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Effect of Deficit Irrigation Practice on Nitrogen Mineralization and Nitrate Nitrogen Leaching under Semi-Arid Conditions

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Abstract

Agricultural sector acts as a major consumer of water which accounts for 70 percent of global freshwater use. Water scarcity acts as an imminent threat to agriculture, there is a need to use those irrigation and management practices that could overcome this overwhelming situation of water scarcity. Lab incubation study was designed to evaluate the effect of different moisture levels (50%, 60%, 70%, 80%, 90%, and 100% FC) on nitrogen mineralization rate. Net nitrogen mineralization was shown at 60% and 80% FC levels. Two optimized irrigation levels ($I_{0.6}$ and $I_{0.8}$) along with four levels of dairy manure (10, 15, 20, and 25 Mg ha^{-1}) were used in a lysimetric trial. Nitrate-nitrogen was measured at four depths (D_1: 30 cm, D_2: 60 cm, D_3: 90 cm, and D_4: 120 cm). Results showed strong interaction of irrigation and dairy manure at all depths. Mean maximum nitrate-nitrogen concentration was shown under full irrigation at 120 cm soil depth with the application of DM @ 25 Mg ha^{-1}. Under two levels of deficit irrigation, $I_{0.8}$ has shown maximum nitrate-nitrogen concentration at 90 cm soil depth with the application of DM_{25}, however, deficit irrigation level $I_{0.6}$ restricted nitrate-nitrogen movement up to 60 cm soil depth, and high concentration was found at 30 cm soil depth. We concluded that deficit irrigation practice along with dairy manure resulted in more nitrate-nitrogen in the upper 60 cm layer of soil where it can be more available for the crops.

Keywords

Dairy Manure, Deficit Irrigation, Nitrogen Mineralization, Nitrate-Nitrogen Leaching

1. Introduction

Water scarcity is becoming an imminent threat to the agriculture sector all over the world and the problem is of much concern in developing countries [1]. According to a report by the UN, by 2025, two-thirds of the world population would be under the water stress conditions [2]. Pakistan is running out of fresh water at an alarming rate. This shortfall will be devastating for a country whose economy is based on agriculture.

Water and nitrogen are the key factors affecting crop growth. The fate of nitrogen in the soil is directly affected by the availability of water in soil [3]. Mismanagement of nitrogen fertilizer is another aggravated problem [4]. Farmers are applying more and more fertilizer without knowing its fate in soil and impact on the environment [5]. Furthermore, the farming community is wasting a tremendous amount of freshwater by using outdated flood irrigation methods. About 95 percent of freshwater is utilized for irrigation, and yet the country is achieving a lower per acre crop production when compared to India and China in the region.

Under current circumstances of water scarcity and for efficient management and utilization of applied fertilizer, there is a need to improve soil properties for efficient utilization of water and nutrients. In this regard use of dairy, manure is countable because manure contains organic carbon that acts as s a key indicator for soil health [6] [7]. Some studies supported the fact that dairy manure acts as a slow-release fertilizer and avoids nutrient losses [8] [9]. On contrary, some studies reported that the addition of manure causes excessive nitrate-nitrogen leaching [10] under full irrigation but very little knowledge exists regarding role of dairy manure on nitrate leaching under deficit irrigation conditions [11].

Dairy manure can ameliorate soil conditions for maximum nutrients and water utilization but very little knowledge is present regarding its role in nitrogen productivity in soil under reduced water conditions. The present study was designed with the purpose to evaluate the comparative effect of deficit and full irrigation on nitrate-nitrogen productivity under different levels of dairy manure to improve soil nutrient status under deficit irrigation conditions.

2. Materials and Methods

2.1. Incubation Study

An incubation study was carried out at Soil Physics Laboratory, ISES, University of Agriculture Faisalabad, Pakistan. The soil used for this experiment was collected manually using a shovel from a depth of 15 cm. Soil belonged to the Hafizabad soil series (Aridisol-loam, mixed) and soil basic characteristics are given below in Table. The soil was air-dried and sieved through a 2 mm sieve and placed on a plastic sheet. Six sets of soil were prepared based on water content (50%, 60%, 70%, 80%, 90% and 100% of field capacity). Soil water retention capacity was determined by the filter paper method [12]. Urea fertilizer was applied equally in all sets of soil to allow mineralization without nitrogen limitation. Soil samples were placed in air-tight plastic jars with a vial of water to maintain humidity. Soil samples were incubated at 25˚C for 40 days. The moisture level was maintained two times a week. For mineral nitrogen measurements, 200 g equivalent oven-dry soil was taken in 1/2 L plastic jars. 20 g of soil samples from each jar were taken after 7, 14, 28, and 40 days of incubation for measurement of mineral nitrogen.

2.2. Lysimetric Trial

The lysimetric trial was conducted at Research Area Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad. Lysimeter used in this study was made of concrete. The area of each lysimeter was 4.5 m^2. Leachate collection was done at 30, 60, 90, and 120 cm depth with the help of a solution sampler installed at the required depth. Wheat variety (cv. Galaxy-2013) was sown and seeds were pre-soaked for 12 hours to facilitate germination. Two optimized moisture levels from the incubation study were applied as $I_{0.6}$ (60% FC) $I_{0.8}$ (80% FC and control $I_{1.0}$ (100% FC). Four levels of dairy manure were applied as DM_{10}, DM_{15}, DM_{20}, and DM_{25}. The dose of NPK was applied as 100-85-65 $kg \cdot ha^{-1}$. Nitrogen was applied in less amount the than recommended rate of 120 $kg \cdot ha^{-1}$. Applied manure composition is shown in Table 1.

Irrigation water measurement

Cut throat flumes were used to apply a measured amount of irrigation water to the lysimetric trial. The time requirement for plots irrigation to desire depth was calculated as follow:

$$Qt = Ad$$

$$t = Ad/Q$$

where, Q = discharge ($m^3 \cdot min^{-1}$), t = time (min), A = area of plot (m^2), d = depth of irrigation (m).

Nitrate concentration ($mg \cdot kg^{-1}$) measurement

Soil solution sampler was installed at four depths (30, 60, 90 and 120 cm) in lysimetric trial. Preparation and installation of solution sampler was done following method given by Webster *et al.* (1993). Nitrate-N in soil was measured by a spectrophotometer method [13].

Table 1. Manure composition.

Parameter	(%)
Moisture contents	61.3 ± 2.7
N	0.81 ± 0.02
P	0.41 ± 0.04
K	1.11 ± 0.06
Organic carbon	47.8 ± 4.12

*Average ± standard error with three repeats.

(STATISTICAL DESIGN)

The data was statistically analyzed through Analysis of Variance technique using CRD for incubation study. For lysimeter trial CRD design was used with split plot arrangements. Further significance of interaction was analyzed using honestly significant difference test (HSD) [13] at 5% probability level.

3. Results

Interactive effect of different levels of moisture and incubation time on nitrate nitrogen release at constant temperature 25˚C is presented in **Figure 1**. Both moisture and incubation time has shown significant effect on nitrate nitrogen release. Nitrate nitrogen release showed direct relation with number of days. An increasing trend of nitrate nitrogen was found with increasing moisture level and maximum nitrate nitrogen was observed at 80% FC, after which decrease in nitrate nitrogen was observed. Incubation time also significantly affected mineralization rate and maximum net mineralization was observed at 28-days of incubation. Temperature was kept constant at 25˚C, as in previous studies it shown that maximum mineralization occurred between temperature ranges of 25˚C - 30˚C. Maximum mineralization occurred after 14 days of incubation period and at 80% FC for nitrate nitrogen. High concentration of nitrate nitrogen in incubated soil may be due to the reason that experimental area soil from where samples were taken is under organic amendments for the past 15-years.

Effect of different levels of moisture, incubation time and their interactive effect on ammonium nitrogen release at constant temperature 25˚C is presented in **Figure 2**. Both moisture and incubation time has shown significant effect on ammonium nitrogen release. Ammonium nitrogen release showed inverse relation with number of days. A decreasing trend of ammonium nitrogen was found with increasing moisture level and maximum ammonium nitrogen was observed under 50% FC, after which decline in ammonium nitrogen was observed. Incubation time also significantly affected ammonium nitrogen release as maximum net ammonium nitrogen release occurred after 7-days of incubation followed by 28-days. Interactive effect of moisture and time (days) also showed significant effect on net ammonium release (**Figure 2**). However, more significant results of interaction of moisture and time (days) were shown for nitrate nitrogen than ammonium nitrogen. Temperature was kept constant at 25˚C, as in previous studies it showed maximum mineralization occurred between temperature ranges of 25˚C - 30˚C.

Under lysimetric trial, mean maximum nitrate nitrogen concentration (22.83 $mg \cdot kg^{-1}$) was shown under full irrigation with application of dairy manure at the rate of 25 Mg ha^{-1} (**Table 2**). Under two levels of deficit irrigation, $I_{0.8}$ has shown mean maximum nitrate nitrogen concentration 16.23 $mg \cdot kg^{-1}$ with application of dairy manure at the rate of 25 Mg ha^{-1} at 90 cm soil depth. Mean maximum nitrate nitrogen concentration was shown at a depth of 120, 90 and 30 cm soil depth for $I_{1.0}$, $I_{0.8}$ and $I_{0.6}$, respectively (**Table 2**). Our study results showed that maximum nitrogen mineralization with reduced nitrate leaching was shown under deficit irrigation level $I_{0.8}$ followed by $I_{0.6}$. Deficit irrigation practice is not only affective for efficient irrigation water management but also ensures nutrients availability within crop vicinity. Furthermore, dairy manure application showed significant result along with deficit irrigation practice. Future research should be focused on the use of other amendments which could perform better at 50% of recommended irrigation rate with no compromise on yield.

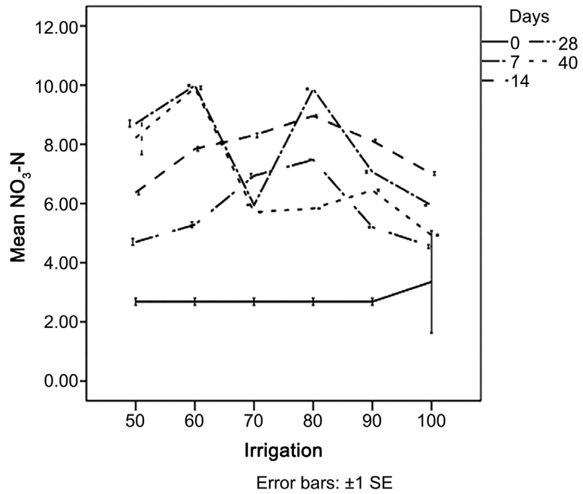

Figure 1. Interactive effect of moisture levels and incubation time on Nitrate nitrogen release. Irrigation levels: 50%, 60%, 70%, 80%, 90% and 100% Field Capacity. Error bar showing standard error value.

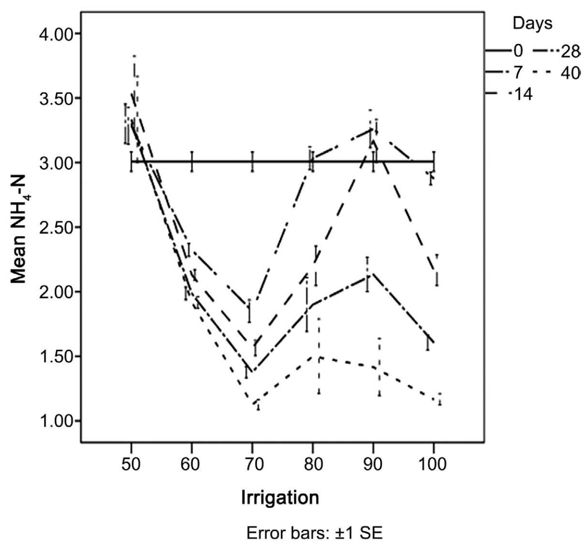

Figure 2. Interactive effect of moisture and incubation time on NH_4^+-N release. Irrigation levels: 50%, 60%, 70% 80%, 90% and 100% Field Capacity. Note: Moisture levels were based on field capacity. Error bar showing standard error value. Both incubation days and moisture levels showed significant effect on NO_3-N release under lab condition.

Table 2. Interactive effect of irrigation and dairy manure on nitrate nitrogen concentration on leachate (mg·kg^{-1}) under different depths in lysimeter conditions.

(a) Irrigation × DM interaction mean ± SE

DM	Irrigation			Mean
	$I_{0.6}$	$I_{0.8}$	$I_{1.0}$	
DM_{10}	7.78 ± 0.58h	6.50 ± 0.78i	9.19 ± 0.98g	7.82 ± 1.48D
DM_{15}	8.78 ± 0.88g	9.72 ± 0.87f	11.38 ± 1.04de	9.96 ± 1.55C
DM_{20}	11.25 ± 1.04e	10.07 ± 1.00f	14.91 ± 1.24b	12.08 ± 1.71B
DM_{25}	13.99 ± 1.20c	11.82 ± 1.13d	16.77 ± 1.34a	14.19 ± 1.98A
Mean	10.45 ± 1.58B	9.53 ± 1.51C	13.06 ± 1.91A	

(b) D × Irrigation interaction mean ± SE

Depth (cm)	Irrigation			Mean
	$I_{0.6}$	$I_{0.8}$	$I_{1.0}$	
D_1	14.60 ± 1.02b	11.14 ± 0.93e	11.10 ± 0.96e	12.28 ± 1.53A
D_2	11.68 ± 1.28d	9.79 ± 0.93f	11.38 ± 1.09de	10.95 ± 1.35B
D_3	8.83 ± 0.94g	11.00 ± 1.43e	16.26 ± 1.67a	12.03 ± 1.78A
D_4	6.69 ± 1.37h	6.17 ± 0.69i	13.51 ± 2.39c	8.79 ± 1.09C

DM: Dairy manure, D: Depth, $I_{0.6}$ = 60% Field capacity, $I_{0.8}$ = 80% Field capacity; $I_{1.0}$ = 100% Field capacity, D_1 = 30 cm, D_2 = 60 cm, D_3 = 90 cm, D_4 = 120 cm. Means sharing similar letter in a row or in a column are statistically non-significant (P > 0.05). Small letters represent comparison among interaction means and capital letters are used for overall mean.

(c) Irrigation × D × DM interaction mean ± SE

DM	D	Irrigation			Mean
		$I_{0.6}$	$I_{0.8}$	$I_{1.0}$	
DM_{10}	**D_1**	10.48 ± 0.90lmn	8.50 ± 0.29rs	7.93 ± 0.752s	8.97 ± 0.83H
	D_2	8.50 ± 0.79rs	9.50 ± 0.29n-r	11.03 ± 0.82klm	9.68 ± 0.99G
	D_3	6.40 ± 0.51tu	4.50 ± 0.29vw	13.17 ± 0.927ghi	8.02 ± 1.32I
	D_4	5.73 ± 0.71u	3.50 ± 0.29w	4.63 ± 0.63v	4.62 ± 0.86K
DM_{15}	**D_1**	12.70 ± 0.92ij	13.10 ± 0.59ghi	9.57 ± 0.85n-q	11.79 ± 1.20E
	D_2	10.32 ± 0.34mno	11.50 ± 0.29k	13.73 ± 0.93fgh	11.85 ± 1.53E
	D_3	6.08 ± 0.36tu	8.57 ± 0.30qrs	15.43 ± 0.99de	10.03 ± 1.41G
	D_4	6.00 ± 0.58tu	5.72 ± 0.40u	6.77 ± 0.39t	6.16 ± 0.88J
DM_{20}	**D_1**	15.83 ± 0.44d	11.07 ± 0.98klm	12.80 ± 0.92hij	13.23 ± 1.72D
	D_2	12.58 ± 0.30ij	8.70 ± 0.21p-s	9.40 ± 0.31o-r	10.23 ± 1.61FG
	D_3	10.10 ± 0.26mno	14.70 ± 0.38ef	17.63 ± 0.81c	14.14 ± 1.81C
	D_4	6.50 ± 0.29tu	5.80 ± 0.42tu	19.80 ± 0.42b	10.70 ± 2.29F
DM_{25}	**D_1**	19.40 ± 0.32b	11.90 ± 0.91jk	14.10 ± 0.98fg	15.13 ± 1.12B
	D_2	15.30 ± 0.35de	9.47 ± 0.66o-r	11.33 ± 0.94kl	12.03 ± 1.87E
	D_3	12.73 ± 0.91hij	16.23 ± 1.28d	18.80 ± 1.42b	15.92 ± 2.90A
	D_4	8.53 ± 0.29rs	9.67 ± 0.48nop	22.83 ± 1.44a	13.68 ± 2.30CD

DM: Dairy manure, D: Depth, $I_{0.6}$ = 60% Field capacity, $I_{0.8}$ = 80% Field capacity; $I_{1.0}$ = 100% Field capacity, D_1 = 30 cm, D_2 = 60 cm, D_3 = 90 cm, D_4 = 120 cm. Means sharing similar letter in a row or in a column are statistically non-significant (P > 0.05). Small letters represent comparison among interaction means and capital letters are used for overall mean.

4. Discussion

Soil moisture acts as an important factor regarding nitrogen availability in soil [14]. Moisture also has strong effect on nitrogen mineralization rate through its use by soil microorganism [14]. The amount of nitrate leach down directly relates with percolation volume. Under incubation study, mineralized nitrate has shown direct relation with moisture level, this may be due to highly connected water filled pore spaces, which results in rapid diffusion of ammonia from mineralization to nitrification site and thus releases more nitrate [15]. Significant increase in nitrogen mineralization was shown when moisture was applied at half of recommend rate of irrigation (50% FC), this may be due to rewetting of dry soil that results in release of nitrogen [16]. Water contents at 60% field capacity also showed high release of nitrate nitrogen and ammonium nitrogen. Zhou *et al.* (2001) found similar results that rate of mineralization increased as moisture content increased with range of 46% - 54%. Overall, net nitrogen mineralization increased when moisture content increased from 70% FC and maximum was noted at 80% FC.

Our results showed significant effect of moisture on mineralization, as other studies also supported this fact that mineralization strongly depends on moisture level in soil [17]. Maximum mineralization found under low moisture levels may be due to rewetting of dry soil causing more release of nitrogen than saturated soils [17] [18].

In lysimetric trial, high nitrate nitrogen concentration was shown under full irrigation as compared to deficit irrigation. Many studies also supported nitrate nitrogen leaching under full irrigation with application of organic amendments, with very few literature on nitrate nitrogen leaching under deficit irrigation level [19]. Under full irrigation conditions, mean maximum nitrate nitrogen concentration found was 117.74% and 101.5% higher than deficit irrigation level $I_{0.8}$ and $I_{0.6}$, respectively. Nitrogen undergoes leaching losses usually under full irrigation [20] as compared to deficit irrigation due to high amount of percolation water, because nitrate nitrogen is negatively charged therefore moves rapidly to deep in soil with water.

Application of dairy manure resulted in significant increase in leaching concentration under all levels of irrigation water, this may be due to the fact that manure application results in improved soil structure and enhanced soil porosity which results in efficient water movement within soil profile [21] [22]. Many studies supported the role of dairy manure in increasing leaching concentration [23] [24]. On the other hand, some studies also shown contrary results that dairy manure application restricts leaching losses because manure act as a slow release fertilizer [25]. Under two levels of deficit irrigation, $I_{0.8}$ in combination with high application of dairy manure (25 Mg ha^{-1}) resulted in movement of nitrate nitrogen deep to soil profile at 120 cm. Under deficit irrigation level $I_{0.6}$, nitrate nitrogen movement was limited up to 60 cm soil depth and mean maximum concentration was shown at 30 cm sol depth. Overall 60% field capacity level provided best results with maximum nitrate nitrogen within root vicinity, but further work in needed to check long-term effect on crop yield and soil properties.

5. Conclusion

Water scarcity is an imminent threat to agriculture industry which is a major consumer of fresh water use. There is a need of time to introduce water management practices with emphasis on minimum use of irrigation water. For efficient utilization of water and nutrients, there is need to improve soil physical conditions for efficient movement of water. In our incubation and lysimeteric study, we concluded that deficit irrigation practice not only resulted in high release of mineral nitrogen (mineralization) but also restricted nitrate nitrogen in upper 60 cm soil layer where it will be highly available to plant roots. While, under full irrigation nitrate nitrogen leached down to profile up to 120 cm soil where it becomes unavailable to crops. Furthermore, application of dairy manure showed direct relation with the release of nitrate nitrogen. Future research is needed on long term experimentation of deficit irrigation practice in combination with organic amendments.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Candela, L., Wallis, K.J. and Mateos, R.M. (2008) Non-Point Pollution of Groundwater from Agricultural Activities in Mediterranean Spain: The Balearic Islands Case Study. *Environmental Geology*, **55**, 587-595. https://doi.org/10.1007/s00254-007-0853-0

[2] Canali, S., Ciaccia, C., Antichi, D., Barberi, P., Montemurro, F. and Tittarelli, F. (2010) Interactions between Green Manure and Amendment Type and Rate: Effects on Organic Potato and Soil Mineral N Dynamic. *Journal of Food, Agriculture and Environment*, **8**, 537-543.

[3] Lenka, S., Singh, A.K. and Lenka, N.K. (2009) Water and Nitrogen Interaction on Soil Profile Water Extraction and ET in Maize-Wheat Cropping System. *Soil Tillage Research*, **102**, 207-211. https://doi.org/10.1016/j.agwat.2008.06.014

[4] Devkota, K.P., Hoogenboom, G., Boote, K.J., Singh, U., Lamers, J.P.A., Devkota, M. and Vlek, L.G. (2015) Simulating the Impact of Water Saving Irrigation and Conservation Agriculture Practices for Rice-Wheat Systems in the Irrigated Semi-Arid Drylands of Central Asia. *Agricultural and Forest Meteorology*, **214**, 266-280. https://doi.org/10.1016/j.agrformet.2015.08.264

[5] Cavero, J., Barros, R., Sellam, F., Topcu, S., Isidoro, D., Hartani, T., Lounis, A., Ibrikci, H., Cetin, M., Williams, J.R. and Aragues, R. (2012) APEX Simulation of Best Irrigation and N Management Strategies for Off-Site N Pollution Control in Three Mediterranean Irrigated Watersheds. *Agricultural Water Management*, **103**, 88-99. https://doi.org/10.1016/j.agwat.2011.10.021

[6] Diacono, M. and Montemurro, F. (2010) Long Term Effects of Organic Amendments on Soil Fertility. A Review. *Agronomy Sustainable Development*, **30**, 401-422.

https://doi.org/10.1051/agro/2009040

[7] Dominguez, J. and Amador, J. (2007) Geographical Information Systems Applied in the Field of Renewable Energy Sources. *Computer & Industrial Engineering*, **52**, 322-326. https://doi.org/10.1016/j.cie.2006.12.008

[8] Reynolds, C.A., Jackson, T.J. and Rawls, W.J. (2000) Estimating Soil Water-Holding Capacities by Linking the Food and Agriculture Organization Soil Map of the World with Global Pedon Databases and Continuous Pedotransfer Functions. *Water Resources Research*, **36**, 3653-3662. https://doi.org/10.1029/2000WR900130

[9] Government of Pakistan (2015) Economic Survey of Pakistan 2014-15. Ministry of Food, Agriculture and Livestock, Federal Bureau of Statistics.

[10] Guntinas, M., Leiros, M.C., Cepeda, C.T. and Sotres, F.G. (2012) Effects of Moisture and Temperature on Net Soil Nitrogen Mineralization: A Laboratory Study. *European Journal of Soil Biology*, **48**, 73-80. https://doi.org/10.1016/j.ejsobi.2011.07.015

[11] Isidoro, D., Quilez, D. and Aragues, R. (2006) Environmental Impact of Irrigation in La Violada District (Spain). II. Nitrogen Fertilization and Nitrate Export Patterns in Drainage Water. *Journal of Environmental Quality*, **35**, 776-785. https://doi.org/10.2134/jeq2005.0065

[12] Smiles, D.E. (1998) Water Flow in Filter Paper and Capillary Suction Time. *Chemical Engineering Science*, **53**, 2211-2218. https://doi.org/10.1016/S0009-2509(98)00061-X

[13] Mikha, M.M., Rice, C.W. and Milliken, G.A. (2005) Carbon and Nitrogen Mineralization as Affected by Drying and Wetting Cycles. *Soil Biology and Biochemistry*, **37**, 339-347. https://doi.org/10.1016/j.soilbio.2004.08.003

[14] Mohanty, M., Reddy, S.K., Probert, M.E., Dalal, R.C., Rao, S.A. and Menzies, N.W. (2011) Modelling N Mineralization from Green Manure and Farmyard Manure from a Laboratory Incubation Study. *Ecology Model*, **222**, 719-726. https://doi.org/10.1016/j.ecolmodel.2010.10.027

[15] Payero, O., Jose, R., Melvin, E., Steven, J., Irmak, A., Suat, K., Tarkalson, D. and David, G. (2006) Yield Response of Corn to Deficit Irrigation in a Semiarid Climate. *Agriculture Water Management*, **84**, 101-112. https://doi.org/10.1016/j.agwat.2006.01.009

[16] Fierer, N., Schimel, J.P. and Holden, P.A. (2003) Variations in Microbial Community Composition through Two Soil Depth Profiles. *Soil Biology and Biochemistry*, **35**, 167-176. https://doi.org/10.1016/S0038-0717(02)00251-1

[17] Roth, G., Harris, G., Gillies, M., Montgomery, J. and Wigginton, D. (2013) Water-Use Efficiency and Productivity Trends in Australian Irrigated Cotton: A Review. *Crop and Pasture Science*, **64**, 1033-1048. https://doi.org/10.1071/CP13315

[18] Lopez-Rodriguez, G., Sotomayor-Ramirez, D., Amador, J.A. and Schroder, E.C. (2015) Contribution of Nitrogen from Litter and Soil Mineralization to Shade and Sun Coffee (*Coffea arabica* L.) Agroecosystems. *Tropical Ecology*, **56**, 155-167.

[19] Sepehrnia, N., Memarianfard, L., Moosavi, A.A., Bachmann, J., Guggenberger, G. and Rezanezhad, F. (2017) Bacterial Mobilization and Transport through Manure Enriched Soils: Experiment and Modeling. *Journal of Environmental Management*, **201**, 388-396. https://doi.org/10.1016/j.jenvman.2017.07.009

[20] Sims, J.R. and Jackson, G.D. (1971) Rapid Analysis of Soil Nitrate with Chromotropic Acid. *Soil Science Society of America Journal*, **35**, 603-606. https://doi.org/10.2136/sssaj1971.03615995003500040035x

[21] Fan, J., Xiao, J., Liu, D., Ye, G., Luo, J., Houlbrooke, D. and Ding, W. (2017) Effect of Application of Dairy Manure, Effluent and Inorganic Fertilizer on Nitrogen

Leaching in Clayey Fluvo-Aquic Soil: A Lysimeter Study. *Science of the Total Environment*, **592**, 206-214. https://doi.org/10.1016/j.scitotenv.2017.03.060

[22] Tarkelson, D.D., Payero, J.A., Ensley, S.M. and Shapiro, C.A. (2006) Nitrate Accumulation and Movement under Deficit Irrigation in Soil Receiving Cattle Manure and Commercial Fertilizer. *Agricultural Water Management*, **85**, 201-210. https://doi.org/10.1016/j.agwat.2006.04.005

[23] Tejada, M., Hernandez, M.T. and Garcia, C. (2009) Soil Restoration Using Composted Plant Residues Effects on Soil Properties. *Soil Tillage Research*, **102**, 109-117. https://doi.org/10.1016/j.still.2008.08.004

[24] Wang, Z., Wu, Z. and Tang, S. (2009) Characterization of Dissolved Organic Matter in a Submerged Membrane Bioreactor by Using Three-Dimensional Excitation and Emission Matrix Fluorescence Spectroscopy. *Water Research*, **43**, 1533-1540. https://doi.org/10.1016/j.watres.2008.12.033

[25] Zabel, F., Putzenlechner, B. and Mauser, W. (2014) Global Agricultural Land Resources—A High Resolution Suitability Evaluation and Its Perspectives until 2100 under Climate Change Conditions. *PLoS ONE*, **9**, e107522. https://doi.org/10.1371/journal.pone.0107522