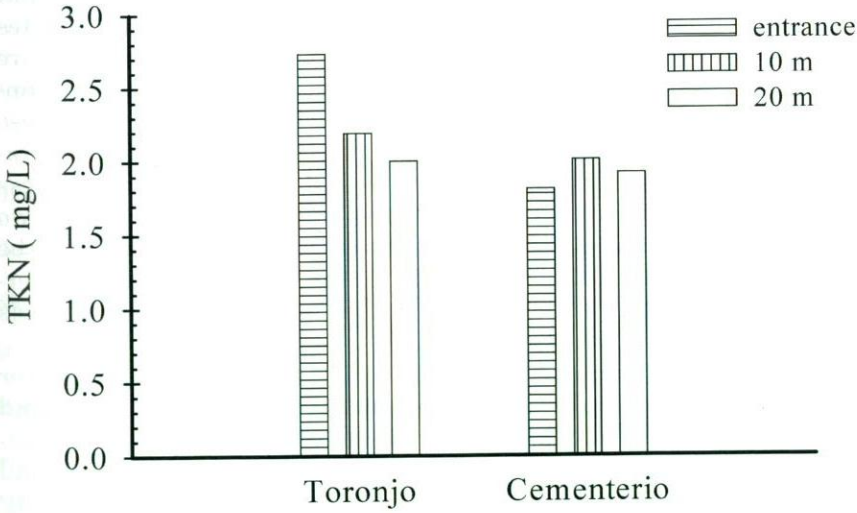

Figure 4. Mean total Kjeldahl nitrogen (TKN) concentrations in runoff in grass filter strip widths of 10 and 20 m in the experiment.

and do not pose a threat to the water quality of nearby rivers. The values obtained in this study are in accord with values reported by Ortega-Achury et al. (2007) under similar conditions (i.e., well covered pasture fields) from two animal farm operations of Puerto Rico. Our results also agree with trends reported by Smith and Abruña (1955), who evaluated the effect of different covers on the extent of soil erosion from a steep-sloped soil under grassland vegetation, thus demonstrating that sediment losses from grass-covered steep soils were minimal. Because of the low suspended solid concentrations observed, it was not possible to determine the effectiveness of the filter strip in reducing the concentrations of this parameter in runoff.

The results presented in this experiment demonstrate that nutrient (primarily TP and DP) reductions in runoff can occur as a result of the presence of edge of field grass filter strips. Filter strips can reduce TP and DP concentrations by 29 and 32% at 10 m, and by 57 and 49% at 20 m, respectively. Although there was some reduction in TKN concentrations with a 20-m filter strip, the results were non-significant. Precipitation length and intensity do not seem to affect nutrient concentrations in the range of regimes that were observed in this experiment, as has been observed in other studies (Daniels and Gilliam, 1996). Rather, what appears to be the main variable affecting nutrient concentrations is the shorter the time interval between application and rainfall that will generate runoff.

Alternatives for reducing nutrient concentrations in runoff are applying manure to other land areas, reducing application volumes but increasing frequency of application, and by spreading manure on dates when rainfall is less expected. Typically, manure application areas are primarily limited by within-farm topographic and geomorphologic conditions such as stream proximity and slope. If the suitability of these areas exists, further limitations include financial constraints for infrastructure expansion. Spreading manure on dates when rainfall is less expected is difficult in this area as rainfall occurs one out of every two days. Alternatives need to be implemented as more P is estimated to be currently applied as dairy manure (2,330 ton P) than is applied as fertilizer P (251 ton P) to forage production areas on an annual basis (Sotomayor-Ramírez et al., unpublished).

Nearly 95% of the land area within the fields was in the "High" or lower soil test P categories suggested by Sotomayor et al. (2004), and only 6% was in the "Very high" or "Extremely high" categories (Ortega-Achury et al., 2007). Using regressions by Sotomayor et al. (2004) and the upper limit of the "High" category as the regressor, background DP concentrations in runoff in these fields are expected to be 0.06 mg DP/L; yet measured DP concentrations were nearly ten times higher. This

observation suggests that dissolved P concentrations in runoff were highly influenced by P in manure overlying vegetative material and soil. Phosphorus in the particulate material can be solubilized and released to runoff, thus increasing P concentrations. Also, as more time passes between application and a runoff event, P is expected to stabilize into less reactive soil pools, thus decreasing P concentrations in runoff. For example Ramírez (2005) observed that DP concentrations in runoff from Ultisols could be from two to four times higher when soils were amended with an organic source (broiler litter), as it occurred in this study, than with triple super phosphate (inorganic P) at equal soil test levels.

A large land area of dairy production farms within northwestern Puerto Rico has Soller soil since it predominates in this geographic area. However, the results should be extrapolated with caution to other soil types of the island and tropical areas because runoff in Soller soil could be lower than that in other soils when it is very dry, and greater than that in other soils after frequent precipitation events. For example, the Soller soil consists to a large extent of expanding clay types, in which infiltration is reduced at high soil moisture content. Also, the soil tends to be of a shallow nature with rocky calcareous substrata and rocky outcrops which reduce the water storage capacity. In contrast, when the soil is very dry, cracks can form which permit preferential flow between the soil layers and the rocky substrata, thus increasing infiltration and decreasing runoff (USDA-SCS, 1975).

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