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Impact of conservation tillage on nitrogen and phosphorus runoff losses in a potato crop system in Fuquene watershed, Colombia

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ABSTRACT

Intensive tillage (IT) in potato crops is considered as one of the main non-point sources (NPS) of local water eutrophication in the Fuquene Lake of Colombia. Therefore, the local government has invested in several programs aiming at the adoption of principles of conservation tillage (CT) which would allow for developing and applying the agricultural best management practices (BMPs). The complexity of hydrological and geological heterogeneity makes the degree of benefit that CT has in different locations uncertain. In this study, the Soil and Water Assessment Tool (SWAT) was used to assess the impacts of changing IT for CT on nitrogen (N*)* and phosphorus (*P*) losses in surface water runoff from the potato crop in the Fuquene watershed. This is done at field and watershed levels. A two-year study quantified the changes in surface water runoff pollutants for three potato crop cycles under the traditional IT practice and CT practice - which included reducing tillage, green manure, and permanent soil cover - at twelve runoff plots installed in the Fuquene watershed (Quintero and Comerford, 2013). This information was used to build, calibrate and validate the SWAT model. The results suggest that CT for the Fuquene watershed can be reduced up to 26% of the sediment yield and 11% of the surface runoff compared with IT, which means an overall reduction of load. The main CT effect on nutrient losses in runoff is an increase in the total N and P (2% to 18% respectively) compared to IT. However, the results at watershed level showed different patterns from those obtained at field level. Despite the model uncertainties, the results show a possibility of using hydrological models to assess the effectiveness of various field management practices in agriculture.

1. Introduction

The decline in the water quality in the Fuquene watershed (Colombia) is a serious environmental problem, especially in Lake Fuquene, where an accelerated eutrophication process has been observed (Japanese International Cooperation Agency—JICA, 2000). Nitrogen and phosphorus runoffs from potato crop fertilizer operations are estimated to be causing the increase of nutrients in the lake, which has in turn has increased the presence of algae bloom (Rubiano et al., 2006b). As a result, the biodiversity in the lake is threatened, as well that the drinking water for the local communities due to the leakage of toxic chemical in the treating process (Hanifzadeh et al., 2017), and also water for agriculture, fisheries and, particularly, for livestock (Quintero and Otero, 2006; Rubiano et al., 2006b). Therefore, the environmental authorities are aiming to address this problem due to the importance of this water source for the communities, agriculture and livestock (Rubiano et al., 2006a).

Intensive tillage (IT) is the conventional management practice used by potato farmers in the Fuquene watershed. This practice is characterized by a lack of plant coverage and low levels of crop residue in the potato cycle. Because of this, the soil is vulnerable to erosion processes and nutrient losses in the runoff (Zhang et al., 2014; Carter et al., 2009). Therefore, research nowadays focuses on agricultural BMPs which endeavor to use nutrients efficiently, conserve the soil structure and reduce runoff (Quintero and Comerford, 2013; Logan, 1993). In this context, agricultural BMPs that focus on non-tillage and reduced tillage are increasingly being adopted by farmers because they have the potential to reduce water pollution and to develop environmentally friendly agricultural systems, which at the same time will offer better income to local farmers (Liu et al., 2013; Sedano et al., 2013;

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Panagopoulos et al., 2011; Soane, 1990). Studies indicated that the BMPs in growing potato crops could reduce the loss of nutrients in surface without any negative effect on the potato yield and quality, although there may be some influence on the potato maturation and harvest date (Carter and Sanderson, 2001). A study done in 14 potato field trials at various locations across Idaho, Oregon over a time period of four years, demonstrated that potato farmers following BMPs received a similar yield with less financial investment than when following a maximum yield approach (Hopkins et al., 2007). Also, Zebarth and Rosen (2007) clarified that even when BMPs are developed to optimize tuber yield and reduce losses of nutrients, it is necessary to select the appropriate rate and timing for applying nitrogen-based fertilizers. In this way, it is possible to control potato growth according to the soil properties, water management, climatic conditions and terrain slope.

In Colombia, the regional environmental authority (Corporacion Autonoma Regional – CAR) in the Fuquene watershed has been investing in adopting conservation tillage (CT) since 1999 for the potato crop system. In this paper, CT is defined as any practice of soil cultivation that reduces runoff and increases infiltration by leaving the previous crop residues on the field (Derpsch, 2003). This also, increases the soil organic matter near the soil surface, improving the soil structure and biological properties in the potato crop (Carter et al., 2009). Experience has shown that CT provides potential benefits for organic matter increase, soil hydraulic properties, and that soil protection may be increased by the impact of rainfall (Carter and Sanderson, 2001). Nevertheless, the management effects of some biological properties are not measurable in the short term (i.e., less than 5 years) (Carter, 1992).

The International Center for Tropical Agriculture (CIAT) has been researching the impact on nutrient and soil losses in this crop since 2010 due to the implementation of CT practices in Fuquene watershed. Experimental runoff plots were installed, and the IT and CT practices applied. The specific CT practices adopted in the pilot project included reduced tillage, green manure, and a permanent soil cover crop prior to potato sowing. Sediment yield and loss of nitrogen (N) as NH_4^+ and NO_3^-, as well as phosphorus (P) as PO_4^{3-} in runoff were measured. The results helped to understand the effect of CT at field level. For example, Quintero and Comerford (2013) investigated the effect of CT in the potato crop system in the Fuquene watershed in order to assess the contribution of CT in potato-based rotations with respect to the aggregated soil organic carbon in the disturbed organic matter. The results indicated that reduced tillage in potato-based crop rotations increased the soil carbon concentration and average C content in the whole profile by 50 and 33% respectively, as compared to conventional farming practices. Thus, CT helps to bring these soils back to their original characteristics (high organic matter soils) (Quintero and Comerford, 2013).

Several studies report the effects of CT on pollutant losses by applying hydrological modeling tools. Many of these studies describe the accuracy of pollutant prediction obtained for each case study. However, the results are found to vary significantly and provide important insights only for particular agricultural watersheds (Park et al., 2014; Amon-Armah et al., 2013; Liu et al., 2013; Bosch et al., 2013; Betrie et al., 2011; Lam et al., 2011). Despite the increased use of modeling tools to assess the impact of CT as an agricultural BMP on the pollutant losses, there are still knowledge gaps in this topic. One of the most common issues identified to date is how to evaluate the effectiveness of BMPs at controlling nonpoint source pollution in order to obtain the necessary information that would help decision-makers to develop environmental regulations and manage the agricultural sector. Therefore, the objective of this research is to assess the impact of CT on sediments, nitrogen (N) and phosphorus (P) losses in runoff for potatoes at field and watershed levels by applying the Soil Water Assessment Tool (SWAT). This paper will contribute by answering the questions: How do the management practices in a potato-based mixed crop system influencing the runoff and soil nutrients (N and P) losses at the field and watershed levels? And, what would be the effect of applying CT extrapolation in current potato systems throughout all the watershed?

2. Material and methods

Parameters related to the crop database, soil and agricultural management practices were set in the SWAT model according to the local crop systems. A calibration process was carried out by combining the data regarding the impact of management practices on soil and nutrient losses and runoff (measured in the field), and streamflow data from gauging stations. Usually, the calibration of the hydrological model calibration process is considered a challenge to be carry out in the Colombia watersheds, where the complexity of shifting cultivation, intensive traditional agriculture, diverse crops and management practices in a landscape, and weather seasonality are predominant. Also, CT management practices for the potato crop were extrapolated to be able to assess the whole basin. Additionally, the IT and CT effectiveness at field and watershed level were assessed in order to provide guidelines for the decision-makers and stakeholders who aim to use these agricultural management practices for the potato crop.

2.1. Fuquene watershed case study

This study was conducted on the Fuquene Lake watershed, located in the northern part of Bogota city (Colombia) (5°28′00″N, 73°45′00″W). The watershed has an area of approximately 784 km^2. The study area is characterized by large, rocky outcrops and mixed topography (flat areas, semi-flat and streams) which varies between 2520 and 3,786 m above sea level (m.a.s.l). The annual mean precipitation is 777.9 mm, and the annual temperatures are between 12 °C and 18 °C, without great variation throughout the year. The relative humidity ranges between 70% and 80% (IDEAM, 2004). The water from the lake is used and distributed by the municipal water supply companies for human consumption, in settlements located downstream of the lake. The water is supplied to more than 500,000 inhabitants of the region (IGAC, 2000). Fig. 1 presents the study area.

The development of agricultural activities in this watershed has become the main economic driver for its inhabitants. Due to the climate and soils, of this watershed, monocultures are predominant. The potato crop is considered as the most important crop in the watershed. It is worth mentioning that the potato crop has been included in the Food and Nutrition National Plan (PAN) as one of the main crops for the daily diet of millions of consumers, especially in low-income sectors (CAR, 2006). The potato-cultivated area in the Fuquene watershed is around 16,933 ha, with an annual production of 280,000 tons. Although the research uses the Fuquene Basin in Colombia as the main case study, the goal is to develop general methodologies that are applicable to similar watersheds.

2.2. Hydrological and water quality model

The watershed model used in this study was the Soil and Water Assessment Tool (SWAT) developed by the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) (Arnold et al., 1998). The model is a continuous-time, semi-distributed, process-based river watershed-scale model, designed to simulate the long-term effects of water management decisions on the water quality and hydrology response (Neitsch et al., 2011). The model is built on a daily time step at sub-basin and watershed scales. The use of sub-basins in a simulation is particularly helpful when different areas of the watersheds are dominated by land uses or soils which are differ in their properties that may impact the hydrology. These are further subdivided into a series of Hydrological Response Units (HRU), which are common land areas within the sub-basin that are composed of unique land cover, soil and agricultural management practices (Arnold et al., 2012). The hydrological cycle simulated is based on the water balance equation, which