NITRATE LEACHING AND CORN YIELD UNDER CURRENT AND FUTURE CLIMATE IN SARDINIA (ITALY)

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Introduction

Groundwater contamination due to NO_3^- leaching has received particular consideration in European Union legislation because non-point-source pollution has significantly increased in numerous areas subject to intensive agriculture (EC, 2000). Projections predict several changes in climatic conditions in the future, including increased atmospheric CO_2 concentrations, increased air temperatures, and altered rainfall patterns (IPCC, 2014). Such changes will affect crop development and therefore crops ability to uptake N from the soil. The work presented here is a continuation of a previous research project (Giola et al., 2012) on a geographical area identified as a nitrate-vulnerable zone (NVZ) according to Nitrate Directive 91/676 (EEC, 1991). The results of that study suggested that current agronomic N management is not in line with Nitrate Directive 91/676. The nature of highly sandy soil of this area accompanied by excessive irrigations and large applications of N amendments (manure, slurry and inorganic N fertilizers) resulted in large amount of nitrate leaching to the groundwater. As a result, in 2010, three N fertilization treatments were used in the field to comply with EU regulations. Therefore, the objectives of this work were to i) evaluate the ability of the crop model to reproduce experimental results for yield and soil nitrogen (N) dynamics under various N fertilizer treatments applied to a nitrate-vulnerable area, ii) estimate the impacts of the various N treatments on nitrate leaching under future climate conditions, and iii) identify the N management strategy most able to minimize N leaching and maximize yield under future climate conditions in this nitrate-vulnerable Mediterranean area.

Materials and Methods

A summer maize (*Zea Mays L.*) - winter triticale (*x Triticosecale WittMack*) rotation system was used for this study. The field experiment was conducted during the 2010 and 2011 season on a commercial farm close to Arborea (Latitude 39° 46' 26" N, Longitude 08° 34' 53" E, 7 m a.s.l.), on the west-coast of Sardinia, Italy. The three N fertilization treatments used in study were no N fertilization (N0), mineral N (urea) fertilization (NMIN), and organic (cattle slurry) plus mineral (urea) N fertilization, which is the conventional fertilization practice adopted by farmers (CONV). The historical weather data (1959-2011) were obtained from the nearby meteorological station located at the "Santa Lucia experimental farm" (Zeddiani, OR; latitude 39°56'03.11''N, longitude 8°41'13.41''E, 15 m a.s.l.) of the University of Sassari. The future climate data were obtained by using MarkSim software on the existing weather data (Jones P.G. and Thornton, P.K., 2013). The scenario used was A1B (medium emission, IPCC 2007). The soil samples were collected on June 2010, before fertilization and sowing, to determine the soil's chemical and physical characteristics at the beginning of the experiment and use them as inputs for the crop simulation model. Moreover, soil and crop samples were taken at various growth stages during the maize-triticale rotation. The soil was sampled to a depth of 140 cm. Slurry samples were collected during April 2010 and 2011. In this study, the SALUS model (*System Approach to Land Use Sustainability*; Basso et al., 2010) was used. The model was calibrated and tested on field data collected in a previous experiment (Giola et al., 2012). The SALUS model was run in a rotational mode to fully account for the carry-over effects of water and nutrients from one year to the next. A first set of rotational simulations was carried out for the experimental years to evaluate the model's ability to simulate the maize crop and soil nitrogen in each treatment; a second set of rotational simulations was carried out for a long-term assessment of the treatments, using the future scenarios on the three treatments and on a best management practice (BMP) that complies with the limits imposed by the NVZs regulation [170 kg N ha^{-1} year^{-1} derived from organic fertilizers (manure and/or slurry)]. The BMP consisted of a total fertilization of 253 kg N ha^{-1}, which was determined on the basis of the observed crop N uptake using the 2010-2011 data samples; the BMP was as follows: 134 kg N ha^{-1} of urea in two applications: 90 kg N ha^{-1} soon after sowing (DOY 176) and 44 kg N ha^{-1} on DOY 189; 119 kg N ha^{-1} of liquid manure given before sowing (DOY 162).

Table 1. Observed and simulated yields for the NMIN, CONV, and N0 treatments at the harvest dates of the maize crops (means, standard errors, root mean square errors (RMSE) and relative errors (R.E.)

Crop	Date	Treatment	Yield (t ha^{-1})		RMSE	R.E.
	(mm/dd/yy)		Observed	Simulated	(t ha^{-1})	(%)
Maize	09/14/2010	N MIN	23.7 ± 1.64	23.0	0.73	3.08
	09/14/2010	CONV	22.5 ± 1.86	22.0	0.45	2.00
	09/14/2010	N 0	20.2 ± 1.65	20.1	0.10	0.49
Maize	09/08/2011	N MIN	25.5 ± 0.43	21.4	4.10	16.08
	09/08/2011	CONV	25.6 ± 0.61	22.1	3.53	13.77
	09/08/2011	N 0	12.7 ± 0.78	12.6	0.12	0.94

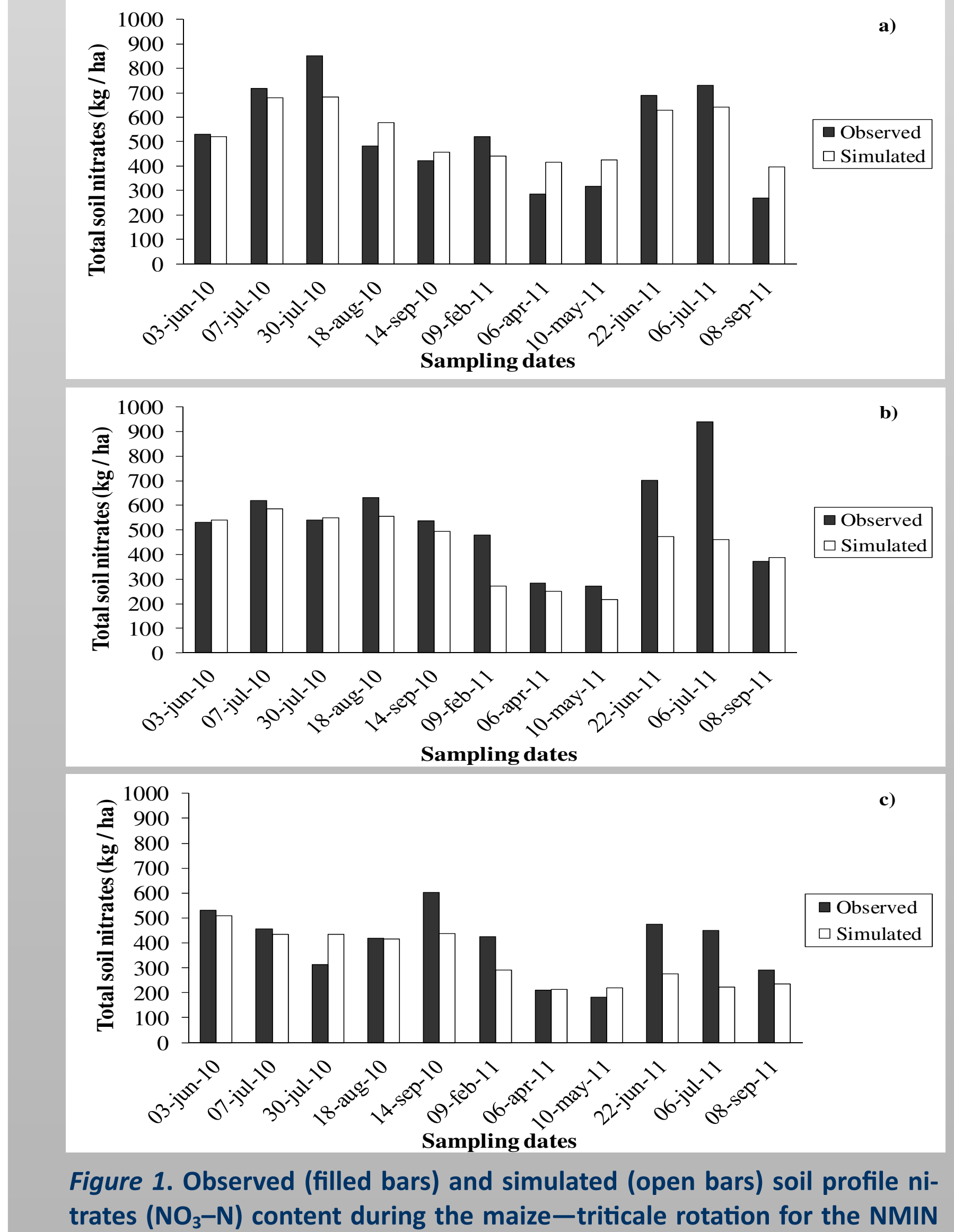

Figure 1. Observed (filled bars) and simulated (open bars) soil profile nitrates (NO_3–N) content during the maize—triticale rotation for the NMIN (a), CONV (b) and N0 (c) treatments.

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Results and Discussion

The soil profile was characterized by a high sand content, with a mean value of 97.2%, and high concentrations of OC and total N in the first 40 cm, which were found at 20.6 g kg^{-1} and 2 g kg^{-1}, respectively. The mean pH was 7.5; the soil had an adequate supply of K_2O and a high level of P_2O_5, especially in the first 60 cm. The soil profile nitrate and ammonium-N content were, on average, 26.9 and 48.6 mg kg^{-1}, respectively. For the three treatments, the concentrations of OC and total N measured at the harvest dates of triticale were lower than the values observed harvest dates of maize, both as a soil profile average and for each of the soil layers. Overall, the values for soil OC and N for triticale were about 36% lower than those for maize. The nitrate concentrations in the soil profile measured at various dates during the experiment ranged between 43.1 and 13.6 mg kg^{-1} for NMIN, 47 and 13.8 mg kg^{-1} for CONV, and 30.6 and 9 mg kg^{-1} for N0. The ammonium-N concentration ranged between 51.3 and 11.9 mg kg^{-1} for NMIN, 81.6 and 4.3 mg kg^{-1} for CONV, and 33 and 8.8 mg kg^{-1} or N0. The model evaluation of maize yield for both growing seasons (2010 and 2011) and for the three N treatments is shown in Table 1. Overall, SALUS was able to reproduce the simulated yield for each treatment. The observed vs. simulated total soil nitrates for the entire soil profile for eleven dates are shown in Figure 1a, b, and c for NMIN, CONV, and N0, respectively. The SALUS model was able to reproduce the patterns of the soil nitrates over the crop rotation for the three treatment, however, in some dates, the values of soil nitrates were underestimated and/or overestimated by the model. The simulation of maize biomass, N uptake, N use efficiency [NUE = yield (kg ha^{-1})/Napp kg N ha^{-1})], N fertilizer efficiency [NFE = N uptake (kg N ha^{-1}) / N applied (kg N ha^{-1})] , and the % fertilizer recovery for the four management (the original three from the field study plus the BMP treatment) using future climate projections are shown in Table 2. The simulated inorganic N in soil under future climate conditions was high for NMIN at the beginning of the long-term simulations, but it decreased by 0.005 kg N ha^{-1} year^{-1}; on the other hand, both CONV and BMP increased by 0.031 and 0.01 kg N ha^{-1}year^{-1}, respectively. (Figure 2). The inorganic soil N for the N0 treatment decreased from the beginning of the season to about 30 kg N ha^{-1} and did not show any significant changes over the long-term simulations (Figure 2). The simulated maize N uptake showed similar patterns for NMIN, CONV, and BMP but decreased sharply for the N0 treatment. The cumulative N leaching increased for all the simulated treatments except for N0, which id not change from about 590 kg N ha^{-1} over the long-term simulations (Fig. 3). The highest N leaching rate was simulated for NMIN and CONV, with 202 and 193 kg N ha^{-1} year^{-1}, respectively; BMP showed an increase in leaching of about 108 kg N ha^{-1}year^{-1}. At the end of the long-term simulation, the total cumulative N leaching was 17332, 15935, 616, and 9392 kg N ha^{-1} for NMIN, CONV, N0, and BMP, respectively. The trade-off between biomass production and N leaching is shown in Figure 4 for the four simulated treatments. N0 was the treatment that produced the lowest biomass (15,500 kg ha^{-1}) and the lowest N leaching (1.4 kg N ha^{-1} year^{-1}), and NMIN was the treatment that produced the highest biomass (18,000 kg ha^{-1}) and highest annual N leaching (202 kg N ha^{-1}year^{-1}). The BMP was the treatment that resulted in the highest biomass (18,000 kg ha^{-1}) and the lowest annual N leaching (108 kg N ha^{-1}year^{-1}).

Conclusions

The results of this study showed that the nitrate concentrations were between 9 and 47 mg kg^{-1}, which were smaller than those previously reported by Giola et al. (2012) in the same zone. This means that the N management methods chosen in this study reduced the amount of nitrate in the soil as compared to the previous study. In this study, the SALUS crop model was used to evaluate NMIN, CONV, and N0 treatments, and it was able to reproduce the patterns of soil nitrates and maize product harvested. Future climate projections show an increase in winter-spring temperature and an increase in summer-autumn rainfall, causing changes in the leaching patterns of the cropping systems. The SALUS crop model can be used to extrapolate the results of experimental data and to test alternative management scenarios beyond a few years of experimental data. The current practices that minimize N losses will not be able to do so in the future because of change in weather patterns. In conclusion, the integration of the information from field experiments and crop simulation models is an important process that will help in designing better farming systems for coping with climate change.

Table 2. Total nitrogen supply, biomass, N uptake, nitrogen utilization efficiency, nitrogen fertilizer efficiency and fertilizer recovery related to the maize crop for the NMIN, CONV, N0 and BMP treatments in the long term rotation (2012—2095). (means and standard errors).

Treatments	Total N supply	Biomass	N uptake	NUE	NFE	Fertilizer recovery
	(kg N ha^{-1})	(kg d.m. ha^{-1})	(kg N ha^{-1})	(kg d.m. kg N^{-1})		(%)
NMIN	230.0	18.1 ± 0.13	419.1 ± 5.06	78.5 ± 0.6	1.82 ± 0.022	120.0 ± 2.20
CONV	304.5	18.1 ± 0.13	417.6 ± 5.05	59.3 ± 0.4	1.37 ± 0.017	90.2 ± 1.66
N0	-	15.5 ± 0.31	153.5 ± 8.55	-	-	-
BMP	253.0	18.1 ± 0.13	418.1 ± 5.00	71.4 ± 0.5	1.65 ± 0.020	108.7 ± 1.98

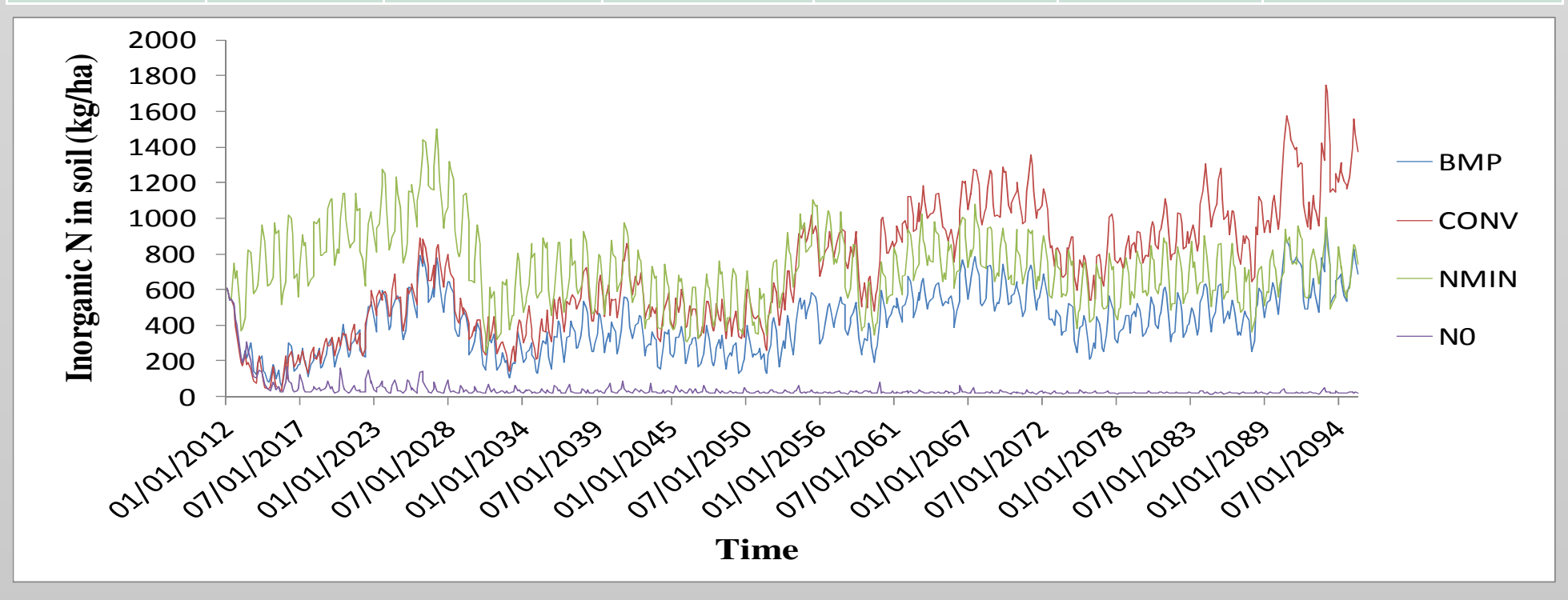

Figure 2. Simulated inorganic nitrates in soil for the NMIN (green line), CONV (red line), N0 (purple line) and BMP (blue line) treatments in the long term rotation (2012—2095).

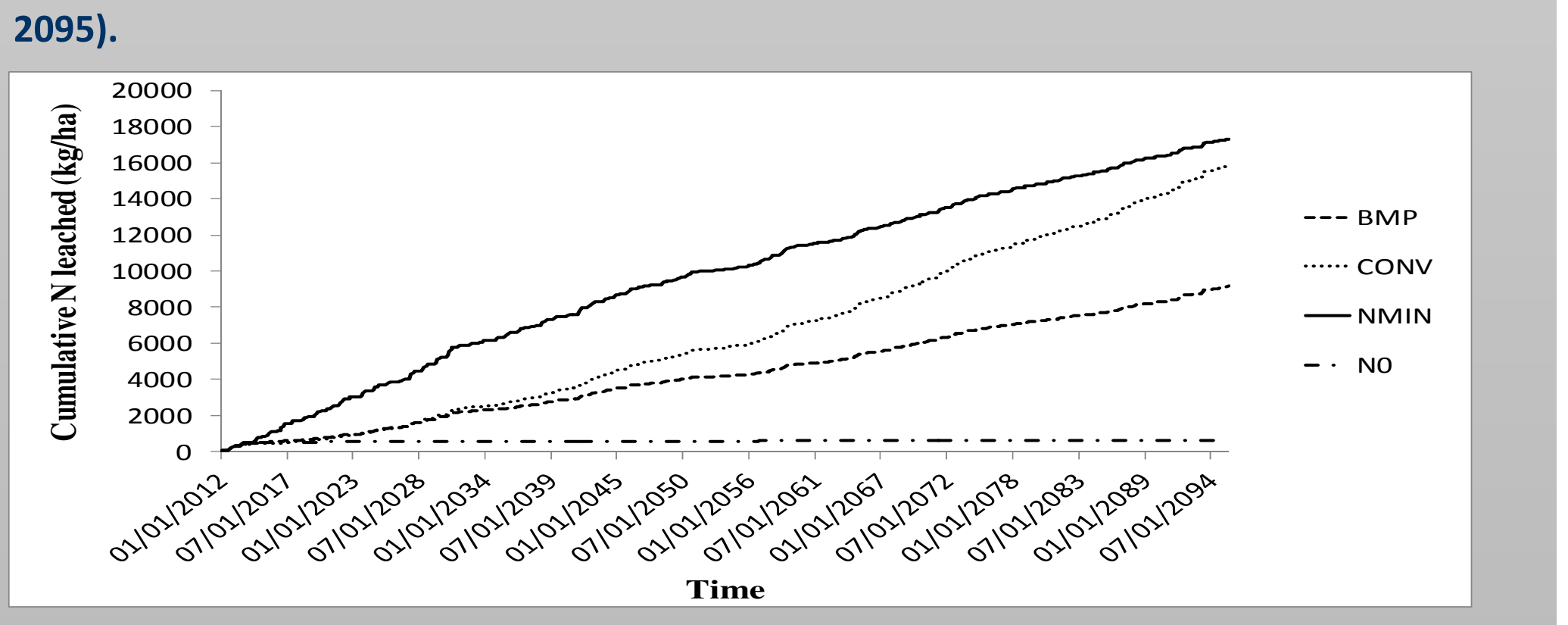

Figure 3. Simulated cumulative nitrate leached for the NMIN (solid line), CONV (dotted line), N0 (dash dotted line) and BMP (dashed line) treatments in the long term rotation (2012—2095).

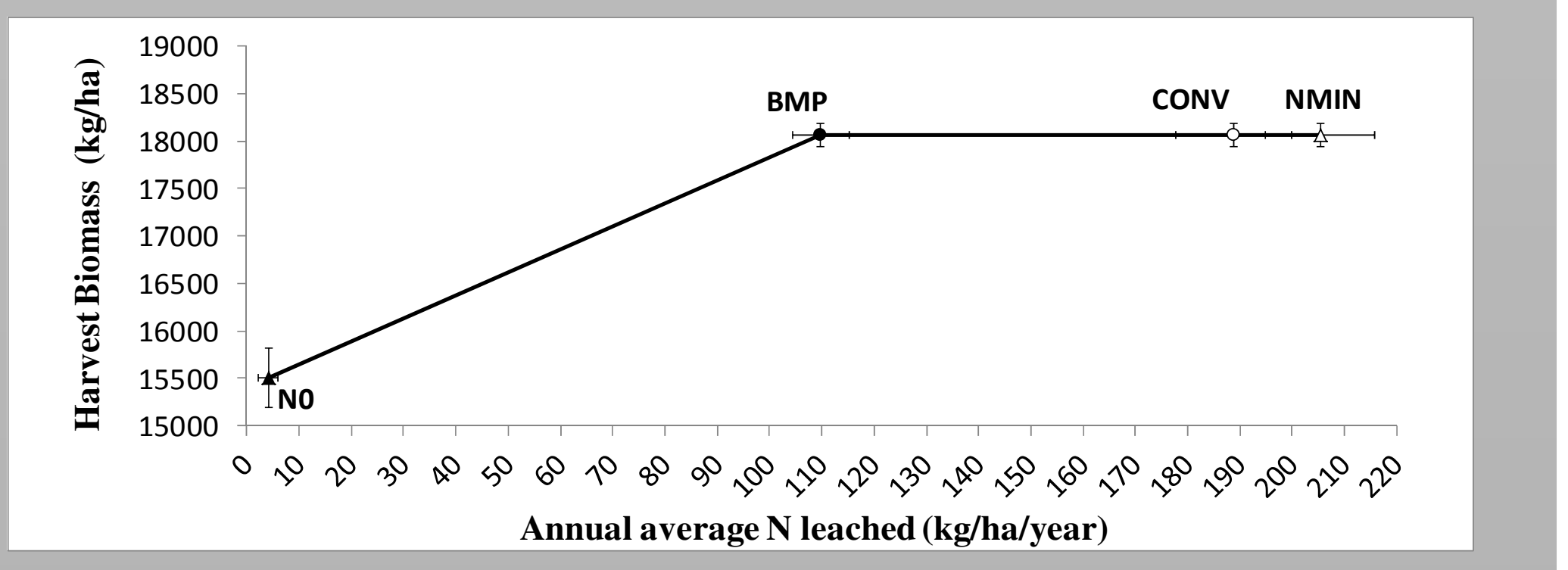

Figure 4. Average annual nitrates leached and harvest biomass for the NMIN (open triangle), CONV (open circle), N0 (filled triangle) and BMP (filled circle) treatments in the long term rotation (2012—2095) (means and standard errors).

Acknowledgements

This work has been supported by the Sardinian Regional Authorities (P.O.R. SARDEGNA F.S.E. 2007-2013 - Obiettivo competitività regionale e occupazione, Asse IV Capitale umano, Linea di Attività l.3.1.) on the research project: *"Impact of agricultural management on greenhouse gas emissions".*