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Chapter 4

Nonpoint Pollution Caused by the Agriculture and Livestock Activities on Surface Water in the Highlands of Jalisco, Mexico

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Additional information is available at the end of the chapter

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1. Introduction

The agriculture and livestock industry in Mexico and particularly in the State of Jalisco, Mexico, has been moved forward technologically, resulting in important productivity increment. However, the use of these technologies involves the application of large amount of fertilizers and pesticides for prolonged periods of time. Furthermore, the fertilizers are often applied incorrectly, increasing the inefficiency and resulting in high environmental impact on soil and water in the lower watershed area.

The current agriculture and livestock lands management practices, with the excessive agrochemical use, have created ecological, environmental and economic problems such as: 1) the soil erosion, which is detrimental to the organic matter availability and soil cover, 2) the surface water and groundwater pollution caused by manure and sediments, 3) the disruption of wild life habitats, and 4) negative effects on the rural landscape. When environmental agrochemical products such as nutrients, pesticides, compost, gases (nitrogen oxide and methane), are used in combination with incorrect agricultural management practices, the result is the nonpoint source pollution (NSP). When this problem is visualized in large scale such as region, lakes or rivers, the result is a high contamination problem in the lowest watershed area, which is both difficult and costly to solve. However, when the pollution sources are in a reduced area, like a small agriculture farm or grassland area, the magnitude decreases and the problem is more easily solved.

On a small scale farm, the combination of management practices for fertilizers and pesticide applications, in accordance with soil and climate characteristics, create a complex processes,

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particularly when they occur in different times and spaces. This situation is particularly difficult to understand and consequently, the preventive or corrective actions that limit the spread of pollution in agricultural/livestock lands and water bodies are difficult to avoid (Flores *et al.*, 2009). The authors stated that a feasible option to solve the NSP problem of surface water is control or prevention in the initial stages, along with reducing the amount of fertilizers and pesticides by the adoption of new technologies or improving the efficiency of agrochemical products. Apart from, the implementation of adequate conservation practices, it is essential to limit the transportation of sediments and nutrients to outside of agriculture and livestock lands. However, before any technology application is implemented, it is necessary to know the processes associated with NSP from the small farm scale to the watershed scale, first, involving the producer efficiency criteria of their land and then, selecting and including the best management practices to prevent and/or control the NSP.

2. The non-point source pollution problem

Contamination is the introduction of substances into the environment indirectly or directly by humans, provoking not only negative impacts on the environment, but also, putting at risk human health or other living organisms by interfering with legitimate environment use. Loehr (1984) mentioned that the pollution sources may be classified as point sources (direct or localized) and non-point sources (diffuse or not localized). The point sources discharge pollutants though piping, channels, or ditches--much like those that come from city wastewater treatment plants, the food processing industry, and runoff from large pig farms. Discharges from these sources are usually constant and also related to the municipal industrial activities.

The non-point source pollution (NSP) is caused by inadequate agricultural and livestock practices, where pollutants move with the runoff, dragging their sediments, and putting at serious risk both the surface water and groundwater. The agricultural sources of NSP includes; the loss of the superficial soil where fertilizer, pesticides and animal manure were applied, and were transported to water sources such as stream and rivers through runoff. The amount of pollutants transported is a function of variables that include the type of soil, the land slope, land use, and the natural route that water follows through the natural drainage networks (Deliman and Leigh, 1990). Some of the variables involved in this kind of contamination are uncontrollable by humans, such as the land topography and the rain, compared to others like cultivation covering, and the time and location of agrochemical application and management, which s can easily be controlled (Loehr, 1984). Nevertheless, combining these variables cannot relate them to the same and unique origin of discharge, which creates the problem of source identification, as well as potential impact evaluation over the transport route and the dams where water is stored (Deliman and Leigh, 1990).

The eutrophication is a natural process that can be accelerated by the water enrichment with excessive inorganic nutrients such as nitrogen (N) and phosphorous (P), which are considered responsible for the excessive growth of algae and aquatic plants in water bodies (Schnoor, 1996). The eutrophication holds a close relation to the dissolved inorganic N (DIN)

and the dissolved inorganic phosphorous (DIP), in the proportion DIN:DIP; from a stoichiometric viewpoint of algae and aquatic plants, if this proportion is greater than 7:1 (Gold and Oviatt, 2005), 12:1 (Pietilainen, 1997) or 14:1 (Schnoor, 1996), P is the limiting nutrient, but if the proportion is lower than 5:1 (Pietilainen, 1997) or 7:1 (Gold and Oviatt, 2005), N is the limiting nutrient. Concentrations in water of 0.3 ppm of inorganic N and 0.015 ppm of inorganic P are the levels in which eutrophication could become troublesome (McCool and Renard, 1990). In the United States of America approximately 90% of lakes studied demonstrated a DIN and DIP higher than 14:1; as a result, P was defined as the limiting factor (Carpenter, 2005; Sharpley *et al.*, 2003).

In México, the total P has been used as an indicator of the trophic state of water bodies. Thus, a level of over 0.118 mg L^{-1} in tropical lakes (Sobrino-Figueroa, 2007), or water bodies in warm environments with more than 0.035 mg L^{-1} (Díaz-Zavaleta, 2007b), is considered eutrophic. With this criterion for the characterization of a trophic state, Díaz-Zavaleta (2007a) found that many bodies of water in México have eutrophication problems. In Tepatitlán, Jalisco, Ramírez *et al.* (1996) it was determined that the N and P contents in water samples at two points and at two depths of the El Jihuite dam, where the proportion of DIN:DIP was 14:1 and 13:1, for the surface and the bottom of the reservoir, and a total P concentration greater than 0.1 ppm, making the dam eutrophized, and P the limiting nutrient. The eutrophication in surface water is one of the principal problems caused by the NSP which comes from agricultural and livestock lands.

2.1. The agricultural and livestock activity in the highland of Jalisco, Mexico

In the Highlands of Jalisco, Mexico, there are more than 241,000 hectares are utilized for agriculture activities with corn being the most common product at about 90%. However, of this, 40% of the corn is forage which is used as feed for dairy cattle (SIAP-SAGARPA, 2011). On the other hand, the cattle inventory in the Highlands of Jalisco is about 226,000 cattle, 1.715 millions of pigs and 82 millions of chickens (SIAP-SAGARPA, 2011); the cattle alone generate about 4.9 millions of tons of manure (Flores *et al.*, 2012). Even though, the manure produced by the Highland region of Jalisco is an important source of nutrients for corn and grassland, it also contains other components such as fecal coliforms bacteria, total coliforms bacteria, and enteric pathogens (Flores *at al.*, 2012). These components may deteriorate the water quality in lakes, dams and dikes (Torres and Calva, 2007; Soupir *et al.*, 2006; Ramírez *et al.*, 1996).

In order to maintain the productivity of the agricultural and grazing lands and to improve the water quality in dams and dikes, a feasible solution to this problem is to use best management practices in agricultural systems where fertilizer and manure were applied; however, before this happens, the transport process of nutrients and coliforms along with other organisms in water must be identified (Mishra *et al.*, 2008; Pachepsky *et al.*, 2006).

2.2. Surface water quality

Rainfall, surface runoff and erosion by water have been identified as some of the means by which agricultural lands, nutrients and micro-organisms are lost; this in conjunction with

inadequate management of superficial water bodies. (Flores *et al.*, 2012; Flores *et al.*, 2009; Mishra *et al.*, 2008; Soupir *et al.*, 2006; Oliver *et al.*, 2005; Jamieson *et al.*, 2004; Ferguson *et al.*, 2003).

The negative impact caused by the inadequate management of the natural resources is well known. In surface water bodies, specifically, the effects of this improper management may cause water quality degradation through the excessive nutrient input, resulting in eutrophication problems. Furthermore, the pollutants can reach the groundwater and contaminate the principal water source for domestic use. The region that composes the Highlands of Jalisco, Mexico is not exempt from this problem; the agricultural activities that take place in the area contribute to the contamination of surface water through runoff. Due to the semiarid climate, this region is also more dependent on dam water for domestic use. The Jihuite dam which is located at 5 km north of Tepatitlán de Morelos in Jalisco, Mexico, is supplying approximately 30% of water for domestic use for about the 120,000 inhabitants of Tepatitlán de Morelos. For its location, the Jihuite dam is the source of many pollutants such as pesticides and excessive fertilizers, applied during agricultural activities along the watershed. The pollutants are carried by the runoff and reach the dam, causing a negative impact. Some studies evaluated the water quality characteristics of the dam using nutrient concentration by sampling eight different sites of said dam; the parameters were the following; pH, temperature, total hardness, color, electric conductivity (EC), salinity, total dissolved solids (TDS), dissolved oxygen (DO), nitrates, nitrites, and chlorides (De La Mora, 2010). Some parameters evaluated by De La Mora *et al.* (2010) have shown an increase with respect to the results obtained by Ramirez *et al.* (1996) such as nitrates, nitrites and TP. In 1996 the superficial nitrates, nitrites and TP concentrations were about 0.018, <0.02, and <0.05 mg L^{-1}, respectively. In 2010 the nitrates, nitrites and TP concentrations were as follows; 1.3875, 0.00775 and 0.54875 mg L^{-1}, respectively.

De La Mora *et al.* (2011) also evaluated the dissolved oxygen concentration at different water depths in three selected sampling sites along the dam; the results were as follows: the DO at sampling site one was from 5.27 mg L^{-1} in the surface to 1.19 mg L^{-1} at six meters of depth. Sampling site two was from 9.5 mg L^{-1} to 1.5 mg L^{-1} at eight meters of depth and sampling site three 7.47 mg L^{-1} to 1.05 mg L^{-1} at eight meters of depth. Results showed that the oxygen reduction at every meter indicates anoxic conditions.

These results demonstrated a significant increment of nitrites, nitrates and TP concentration, which suggests the deterioration of water quality in el Jihuite dam. Results also suggest that the increment of agricultural industries in the watershed is the principal cause of the water deterioration. Moreover, additional water analyses have to be performed in order to evaluate the toxicological characteristics of the water for concerned citizens and policy makers.

2.3. The rainfall effect on the non-source pollution

The rainfall plays an important role in the NSP process in the agricultural lands, particularly the characteristics related to rainfall distribution and to the intensity and quantity of rain;

the latter is very much associated with the time of the fertilizer and manure application (Oliver *et al.*, 2005; Ferguson *et al.*, 2003; Saini *et al.*, 2003).

The NSP initiates with the impact of raindrops on the soil or on the manure that is left on grazing lands. The process of soil wetness by rainfall provokes saturation of the superficial soil level, removal of soil particles, and the destruction of cow manure. This process becomes even more critical when the soil is continuously wetted and dried when combined with soil tillage. Alcalá (2011) demonstrated that the first storms of the rainy season that produced runoff in corn crops with the application of cattle and chicken manure generated the highest levels of fecal coliforms. But furthermore, Flores *et al.* (2012) showed that storms with a smaller quantity of rain have a larger quantity of coliforms when the manure is applied to corn; when the quantity of rain increases the level of coliforms, the water diminishes, causing dilution of coliforms in rainwater. However, the authors found the opposite effect in grassland where the cattle graze, which requires a larger quantity of rain to increases the amount of fecal coliforms in the water (Figure 1).

On the other hand, the threshold of rain to produce superficial runoff depends on the type of crop and the kind of covering that is present on the topsoil. It can be noticed in Table 1, that the corn and grassland areas showed the lowest rainfall value when compared to bare soil and tequila-making agave. The value of the rain threshold that has been used to define storms with runoff is about 12 mm (Xie *et al.*, 2002) or 12.7 mm (Wischmeier and Smith, 1978).

Soil covering types	Threshold rain (mm)
Bare soil	6.2
Agave tequilero	6.7
Native grass	12.4
Corn	9.5

Table 1. Rain thresholds that produce surface runoff in four different kinds of soil covering (Flores *et al.*, 2009).

2.4. The soil erosion effect on the non-source pollution

The soil erosion is defined as the process of detachment, transport and deposition of particles by erosive agents, like the rainfall, surface runoff or wind (Meyer and Wishmeier, 1969; Hairsine and Rose, 1992). The detachment and transport of particles is related to flow mechanisms in rill and interril erosion. The rill erosion is considered a function of the superficial flow capacity as a means of detaching sediment, the sediment transport capacity, and the present sediment load; the interrill erosion is described as the detachment process of particles caused by the impact of rain drops followed by transportation in the wide and shallow superficial flow transport and their delivery to furrows and channels (Flanagan *et al.*, 1995).

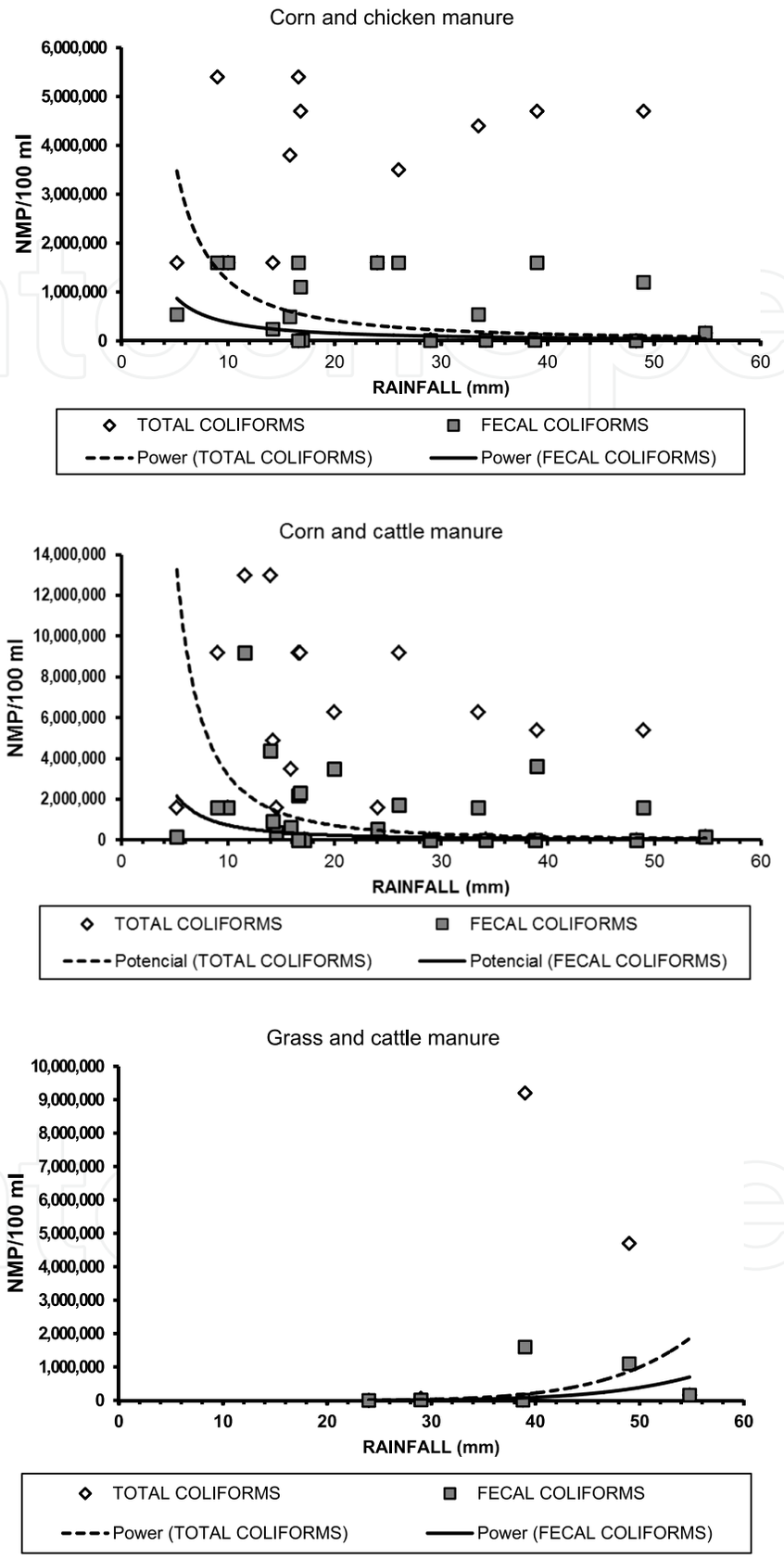


Figure 1. Tendency of fecal and total coliforms correlation with rainfall and corn treated with cattle and chicken manure, and grass treated with cattle manure (Flores *et al.*, 2012).

The soil loss in corn, agave tequilero and grass land with coverage in fields of Highland Jalisco are shown in Table 2 (Flores *et al.*, 2009). It can be observed that the highest soil loss was in the agave with respect to the pasture coverage and intermediate maize coverage. The largest loss of the tequila-agave soil, with respect to soil with respect to soil coverage, was attributed to morphology of the agave leaves; this plant has leaves designed to capture water and lead it to the plant base so that it is absorbed through its root system.

Crop	Soil Loss (t/ha)		Superficial Runoff (mm)	
	2002	2003	2002	2003
Corn	13.35	11.62	159.4	180.2
Grass	0.51	0.38	78.6	68.1
Agave tequilero	27.04	36.59	237.6	278.1
Bare soil	24.93	35.13	222.5	248.6

Table 2. Soil loss and superficial surface runoff in corn and agave crops, grassland bare soil, observed in an Alfisol, of the Highlands of Jalisco, Mexico.

However, the type of flow created plays an important role in the loss of soil generated by the agave tequilero. The transport of particles removed by splashing along the slope rapidly decreases with the depth and velocity of flow, along with other important factors that influence this process such as the raindrop size and the final velocity of rain fall (Kinnell, 1993). The transport capacity inter rills result highly depends highly on the rain intensity and the length and slope of the land, even though momentum of rain *momentum* and the kinetic flows of energy also explain the increment in the transport capacity (Nearing *et al.*, 1991; Guy *et al.*, 1987; Gilley *et al.*, 1987). Also, an increment in the rate of removed particles has been observed under turbulent flow conditions (Nearing and Parker, 1994), such as what is generated after water flows out from agave plant.

Figure 2 shows the accumulation of the loss of soil over time and the kinetic energy of rain for corn, agave tequilero, grass and bare soil. It can be observed that grass has very low soil erosion, indicating the protective effect that it has on soil during the rainy season. Corn has a high response to soil erosion up until the crop has complete coverage over the soil, except when there are storms with a highly intensive erosive level. The agave tequilero has a slightly different behavior in bare soil, an effect caused by the generation of flows concentrated in the base of the agave tequilero.

In the context of soil erosion, the size and the type of particles that are transported also play an important role in the dispersion of contaminants, particularly those of phosphorous and pesticides. The content of lime and silt particles of soil is considered as the medium of transportation of nutrients to the bodies of water. (Sharpley and Menzel, 1987). Gabriels and Moldenhauer (1978) concluded that the distribution of the size of sediment particles (PSD) has an important implication for the carrying capacity and for the chemical deposition mechanism which can result in contaminated materials. Miller y Baharudd (1987) found that in Alfisol and Ultisol soils of Georgia, USA, that when the runoff started the fine layer of sediments was the predominant, but after 15 minutes, the layer from 0.15 to 0.05 mm

became dominant, having lower amounts of sand and. However, Braskerud (2005) mentioned that the fine sediment particles are maintained in suspension for a longer period of time when runoff increases, which allows for its transportation at greater distances.

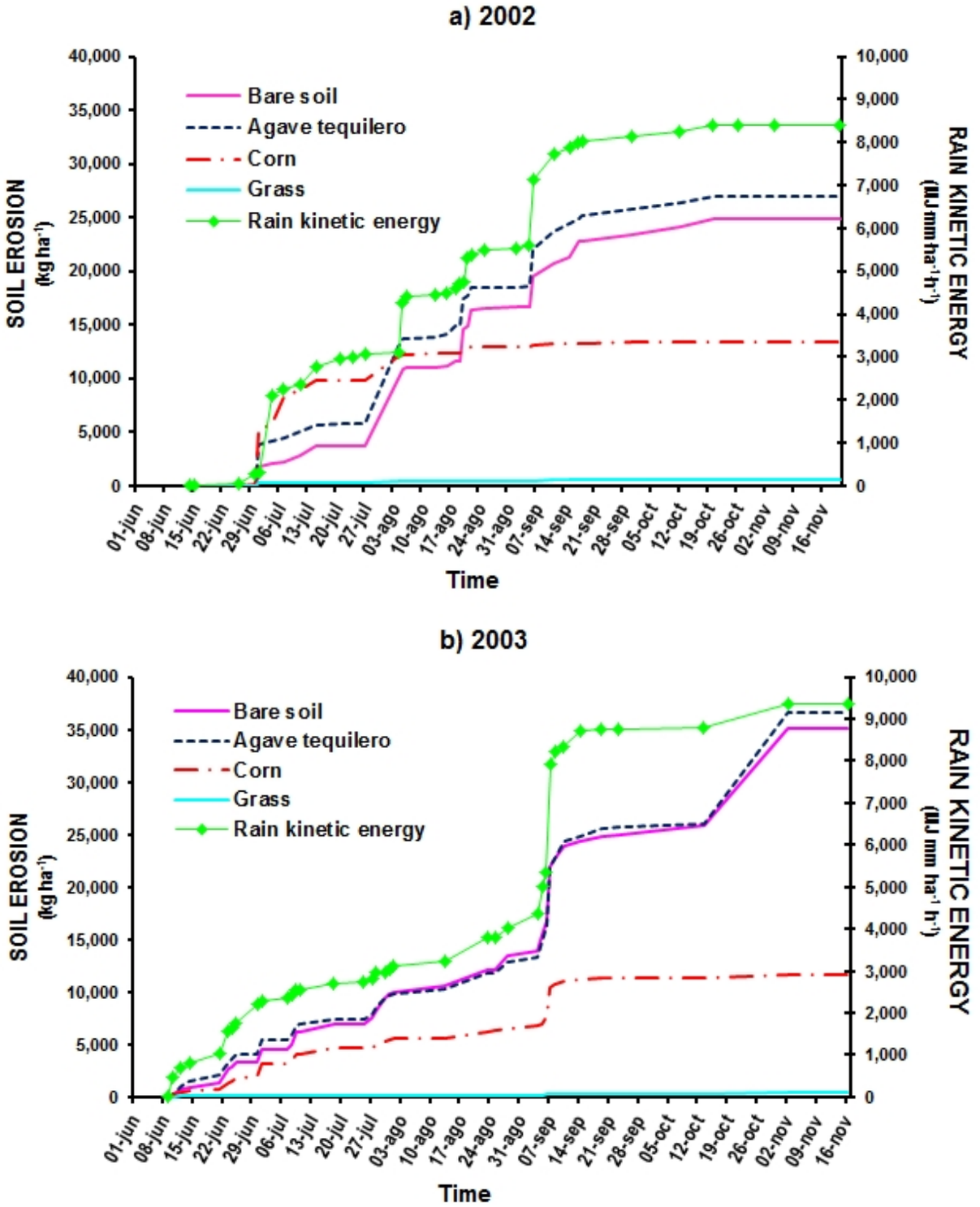


Figure 2. The soil erosion accumulated and the rain erosivity, observed during 2002-2003 cycle, in corn, grass, agave tequilero and bare soil, in the Highlands of Jalisco, Mexico.

Flores *et al.* (2009) carried out the PSD soil analysis for Alfisol in the Highlands of Jalisco. The sediment in suspension and that, which precipitated from the runoffs of fields where corn, agave tequilero and bare soil are present, are showed in Figure 3.

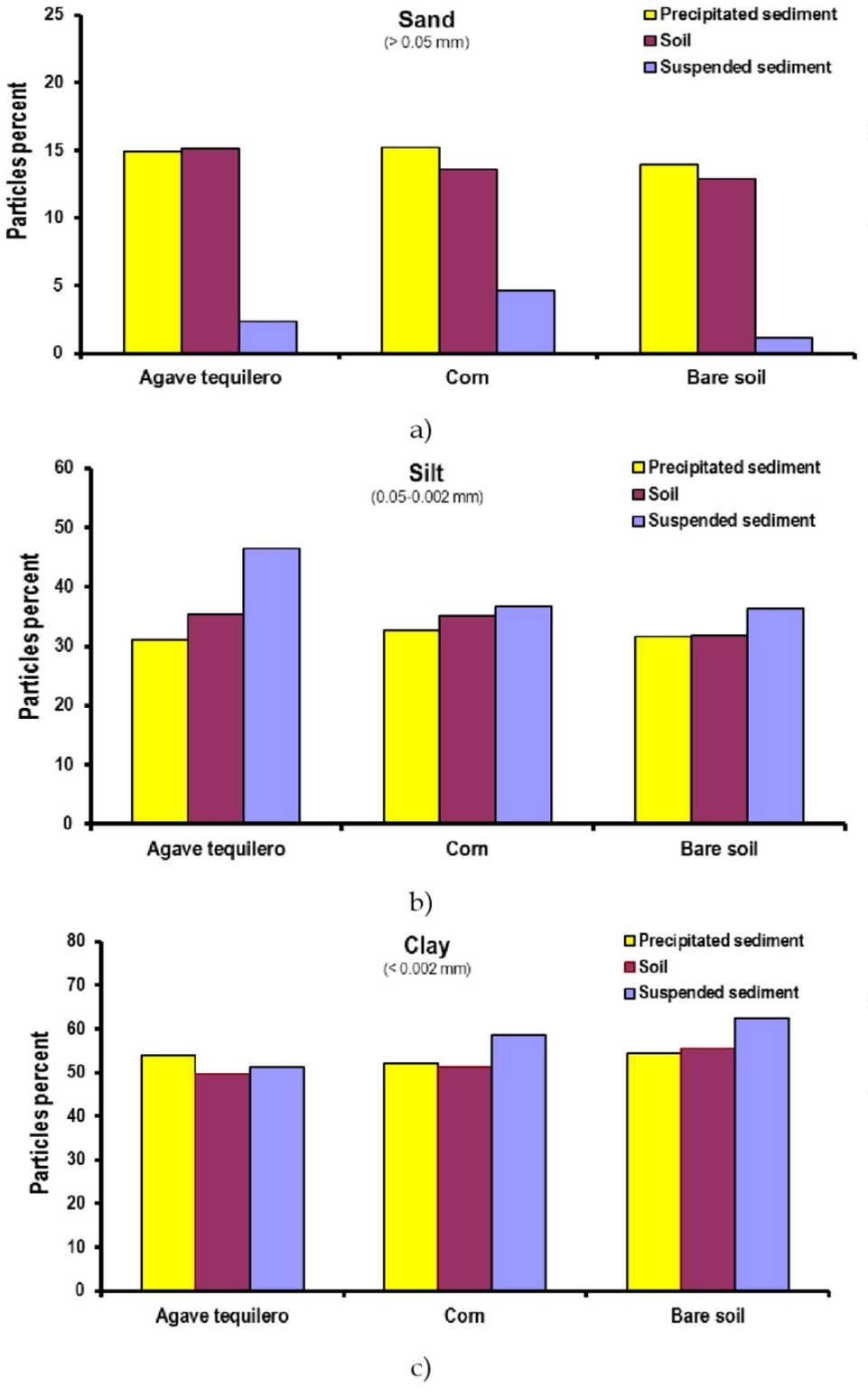


Figure 3. Percent of particles: a) sand, b) silt and c) clay, proceeding from soil and suspended and precipitated sediment, of site runoff of the agave tequilero, corn and bare soil.

The sand content in soil and the precipitated sediment is similar; however the suspended sediment is reduced by important proportions, particularly in bare soil. The silt content in soil and the precipitated and suspended material from the agave tequilero, corn and bare soil are similar, but the suspended material increased for the three crops, although the silt amount was more considerable in agave tequilero; this was probably due to the increase in runoff observed for agave tequilero with respect to bare soil and corn. In general the silt layer of soil is considered more easily transported (Young, 1980) and is also the one maintains its proportion through a storm (Gabriels and Moldenhauer, 1978; Miller and Baharudd (1987). The percentage of clay in soil, precipitated material, and suspended material in the agave tequilero, corn, and bare soil are very similar. However, the clay in suspended sediment of corn and bare soil increases slightly, while the agave tequilero is reduced with respect to the precipitated sediment. It's reported that the particles size depends on the texture of the layer from the origin (Young, 1980), as in the present case where the clay layer in soil predominates; also important, is the duration of the storm (Miller and Baharudd, 1987) and the soil cover (Gilley *et al.*, 1986).

2.5. The surface runoff effect on the non-source pollution

Part of rainfall which is converted into runoff is grouped in three routes: superficial flow, subsurface flow, and subterranean flow (Linsley *et al.*, 1988). The runoff is a hydrologic term that describes the lateral movement of water which flows from the ground in surface and subsurface from causing a short term increase in the outflow of the drainage area, Meanwhile, the surface runoff only considers the movement of water over the soil surface occurring during heavy rain and flowing until it reaches a channel in the direction of the slope (Haygarth and Sharpley, 2000).

The surface runoff occurs in a laminar flow over the soil surfaces without an existing, precise concentration clearly moving towards the draining channel as such, the flow is visualized as one-dimensional process, proportional to the potential of storage per unit area (Mays, 2001; Wanielista *et al.*, 1997). On the other hand, the surface flow is considered as laminar in its initial condition, but when the depth and flow velocity increase to a critical value, it is converted into a turbulent flow, defined by the Reynolds Number (adimensionless index that express the product of medium-flow velocity in a channel and its effective hydraulic radius divided by the cinematic viscosity) higher than 500. The turbulence created by this surface flow delays the particles' sedimentation and maintains them in suspension, apart from increasing the flow capacity to separate new soil particles (Hillel, 1998).

Table 2 shows the surface runoff of corn, agave tequilero, grass and bare soil. The highest runoff was observed in agave tequilero, and the lowest in grass, corn and bare soil, had intermediate rate. The runoff observed in agave tequilero is attributable to the foliar plant structure; leaves reduce direct impact capture the water which falls over its leaves and is transported to the plant base, creating a concentrated flow in the soil. Table 2 shows the highest amount of runoff occurs in the agave tequilero, followed by the bare soil and corn, with grass being the least amount.

The surface runoff also plays an important role in corn and pasture when it interacts with the application of manure particularly from a point of view of water quality with fecal matter and total coliforms. Figure 4 shows the surface runoff with the content of fecal and total coliforms which increases with overland flow; however dilution of coliforms in water also occurs (Flores *et al.*, 2012).

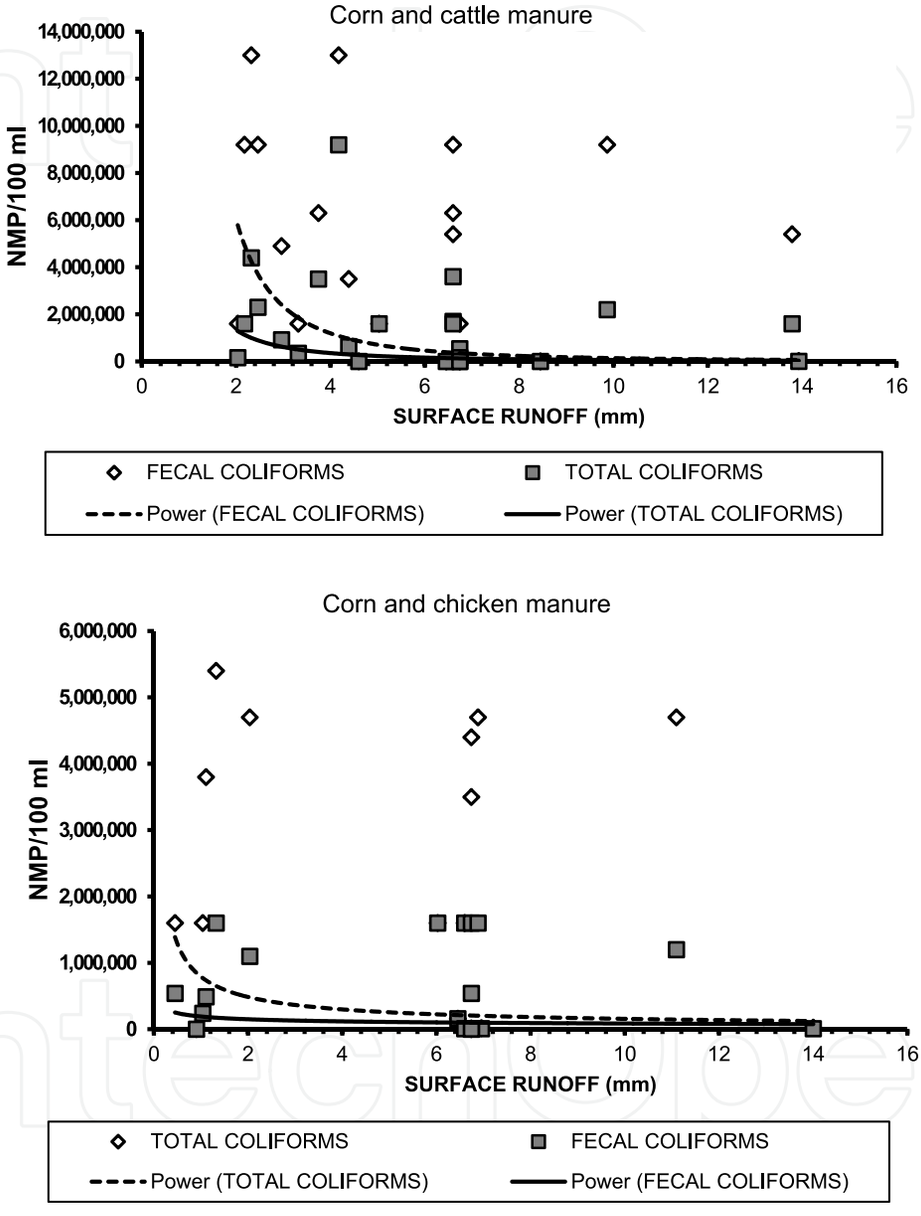


Figure 4. Relation of surface runoff with the total and fecal coliforms content in corn where treated with cattle and chicken manure.

2.6. Nitrogen losses from agricultural system

Water and nutrient deficiencies (nitrogen, phosphorous, calcium, etc.) are the most important factors that limit the productivity in any crop. One ton of agricultural soil in the first centimeters of the superficial layer can contain 4 kg of nitrogen, 1 kg of phosphorous, 20

kg of potassium and 10 kg of calcium. The soil erosion with a soil loss of about 18 $tha^{-1}year^{-1}$, would represent a total of 72 kg ha^{-1} of nitrogen, which is almost half of the average of nitrogen fertilizer (152 kg $ha^{-1}year^{-1}$) applied to corn crops in the United States (Pimentel *et al*., 1989).

Haygarth and Jarvis (1999) make reference that the practice of tilling on agriculture lands may have direct effects on the loss of phosphorous , also favoring vulnerability of the soil to erosion as a result of the removal of the vegetation cover . It was also indicated that the comparison between conventional tillage against conservation tillage resulted in 67% more runoff a, 90% loss of sediment, and a 90% increase in the loss of phosphorous.

From the combination of nutrient management practices in crops and soil, and rain characteristics, processes of such complexity arise, that when visualizing them as system, with different scales and occurrence times, understanding becomes difficult. This situation makes it difficult to define the preventive or corrective actions that should be taken to limit the transportations of nutrients from agricultural and pastoral lands to the bodies of water. One option is to consider the transportation of nutrients from land to surface water bodies as a system that requires knowledge of the components and an understanding of the interactions that exist between them.

The surface runoff is the means of nitrogen transportation, while the mechanisms that regulate it are the characteristics of storms, soil and the very own crop (Follett and Delgado, 2002; Haygarth and Jarvis, 1999). In Mexico, several studies demonstrate that organic and inorganic nitrogen, applied to the soil, is directly related to the amount of nitrates and ammonium in surface and groundwater during the NSP processes.

Estrada-Botello *et al.* (2002), in a study about the balance of inorganic nitrogen in the humid tropics of Mexico, found that the ammonium nitrogen loss was about 6.8 mg $N\text{-}NH_4$ L^{-1} in the surface runoff, while the underground drainage was about 2.7 mg $N\text{-}NO_3$ L^{-1}; however, when some type of drainage is introduced in farming lands, the values of nitrogen leaching can be about 16.53 kg ha^{-1} $año^{-1}$ without applying surface drainage and with maximum nitrate and ammonium concentrations at about 26.4 mg L^{-1} and 22.0 mg L^{-1}, respectively. (Estrada-Botello *et al*., 2007). In the region of Tuxtla in Veracruz, Mexico, Uribe-Gómez *et al.* (2002) found that the average loss of nitrogen in living wall terraces was around 23 kg ha^{-1}, probably due to the high levels of nitrogen from the decomposition pruning refuse that was placed on the surface soil.

In the Highlands of Jalisco, Mexico, the loss of nitrogen is mainly associated with hydrologic and edaphic factors along with the management of the production systems for agave tequilero, corn and pasture. As a result, the nitrates may be leached and contaminate the groundwater or transport the runoff toward the surface water together with the ammonic nitrogen and nitrate nitrogen (Goulding, 2004). However, it very difficult that they adsorb to iron oxides, like the goethite or hematite which are presented in the Luvisol soils in the Highlands of Jalisco (INEGI, 1994), due to the fact that the electrostatic attraction forces acting in this kind of mineral are weak (Parfitt, 1989).

In agreement with nitrogen measurements in runoff from field plots with agave tequilero runoff, pasture and corn, Flores *et al.* (2009), found tendencies of the related nitrogen loss with surface runoff, shown in Figure 5. The highest rate of nitrogen loss due to surface runoff was found in native pasture due to the contributions of refuse. Meanwhile the agave tequilero and corn had a medium rate, while the lowest rate of nitrogen loss was found in bare soil.

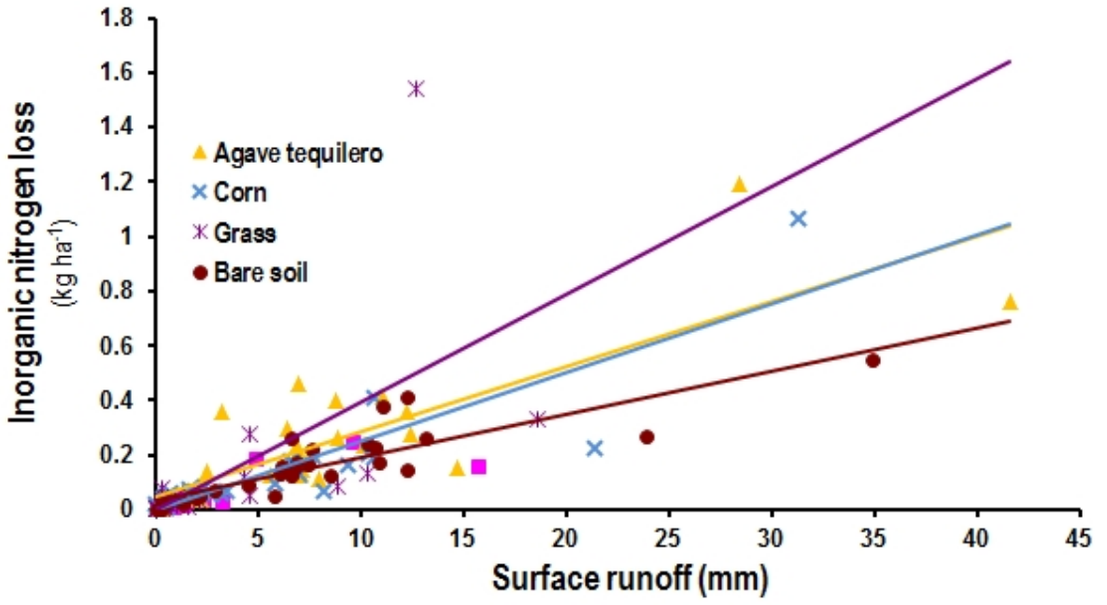


Figure 5. Relation between the loss of inorganic nitrogen and the surface runoff, in runoff plots that have bare soil, agave tequilero, corn and native grass.

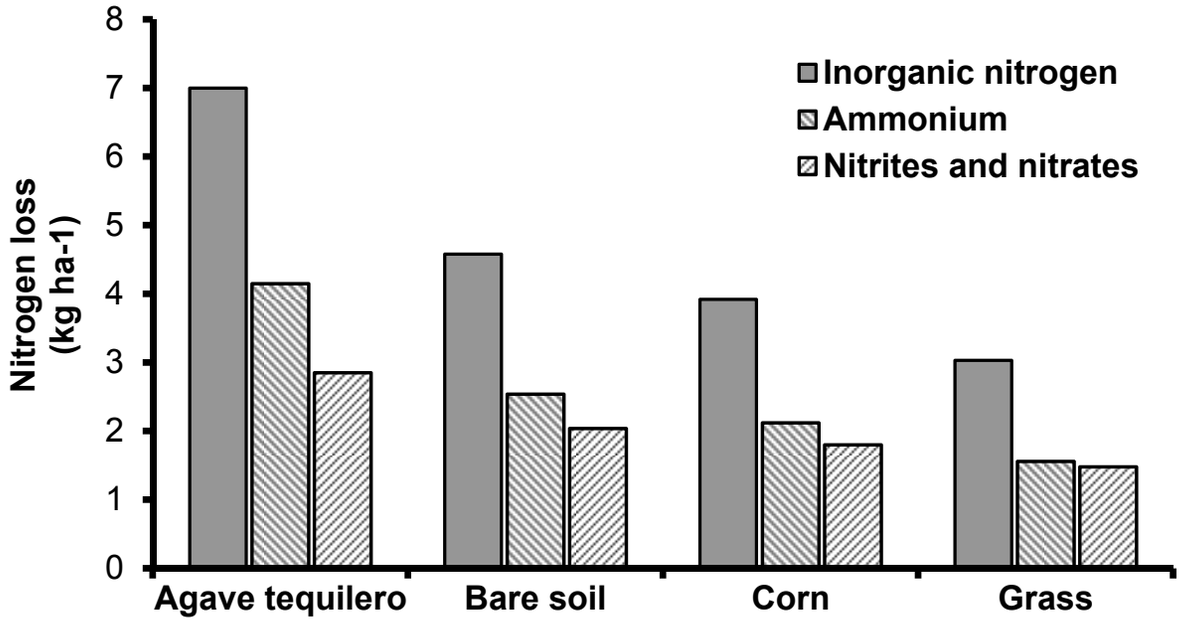


Figure 6. The loss of inorganic nitrogen in the form of ammonium, nitrites and nitrates s in four runoff plots the Highland of Jalisco, Mexico.

Figure 6 shows that the highest loss of inorganic nitrogen occurs in the agave tequilero with 7 kg ha^{-1} and 4.15 kg ha^{-1} of ammonic nitrogen at 2.85 kg ha^{-1}, of nitrate, and lower values for native grass lands at about 3.03 kg ha^{-1}, with nitrates at 1.56 kg ha^{-1}, and about 1.48 kg ha^{-1} of ammonia nitrogen.

2.7. The loss of phosphorous in agricultural and livestock systems

In the south of the Jalisco Highlands soils are rich in iron oxides (INEGI, 1994), a characteristic that makes the loss of phosphorous utilized as the principal means of transporting mainly sediments to finer layers (Flores, 2004; Sharpley *et al.*, 2003; Sei *et al.*, 2002).

Figure 7, shows the content of total phosphorous (TP), organic phosphorous (OT) and inorganic phosphorous (IP), in the exported, precipitated and suspended sediments, which was measured in the runoff fields with agave tequilero, pasture, bare soil and corn. The concentration of IP loss was higher in the suspended sediment with respect to the precipitated sediment, due to the fact that the size of sediments is finer in the agave tequilero, bare soil and corn. For pasture, the IP in precipitated sediments was higher when compared with the others crops, but due to the fact that suspended sediment was not present in adequate amounts for the analysis, the IP was considered inestimable. This response is associated with a high clay content in suspended sediment, as can be observed in the distribution of sediment particle sizes for corn, agave tequilero and bare soil, results are shown in Figure 7.

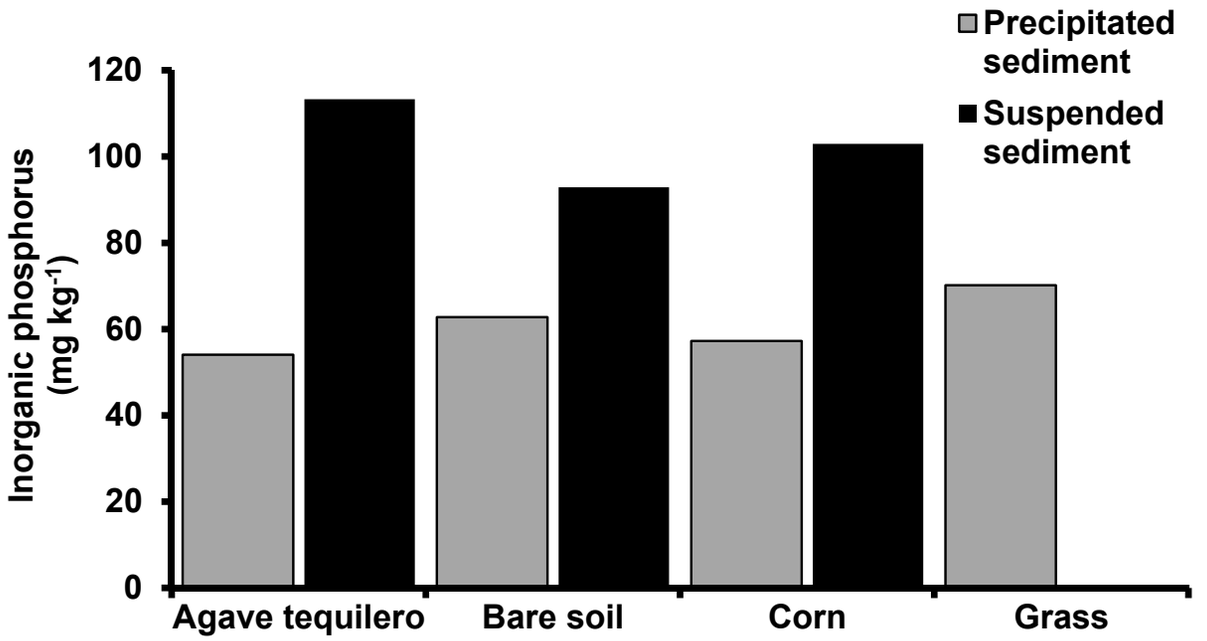


Figure 7. Content of inorganic phosphorous, in the exported, precipitated and suspended sediment, which was measured in the field plots of agave tequilero, grass, bare soil and corn.

Figure 7 shows the loss of TP, OP and IP, measured in fields for the agave tequilero, corn, grass and bare soil. In all of the cases, the loss of OP was about 71 to 80% of TP. Due to the fact that phosphorous particles are dependent on the exported material size, the agave tequilero showed the highest hydric erosion and consequently the highest TP loss. In contrast, grassland had the lowest soil erosion resulting in a minimum loss of TP.

Even though, the P loss is mainly associated with the finest layer of sediment (suspended sediment), high amounts of precipitated sediment have a similar granulometric composition to the original soil (Table 3). For that reason, this nutrient that is removed from soil and deposited along the land surface and in the drainage network can in the future, be considered as phosphorous source when it once again enters into the surface runoff. (Haygarth *et al.*, 2000; Haygarth and Jarvis, 1999). Table 3 shows the soil and precipitated sediment amount; clay layers (< 2 μm), silt layers (2 – 50 μm) and sand layers (> 50 μm), with the P retention percent in the precipitated sediment. The precipitated sediment and the soil presented a similar granulometric composition; clay is around 55%, silt is about 32% and sand is approximately 13%. Table 3 also shows that the clay layer has a higher P retention (about 57.5%), and the sand has the lowest P retention (20%). Significant differences were found between layers.

Name	***Layer**	**Precipitated sediment (%)**	**Soil (%)**	****P** $_{retained}$ **(%)**
Clay	< 2 μm	54.40	55.40	57.52 *a*
Silt	2 - 50 μm	31.65	31.71	39.59 *b*
Sand	> 50 μm	13.95	12.89	20.07 *c*

* From pipette method.
** Includes around 50% of layer< 2 μm.

Table 3. Percentage of Granulometric layers in the suspended and precipitated exported material of the soil and the $P_{retained}$ in the precipitated sediment layers.

On the other hand, the suspended sediment principally constitutes for silt and clay (Table 3). This condition allows the particles be transported for greater distances to reach the superficial water bodies and transport with them, an important quantity of P (Figure 8). Much of the P contained in the exported material is of organic origin, but from the point of view of eutrophication, the inorganic P is more important; furthermore, a large amount is presented in suspended sediment. Pimentel *et al.* (1989) suggested that the soil erosion does not remove all the soil components in the same way; in fact, many studies indicate that the exported material is generally 1.3 to 5 times richer in organic material than the soil that remains. Organic matter is important to soil quality because of it's the positive effects on the water retention, the soil structure and the cationic exchange; furthermore, it is the highest nutrient source for plants. For this reason, 95% of nitrogen and the 15% to 80% of phosphorous is located in the organic matter.

From the results shown here, the transportation of P in the agricultural and pasture lands to the aquatic environments occurs by water erosion through surface runoff, in such a way that P is absorbed by soil particles and organic matter that is transported during runoff.

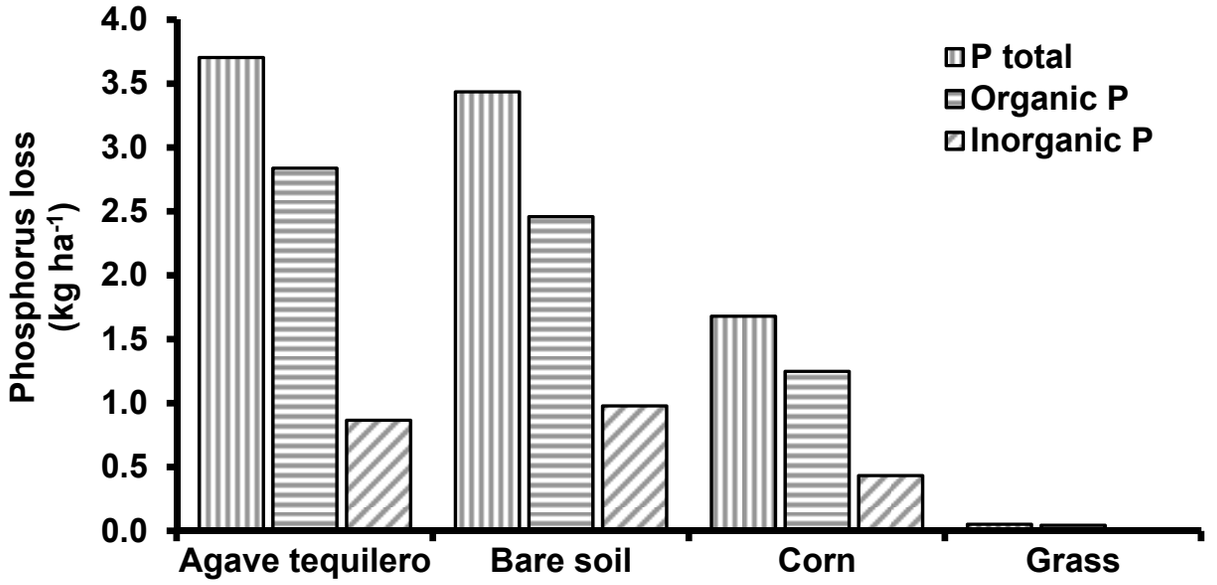


Figure 8. Loss of total phosphorous, organic and inorganic agave tequilero, corn, pasture lands and bare soil measured in field plots.

Golterman and Oude (1991) indicated that the surface freshwater reservoirs (lakes, dams, or dikes), requires a reduction of P and N before entering to the system, even though this task requires a large amount of money to improve reduction from 40% to 70% of the nutrients that cause the eutrophication. Loehr (1984) mentioned that using the Best Management Practices is a cost effective method to prevent or control the NSP from the agricultural and livestock industries.

2.8. Effects of Management Practices on pollution diffusion

The Best Management Practices (BMP) is conceptualized as the combination of cultural recommendations of management, structure and norms that in an effective and economic manner avoids, minimizes or mitigates the environmental impact on the productive processes of the agricultural and livestock systems (Minnesota Pollution Control Agency, 2000). However, giving sustainable solutions to NSP problems through the BMP's should stem from the farmers' decision making, identifying the causes and quantifying the effect. The simulation model is a tool that can be used for such purposes. Furthermore, this tool considers the farmers' decisions related to the agricultural management practices, that are based on processes associated with crop growth and its productivity, the soil erosion, and surface runoff from agricultural lands. Such is the case of the EPIC model (Erosion-Productivity Impact Calculator) which has been utilized to carry out the task at the field scale (Flores *et al.*, 2011; Flores *et al.*, 2009; Semaan *et al.*, 2007; 2006; Wang *et al.*, 2006; Guerra *et al.*, 2005; Villar-Sánchez *et al.*, 2003; Lacewell *et al.*, 1993), However, in combination with geographic information systems (GIS), it is possible to evaluate the impact of the agricultural systems at the watershed scale (Liu *et al.*, 2007).

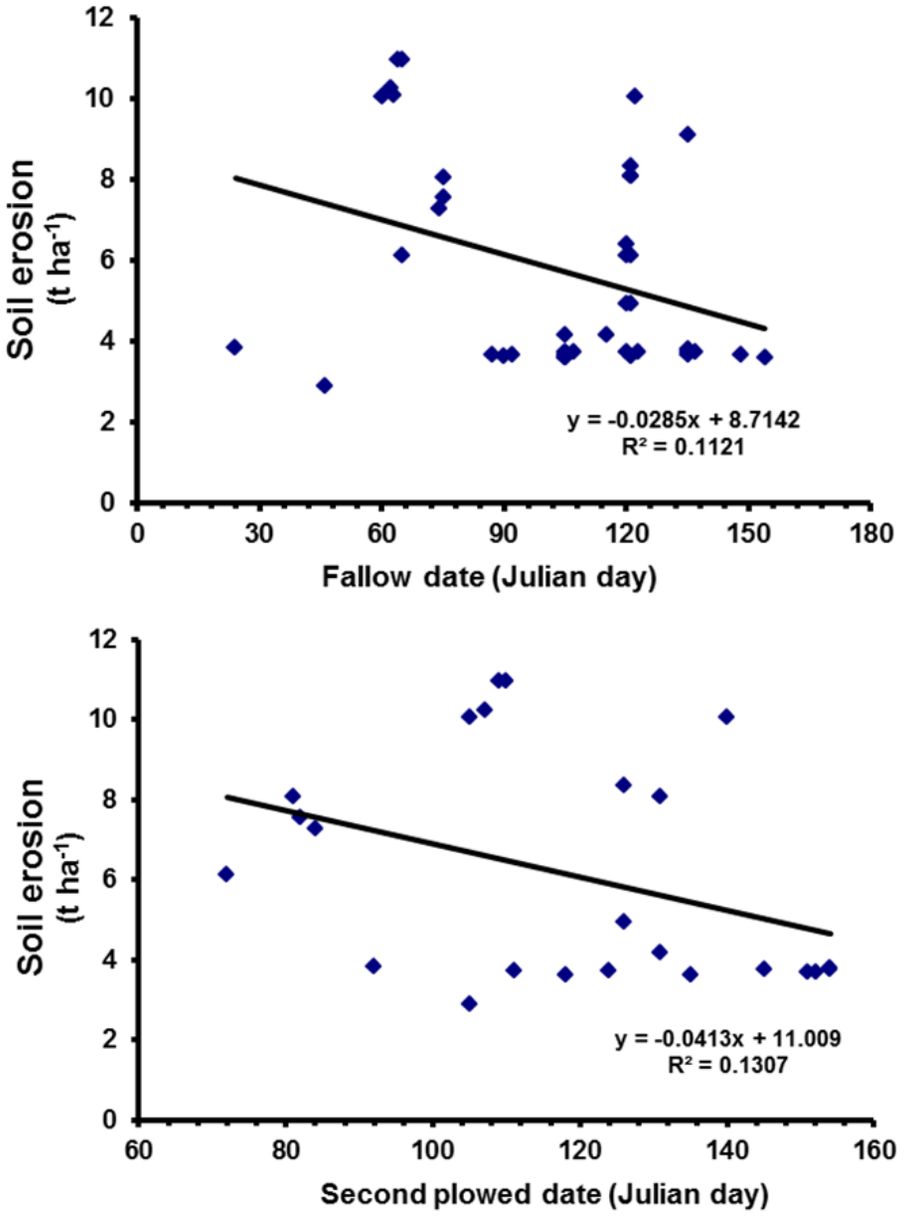


Figure 9. Relation between soil erosion in the corn field with the dates of fallowing and tilling during soil preparation.

Flores *et al.* (2009) used EPIC to estimate soil erosion to corn crops in the Highlands of Jalisco. The authors identified that the corn management practices correlated to soil loss at probability level ≤10 % significance, as follows: the fallow date (-0.335), the second plow date (-0.362), the sowing date(0.896), the amount of seed utilized (-0.250), the organic fertilization date (-0.418), the date of the first chemical fertilization (0.851), the date of the first weed control (0.390), the emergence date of corn plants (0.933), the second weed control date (0.939),the date of pest control for soil (0.835), the amount of products utilized in the soil to control pests (0.399), the silage date (-0.405), the corn harvest date (0.546). In the soil preparation, two practices are associated with soil erosion: fallowing and tilling of the ground as Figures 9a and b show. From these figures it can be seen that when these practices

are carried out near to the sowing date, the tendency is to reduce the loss of soil, an effect associated with soil rugosity, which, when there is high soil erosion, reduces to produces a decrease in the runoff velocity, favoring the water infiltration (Kirkby, 1988; Podmore and Hugins, 1980).

Other management practices that resulted in important effects for soil loss were the sowing date (SD) at a rate of 429.5 kg for day with a delay in planting as shown in Figure 10. However, when the corn SD was separated from the corn systems at the date before start of growing season (GS),a loss of soil at a rate of about 30.4 kg per day was observed, while the later SD at the beginning of GS, had soil erosion increases at rate of 362.9 kg per day that was delayed by the SD.

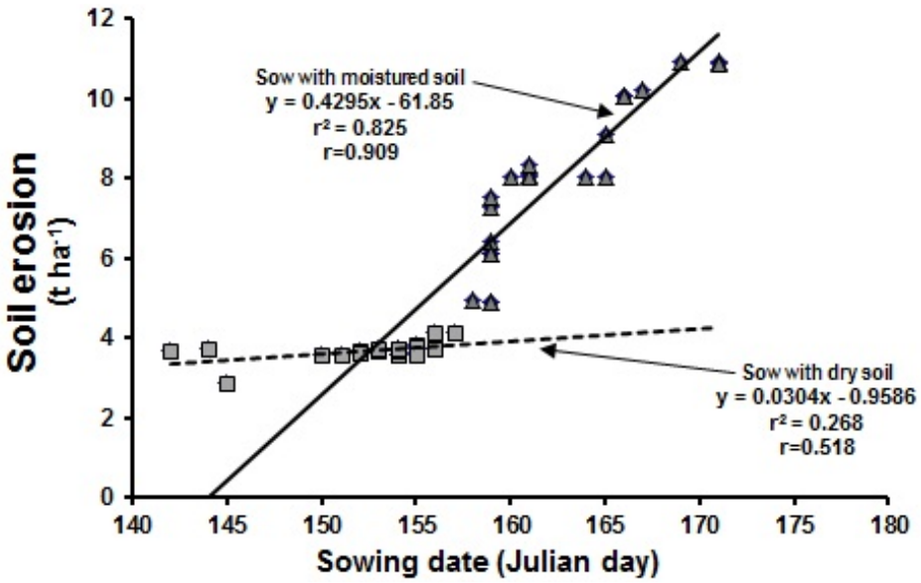


Figure 10. Relation between the losses of soil by erosion with the planting date of seasonal corn in the Highlands of Jalisco, Mexico.

On the other hand, the average accumulation of soil loss (SL) at field scale, cultivating corn was about 6.12 t ha^{-1}. But at the time when the accumulation of soil losses was separated from the SL in the crops with ST before the beginning of the GS, and the sowing was started after the GS, the average soil erosion was about 3.67 kg ha^{-1} y 7.89 kg ha^{-1}, respectively (Figure 11). Figure 11, shows that the protective effect of foliage against soil erosion; the highest loss of soil occurs before the corn foliage covers the soil, which occurs around 40 days after the emergence of the crop. Afterwards, only storms with high erosive qualities can generate SL in the corn.

2.9. Scaling effects on the soil erosion, surface runoff and nutrient loss

Sims and Wolf (1994) mentioned that the processes of soil erosion, surface runoff, and nutrients loss, can be visualized through their management at three scales; 1) field scale, 2) farm scale, and 3) watershed scale, region and/or State level. At the field scale, the management practices are developed efficiently, favoring or limiting the impact of practices

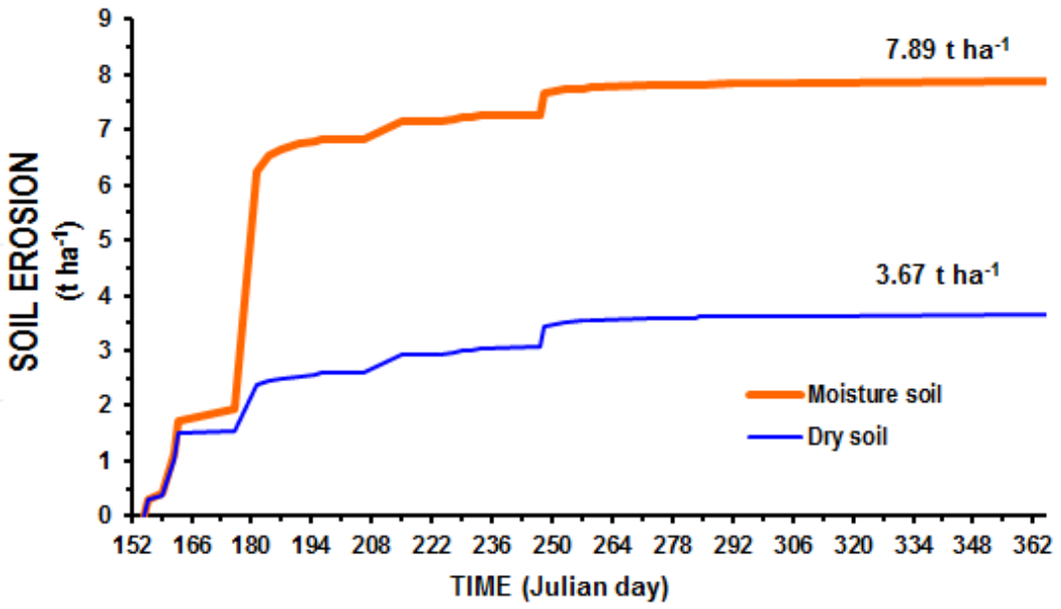


Figure 11. The effect of humid conditions on planting over the soil loss in farmlands of the watershed El Jihuite.

on soil erosion, surface runoff, nutrient loss and crop productivity, as an effect of physical processes such as volatilization, leaching, erosion, runoff and etc. At the farming scale, the farmer's decision is considered over many farms where practices are applied and the effect can be reduced or amplified depending of the environmental characteristics. At the watershed scale, regionally or stately, it is a similar scenario to the farm scale;, however at this level, the effects occur at different time and spaces of origin, with a high magnitude and an elevated cost to remediate the impact.

Flores (2004) showed the scale effect on soil erosion, surface runoff and the loss of inorganic P and N which have a non-lineal relationship with an area increase (Figure 12). Canto *et al.* (2011) also showed a non-lineal effect similar to that of Flores *et al.* (2004) between a runoff area with the production of sediments, even though this non lineal effect could be modified by soil coverage and other soil and drainage area characteristics (Liu *et al.*, 2012; Delmas *et al.*, 2012; Descroix *et al.*, 2008). With a precipitation of about 1019.3 mm, a substantial reduction was observed in the amount of runoff in accordance with the measurement scale, such as show in Figure 12.

At a small scale of field plots (about 50 m^2 in area), a higher surface flow was generated, however, at drainage scale (about 22 hectares), the runoff was significantly lower. The runoff is generated during the period of flooding and excessive rain (Stomph *et al.*, 2002); the influence of these mechanisms may reduce when the contributing area increases (Critchley and Siegert, 1991).

The soil erosion the same scale effect can also be observed where the great part of soil loss occurs during runoff in corn field, less in farm scale and even less in the drainage scale: furthermore, this exhibits a non-lineal correlation (Figure 12). At the watershed scales, Martínez *et al.* (2001) a non lineal response was found with the production of sediments in function to contributing area.

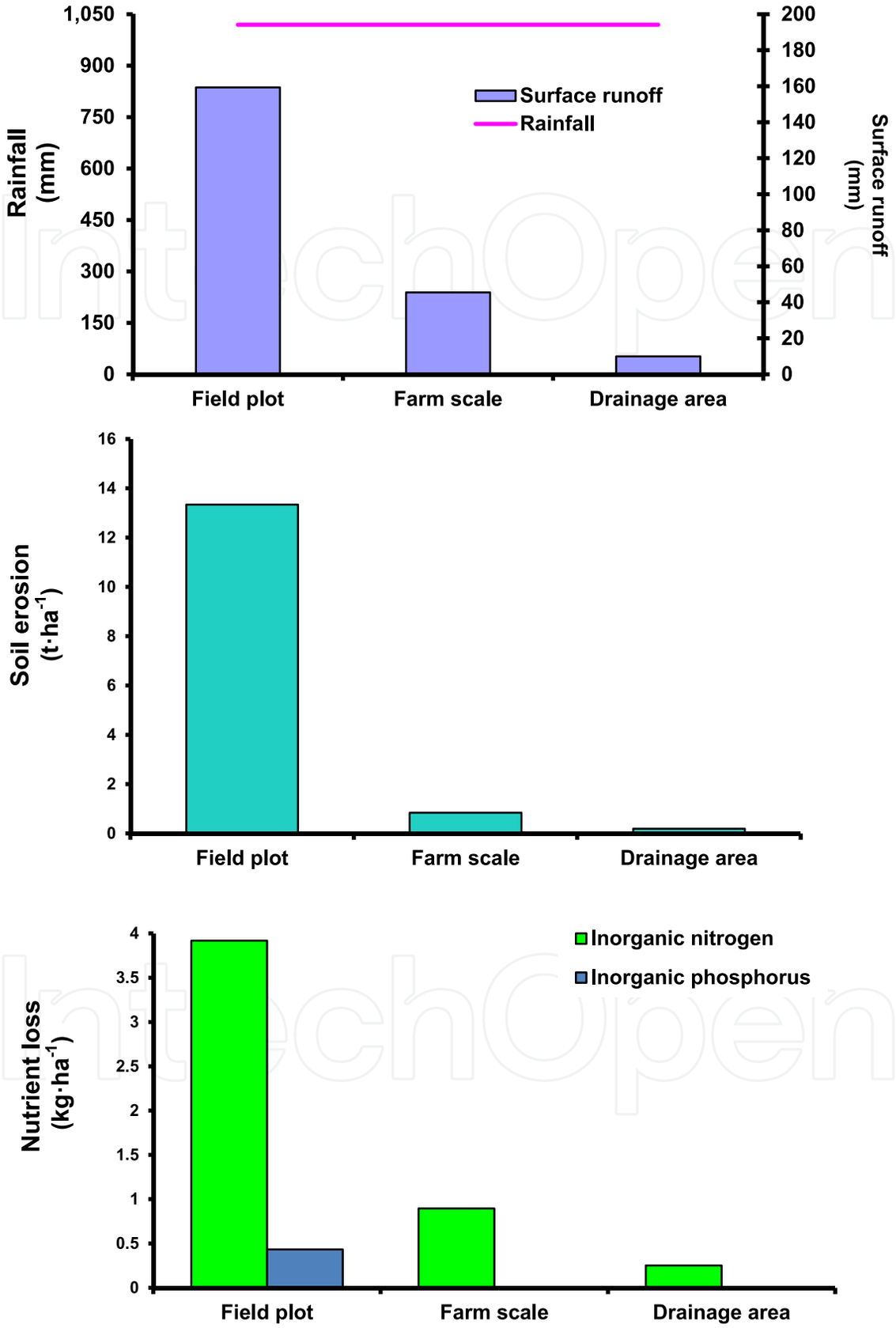


Figure 12. The surface runoff, soil erosion and loss of nutrients losses in measurement scales of corn field plots (50 m²), farm scale denominated watershed (5000 m²) and drainage area (22 ha).

The loss of nitrogen and phosphorous showed a non lineal response similar to that of the runoff and soil loss greater in the corn field plot and the lower in the drainage area, even though, the results were more contrasting with the nitrogen. The nutrient input depends on the characteristics of the drainage area the nutrient concentration, in a way so that the organic nitrogen has been correlated with arable land and the stream density, while the phosphorous with the soil texture (Arheimer and Lidén, 2000).

3. Conclusion

The agriculture and livestock industry in the Highlands of Jalisco, Mexico, has been an important source of economic growth. However, the use of technologies involving the application of large amounts of fertilizers and pesticides for prolonged periods of time, and often applied incorrectly, increases inefficiency and results in high environmental impact on the soil and water of the lower watershed area. This is known as non-point source pollution, which is considered to be the principal cause of the water deterioration in this region of México.

The first storms that had a smaller quantity of rain during the growing season and produced runoffs in the corn crops where cattle and chicken manure had been applied generated the highest levels of fecal coliforms. But the opposite effect was noticed in grassland where cattle graze, which requires a larger quantity of rain to increases the amount of fecal coliforms in the water.

The surface runoff for corn, agave tequilero, grass and bare soil exhibited different behavior. The highest runoff was observed in agave tequilero, and the lowest in grass, corn and bare soil, had intermediate rate. The runoff observed in agave tequilero is attributable to a concentrated flow created in the soil. The surface runoff plays an important role in corn and grass when it interacts with the application of manure, thereby reducing water quality with fecal matter and total coliforms, and adding nutrients.

With respect to the loss of soil, it was observed that the grassland has very low soil erosion, which indicates the protective effect that it has on soil during the rainy season; corn, however, has a high propensity to soil erosion up until it has complete soil coverage; the exception is when there are storms with a highly intensive erosive level. The agave tequilero has the highest soil erosion rate, and finally, the soil bare exhibited the slightly different behavior, an effect caused by the generation of flows concentrated in the base of the agave tequilero.

Nutrient loss in the aforementioned crops is mainly associated with hydrologic and edaphic factors. The highest rate of nitrogen loss due to surface runoff was found in native grass due to the introduction of refuse; meanwhile the agave tequilero and corn had a moderate rate of nutrient loss, while the lowest rate of nitrogen loss was found in bare soil.

The amount of exported phosphorus is dependent on the exported material size. The agave tequilero showed the highest level of soil erosion by water and consequently the highest

total phosphorus loss. In contrast, grassland had the lowest soil erosion resulting in a minimum loss of total phosphorus. The loss of organic phosphorous was about 71% to 80% of total phosphorous. The inorganic phosphorous loss was higher in the suspended sediment than in the precipitated sediment, due to the fact that the agave tequilero and bare soil had high phosphorus loss, while corn and grass had less.

The management practices had an important impact on the process of soil erosion, runoff and nutrient loss. The most important effect that the sowing date had on the soil erosion rate may reduce when the planting date is delay. However, when corn was sowing before the growing season, the soil erosion had a rate of 30.4 kg per day. Nevertheless, sowing later of the growing season, the soil erosion increases at 362.9 kg per day.

The scale effect was observed in soil erosion, runoff, and nutrient loss. The loss of all of these showed a non-lineal response with the runoff and soil loss greater in the corn field plot and lower in the drainage area; this occurred even though the results were more contrasting with the nitrogen.

Due to, the highest surface runoff, nutrient loss and soil erosion effect occurs in the agricultural field scale (depending on the type of crops), the modification of current agricultural management practices toward sustainable practices is necessary. To achieve this goal, it is necessary to encourage farmers to use sustainable management practices, to reduce the rate of soil loss and runoff, and to improve efficiency in the use of nutrients in farmland and grazing. The results of these actions would be observed with sustained soil productivity and an improvement in the quality of water in dams, dikes or rivers of the region. At the watershed scale, legislative and socio-economic aspects that favor the improvement of agricultural systems, contributing not only to its development but also to the quality of life of the region's inhabitants, needs to be taken into consideration.

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