Poll Res. 37 (May Suppl.) : S153-S159 (2018)
Copyright © EM International
ISSN 0257–8050

RAINFALL SIMULATIONS TO EVALUATE PATHOGEN AND NUTRIENTS RUNOFF LOSS UNDER CONTROLLED CONDITIONS

MARÍA ISABEL DELGADO[1], RAMESH KANWAR[2,3], CARL PEDERSON[2], CHI HOANG[2] AND HUY NGUYEN[2]

[1]*National Scientific and Technical Research Council (CONICET), National University of La Plata, Argentina.*
[2]*Iowa State University, Ames, Iowa 50014, USA.*
[3]*Lovely Professional University, India.*

(Receievd 1 February, 2018; accepted 20 March, 2018)

ABSTRACT

Soil fertilizing the old-fashioned way, with raw manure, is a well-known procedure to increase land productivity. However, the fertilization value of organic amendment to the soil depends among others, on the composition of manure and manure application rates, timing and placement. When a rainfall event occurs soon after organic fertilizer application, it might help increase nutrient and pathogen concentrations in superficial runoff, carrying out negative consequences on water quality. The aim of this research was to study the effect of variable rates of poultry manure application and landscape slope on bacterial pathogens, nutrients and sediment transport with surface runoff. Experimental assays were performed with an indoor rainfall simulator; a constant 25 mm. h^{-1} intensity was applied for 2.5 hours. We evaluated interactions between slopes (2%, 4% and 9%) and application rates of poultry manure. Trial conditions tested tend to reproduce the typical farming practices applied in the central area of Iowa State, which is part of the productive area known as the Corn Belt (USA). Nutrient present in surface runoff showed a positive correlation with manure application rates. Also, when manure application rate was doubled, *E. coli* FCU increased correspondingly. This study emphasized the need for proper manure management (rate and timings of application) in order to optimize fertilization efficiency and to avoid negative impacts on downstream water quality of productive areas and on the ecological systems surrounding them.

KEY WORDS : Rainfall simulator, Runoff, Pathogens, Total suspended solids, Poultry manure

INTRODUCTION

The effects of rainfall characteristics on runoff and soil loss are considered highly complex and affected by many factors, but even nowadays they are not completely understood (Qihua *et al.,* 2012). Soil loss can reduce cultivable soil depth and soil fertility. At the same time, sediment may affect water bodies due to eutrophication, by increasing nitrogen (N) and phosphorous (P) levels (Dimoyiannis *et al.,* 2002). Deficiency in planning and designing of management strategies might carry negative consequences to the ecosystem, such as fertilizers and pesticides excess, known as none point source pollutants (Davie, 2008). In cultivated fields, the interaction of natural landscape and rainfall intensity and length can drastically shape the transport of nutrients and pathogens carried by surface runoff (Delgado *et al.,* 2010). One of the sources affecting water quality in the United States, mainly in the upper basin of the Mississippi River and in the region known as the Corn Belt, is represented by runoff losses of P derived from cultivated fields (Baker, 2004). P delivery rate to water bodies might be influenced by various factors, including P application source, rate and method,

***Corresponding author's email:** isabeldelgado@agro.unlp.edu.ar

soil P levels, field slope, soil erosion, surface runoff, subsurface drainage, and proximity to surface water (Allen *et al.*, 2006).

Considering that crop yield results from multifaceted processes such as nutrient uptake and availability, ecological functioning of soil, input use and management practices (van Noordwijk and Brussaard, 2014), and that several studies have separately investigated the effect of fertilizers and soil slope, there is still scarce information on the combined effects of manure application rates and soil slope on pathogen, nutrient and sediment transport within runoff water. In this context, the aim of this work was to study under controlled conditions, the combined effect of manure application rates together with soil slopes, on the movement of pathogens, sediments and nutrients in surface runoff.

MATERIALS AND METHODS

A laboratory rainfall simulator was used to create a similar scenario to that of plots exposed to natural rain. The experiment combined three poultry manure application rates and three artificial slopes, resulting in nine treatments. It was carried out by the end of the summer of 2010.

Soil sampling

Samples were brought from ISU Agricultural and Agronomy Farm, Boone County (Fig. 1). This site had received herbicides treatments in the past years, but no tillage or manure treatment; it is currently used as a bulk area for production of field corn and soybean. It is located on Nicollet loam soil formed in glacial till with organic matter content of about 4%; moderately permeable, somewhat poorly drained, with surface runoff, high available water capacity, and seasonal high water table (Chinkuyu *et al.*, 2000). Elevation varies from 244 to 479 m asl and slopes go from 0 to 5 %. The USDA (2011) classified it as a mesic Aquic Hapludoll, with a fine-loamy texture.

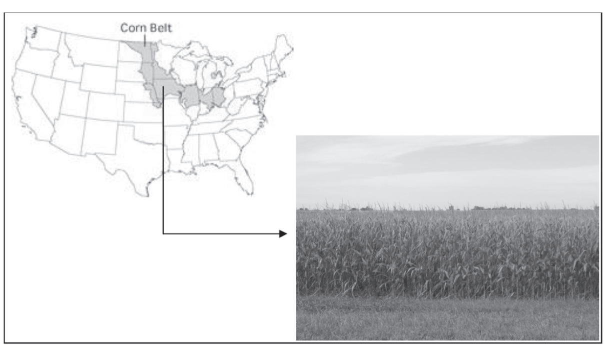

Fig. 1. Location map of the Agricultural and Agronomy Farm (Iowa State University), in the US Corn Belt. Representative map taken from USDA webpage

Soil samples were collected from 0-15 cm soil depth and taken to the laboratory (initial gravimetric moisture was 12.69 %). Soil was dried and passed through a testing sieve. After mixing it with the proper quantity of poultry manure, the mixture was compacted into the trays (reaching 1.4 $g.cm^{-3}$ density); then, it was sprayed with water in order to reach 10 % of moisture content.

Characteristics of applied manure

Sparboe Farm in Eagle Grove (Iowa) provided the poultry manure. Moisture and nutrient contents (N, P, and K) were analyzed at the Minnesota Valley Testing Laboratories Inc. (Nevada, Iowa). Three manure samples were selected for previous determinations: mean levels of N, P, K and moisture were 3.4 % (± 0.7), 3.3 % (± 0.3), 2.0 % (± 0.1) and 20.6 % (± 5.8), respectively.

The average N fertilization rate used in the area is 168 kg $N.ha^{-1}$ (Pappas *et al.*, 2008). Soil was mixed along with poultry manure to obtain three different N concentrations: Control, Ma and Mb (0, 168, and 366 kg $N.ha^{-1}$, respectively), in order to reflect field conditioning by farmers.

Rainfall simulator

Applied rainfall represented a precipitation of 2.5 hours with an intensity of 25 $mm.h^{-1}$; which according to ISU (2009) corresponds to a six months return period for the area. The rainfall simulator used in this study belongs to the Porous Media Laboratory of Davidson Hall, Department of Agricultural and Biosystems Engineering, Iowa State University. It provides uniform rainfall, covering a surface of 1.5 x 3 m, with 12 spraying nozzles. Pressure in water pump was kept at 10 p.s.i., height from trays to nozzles was 2.1 m. Calibrations were done in order to verify the intensity and spatial distribution drops. Tap water was used for simulations.

Experimental design and Sampling details

Treatments included four replications of three different N application rates from poultry manure (Control, Ma and Mb) and three landscape slopes (2%, 4%, and 9%).

We used a randomly completed block design (RCBD) in order to remove the source of systematic variation from the estimate of residual natural variation (Sokal and Rohlf, 2001). Each block corresponded to one replication containing the nine treatments, block components were arranged randomly.

The free version of the software InfoStat® (Di Rienzo *et al.*, 2011) was used for statistical analysis. Significance of differences between the means was established by the analysis of variance (ANOVA).

We used nine steel trays (55.2 cm by 29.2 cm) with a depth of 5 cm. Runoff was directly collected into plastic bottles placed at the tray´s outlet sink. Splash effect of water drops among trays was avoided by installing divisions between them. Individual pluviometers were attached to trays in order to check rainfall intensity while running the experiment.

At the beginning of the experiment a 500 ml bottle was positioned at the outlet of the tray, being replaced by a 125 ml bottle after 10 min. By the time this last one was filled up to 100 ml, another 500 ml bottle was placed at the sink; this practice persisted until the end of the experiment. Thus, we collected samples for analysis of pathogens and nutrients every 10 min, getting at least seven samples per treatment. After rainfall ended runoff was collected for 10 additional minutes, in order to include the delay effect.

Laboratory determinations

Pathogens, nutrients and sediments were analyzed at the National Swine Research and Information Center (NSRIC) Building, placed at the Iowa State University campus:

Pathogens: *Escherichia coli* presence was tested with the Membrane Filtration Method, providing direct counting of *E. coli* based on colonies development growing on the surface of the membrane filter. After filtering, the membrane was placed on modified mTEC Agar, and then incubated for 24 h at 44.5 ± 0.2°C (EPA, 2002). *E. coli* colonies were identified in magenta color after incubation period.

Four dilutions were prepared, both in phosphate buffered water and tap water, and incubated for 24 hours; this allowed us to calculate the correct dilution to be used in the counting of Faecal Coliform Units (FCU).

Nutrients: they were evaluated by the content of NO_3-N and PO_4-P, expressed as mg.L^{-1}. Detection limits were 0.25 mg/L for NO_3-N and 0.005 mg/L for PO_4-P.

Sediments: for Total Suspended Solids (TSS) 100 ml of runoff sample were filtered, then the filter was dried in an oven for twelve hours (up to constant weight), to estimate the dried weight TSS were expressed as mg.L^{-1}.

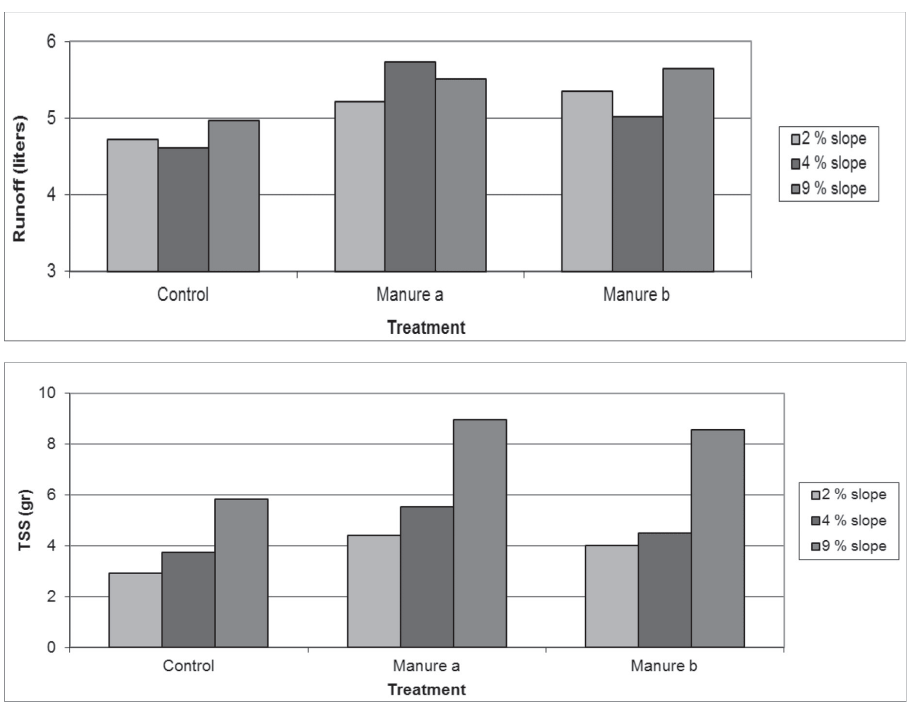

Fig. 2. Runoff and sediment yield at different slopes. a) Mean runoff volume per treatment (in Liters); b) Mean sediment yield (TSS) per treatment (in grams)

RESULTS

Runoff and Soil loss under different treatments

Total runoff collected per treatment and sediment yield are shown on Figure 2 a, b).

Total runoff obtained from each treatment showed no significant differences in the volume collected at different field slopes, mean values were 5.10 liters for 2 % slope, 5.12 liters for 4 % slope and 5.38 liters for 9 % slope.

With regard to sediment yield, soil erosion showed an overall increment with slope for all treatments. Manure a, Manure b and Control samples doubled TSS value at 9 % compared to 2 % slope. Also, sediment yield was higher for manure treated samples compared to controls.

Nutrients and Pathogens

The nutrient dynamic during the rainfall experiment was analyzed dividing runoff data in early (t1) and late runoff (t2); t1 included samples collected at 10, 20, 30 and 40 minutes, t2 comprised the rest of the collected samples.

NO_3^- runoff data is shown in Figure 3.

As a general observation, the NO_3^- concentration for the most diluted manure (Ma) showed a positive correlation with slope; when concentration of manure was doubled (Mb) the NO_3^- runoff seems to be less influenced by slope. Lineal curve fit showed an excellent correlation (R^2> 0.9, except for Mb at early runoff).

NO_3^- transported through runoff varied between treatments: for Ma, NO_3^- concentration was doubled at late runoff (t2) compared with early runoff (t1). Mb runoff was significantly higher than that observed for Ma, both at early and late runoff; also NO_3^- values for Mb late runoff were larger than those obtained at early collection. In Control treatments, most of the NO_3^- values were below the calibration standard value (0.25 mg/L).

Results for PO_4^- runoff are shown on Figure 4, for the two runoff fractions considered.

PO_4^- runoff did not show a linear curve fit, except for Mb at late runoff. For Ma treatment the PO_4^- amounts released remained fairly constant (< 1mg/L) both with runoff collection time and slope. PO_4^- concentration released after Mb application were approximately doubled compared with Ma; a slight increment was observed with increasing slopes.

Concerning pathogens presence, *E. coli* FCU values in the runoff showed high variability, highest point values were above 300 FCU/mL, lowest values remained about 20-30 FCU for 2% slope for all conditions. As expected FCU values were higher for Mb compared to Ma manure application at the higher slopes (4% and 9%).

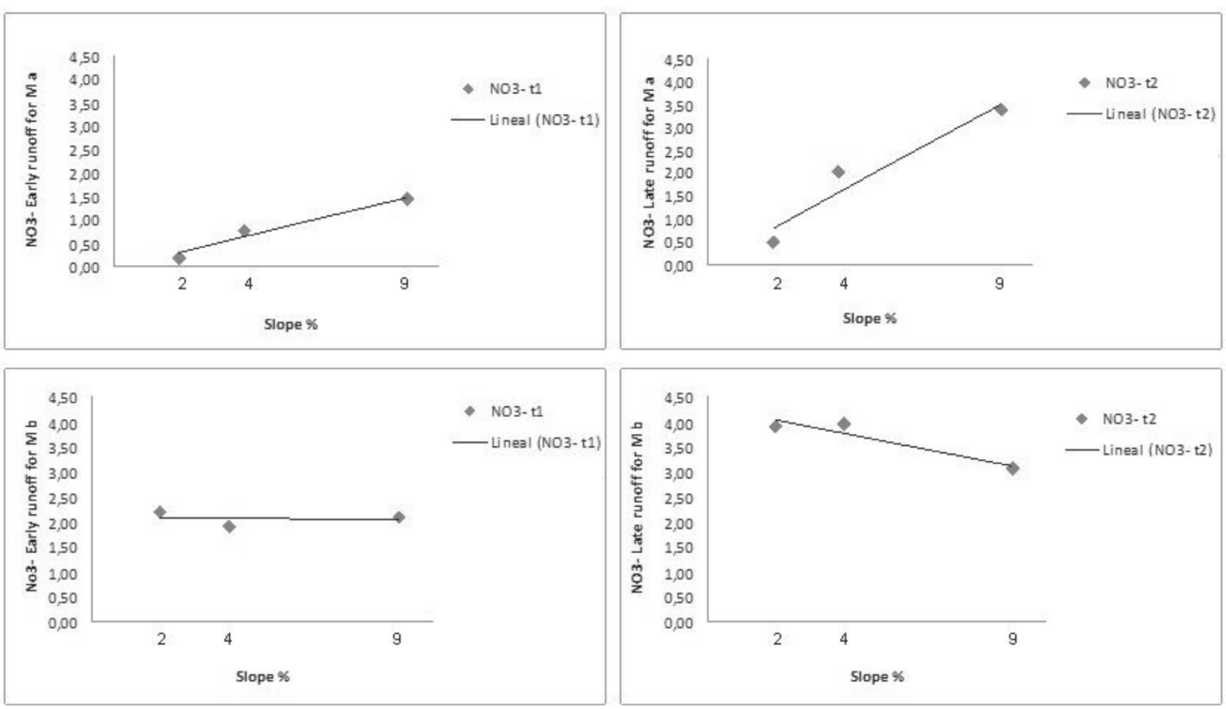

Fig. 3. NO_3^- (mg/L) at early and late runoff (t1 and t2), for Ma and Mb manure concentration and different slopes

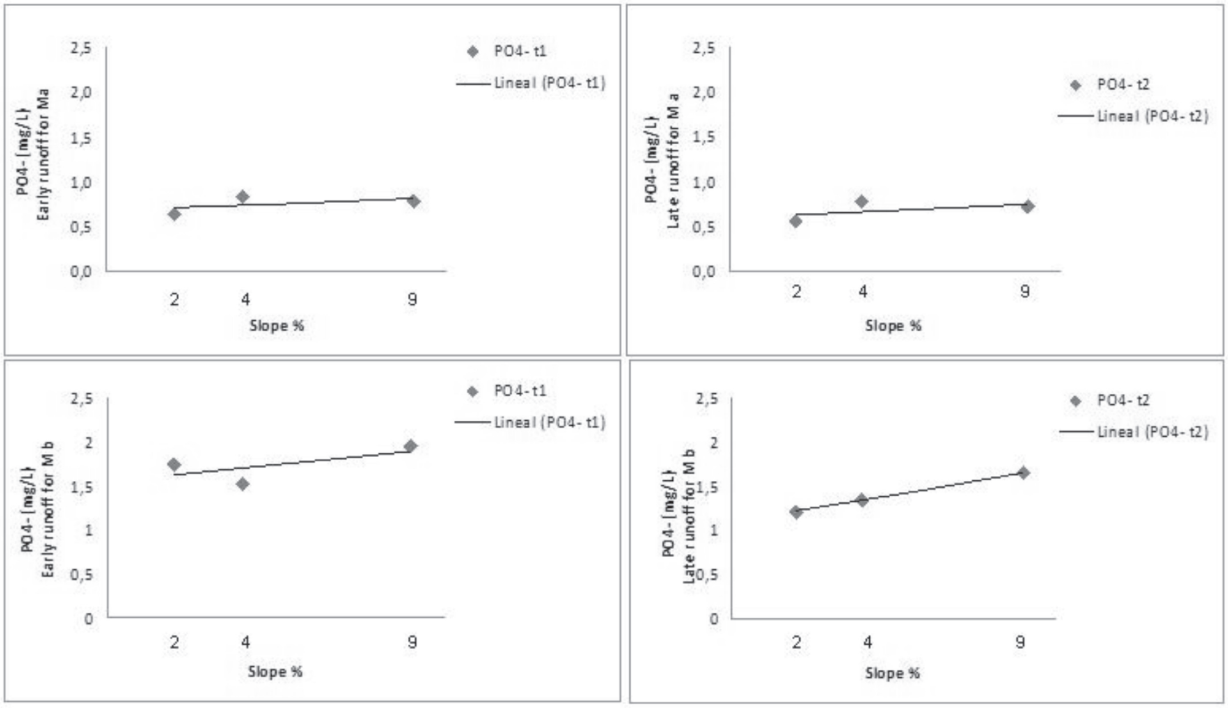

Fig. 4. PO_4^- (mg/L) at early and late runoff (t1 and t2), for Ma and Mb manure concentrations and different slopes

For Ma, early and late runoff showed similar behavior with slope, with FCU values growing at the 9 % slope. Mb treatment showed larger FCU values compared to Ma at 4 % slope and 9 % slope; also late runoff showed higher FCU compared with earlier runoff.

DISCUSSION

Sediment yield increased according to slope for each manure application rate. Significant differences in TSS were observed at 9% slope between control and manure treated soils, but manure application did not seem to affect TSS at lower slopes compared to control.

Sediment yield not only might cause damage to quality of surface water by carrying pathogens, nutrients and a wide variety of other chemical substances such as pesticides; when soil erosion occurs it tends to degrade productive lands with the well-known consequent decrease of crop yield.

EPA (2017) estimated N and P produced from animal manure per farm land area in the State of Iowa 3,198 (kg of N/km^2) and 1,163 (kg of P/km^2). As mentioned by Doydora *et al*. (2011) ammonia loss from fertilizing with poultry litter is environmentally important, since deposition of ammonia can lead to excessive loading of N in lakes, indirect soil's acidification and damage of sensitive crops. Furthermore, N contamination might also carry on P contamination in runoff. In this research, for the usually applied concentration of manure in agricultural fields (Ma) NO_3^- loss increased according to slope; in addition NO_3^- loss increased throughout the experiment (as previously mentioned, t2 concentration doubled t1 concentration).

Fertilizers are usually applied at doses to reach crop's N requirements, ending up in P excessive application (Baker *et al.*, 2007). However, some P loss cannot be avoided, such as during large storm events (Sharpley, 2016). Hoang *et al.* (2010) found that phosphorus concentrations in subsurface drainage water were highly variable and not always consistent with the amount of phosphorus applied from manure and/or commercial fertilizer. In this study we found that PO_4^- concentration released by Ma application was almost doubled at higher manure application (Mb).

E. coli FCU counting in runoff were highly variable, thus preventing conclusive discussion. The *E. coli* concentration showed positive correlation with the initial concentrations in manure, in agreement with reports by Muirhead *et al*. (2006) describing high variability with a range of several orders of magnitude and a strong correlation with the number of *E. coli* in fresh faeces.

Final considerations

Agricultural management systems are known to determine agro-ecosystem's properties, lastly affecting different variables of ecosystem such as its efficiency, productivity, stability and sustainability (Srivastava *et al.*, 2016). In this context, the relevance of this research, reproducing conditions of real agricultural practices of central Iowa, relies on studies such as the Mississippi River Collaborative (2016) that pointed out Iowa's nutrient pollution as a major contributor to the Gulf of Mexico Dead Zone.

This experiment attempted to describe soil response to rainfall after poultry manure fertilization, reflecting usual agricultural practices in the Upper Midwestern United States. The rainfall simulation runs provided information on soil response to rainfall under well defined conditions. As mentioned by Feiner *et al.* (2011), the possibility to keep controlled rainfall conditions makes it easier to compare treatments, usually difficult under variable natural conditions. Further studies are necessary to reach a proper manure management in order to optimize fertilization efficiency, reducing negative impacts on downstream water quality of productive areas as well as on the ecological systems surrounding them.

ACKNOWLEDGMENT

We thank students of ABE Department at ISU, who contributed in conducting the assays. We would also like to thank Dr Michelle Soupir, for her advice concerning *E. coli* analyses.

REFERENCES

Allen, B.L., Mallarino, A.P., Klatt, J.G., Baker, J.L. and Camara, M. 2006. Soil and surface runoff phosphorus relationships for five typical USA Midwest soils. *Journal of Environmental Quality.* 35: 599-610.

Baker, J.L. 2004. In field nutrient availability and balances, and potential implications on management systems to reduce losses. *Agriculture and the Environment Conference.* Ames, IA 50011.

Baker, B.J., King, K.W. and Torbert, H.A. 2007. Runoff losses of dissolved reactive phosphorous from organic fertilizer applied to sod. *Transactions of the ASABE*. 50 (2): 449-454.

Bakhsh, A, R.S. Kanwar, C. Pederson and T.B. Bailey. 2007. N-source effects on temporal distribution of NO3-N leaching losses to subsurface drainage water. *Water Air Soil Pollut.* 181: 30-50.

Chinkuyu, A.J., R. S. Kanwar, J. C. Lorimor, H. Xin, and Bailey, T.B. 2002. Effects of Laying Hen Manure Application Rate on Water Quality. *Transactions of the ASAE.* 45(2): 299-308.

Davie, T. 2008. Fundamentals of hydrology. Second edition. Routledge fundamentals of physical geography series. Taylor & Francis Group. Pp 221.

Delgado, M.I., Hoang, C., Nguyen, H., Pederson, C. and Kanwar, R. 2011. Poultry manure and landscape slope effect on E. coli transport with surface runoff. 2011 ASABE Annual International Meeting (American Society of Agriculture and Biosystem Engineering). Louisville, Kentucky (USA). Paper Number: 1111347.

Dimoyiannis, D.G., Valmis, S. and Vyrlas, P. 2002. A rainfall simulation study of erosion of some calcareous soils. *Global Nest: the Int. J.* 3 (3): 179-183.

Di Rienzo, J.A., Casanoves, F., Balzarini, M.G., Gonzale,z L., Tablada, M. and Robledo, C.W. 2011. InfoStat versión 2011. Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina. URL: http://www.infostat.com.ar

Doydora, S.A., Cabrera, M.L., Das, K.C., Gaskin, J.W., Sonon, L.S. and Miller, W.P. 2011. Release of Nitrogen and Phosphorus from Poultry Litter Amended with Acidified Biochar. *Int. J. Environ. Res. Public Health.* 8: 1491-1502.

EPA. 2002. *Method 1603: Escherichia coli (E. coli) in Water by MembraneFiltration Using Modified membrane-Thermotolerant Escherichia coli Agar (Modified mTEC).* Office of Water Environmental Protection. Agency 20460. Washington DC.

EPA. 2017. Estimated Animal Agriculture Nitrogen and Phosphorus from Manure. United States Environmental Protection Agency web page. *https://www.epa.gov/nutrient-policy-data/estimated-animal-agriculture-nitrogen-and-phosphorus-manure* Last visit: 20th October 2017.

Fiener, P.; S.P. Seibert and K. Auerswald. 2011. A compilation and meta-analysis of rainfall simulation data on arable soils. *Journal of Hydrology.* 409: 395-406.

Hoang, C., Kanwar, R. and Pederson, C. 2010. Phosphorus losses through subsurface drainage in a loamy soil of Iowa: Effects of rates, timing and method of swine manure and fertilizer application. *International Agricultural Engineering Journal.* 19 (1).

Iowa State University 2009. Institute for Transportation. Iowa Stormwater Management Manual. 2C-2 Rainfall and Runoff Analysis Available online at http://www.intrans.iastate.edu/pubs/stormwater/

Design/2C/2C-2%20Rainfall%20and%20Runoff%20Analysis.pdf

Mississippi River Collaborative. 2016. Decades of delay. EPA Leadership Still Lacking in Protecting America's Great River. 76 p.

Qihua, R., Danyang, S., Peng, L. and Zhiguo, H. 2012. Experimental study of the impact of rainfall characteristics on runoff generation and soil erosion. *Journal of Hydrology*.424–425: 99-111.

Sharpley, A. 2016. Managing agricultural phosphorus to minimize water quality impacts. *Sci. Agric*. 73 (1): 1-8.

Sokal, R.R. and Rohlf, F.J. 2001 Biometry, 3° ed., W.H. Freeman & Co., New York.

Srivastava, P. and Singh, R., Tripathi, S. and Singh Raghubanshi, A. 2016. An urgent need for sustainable thinking in agriculture – An Indian scenario. *Ecological Indicators.* 67: 611-622.

USDA. 2011. Natural Resources Conservation Service, Soil Survey Staff, Official Soil Series Descriptions. Available online at http://soils.usda.gov/technical/classification/osd/index.html. Last Accessed [June 11th 2011].

van Noordwijk, M. and Brussaard, L. 2014. Minimizing the ecological footprint of food: closing yield and efficiency gaps simultaneously? *Current Opinion in Environmental Sustainability.* 8: 62-70.